Overview of STAR Results

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For the STAR Collaboration
Outline

- STAR detectors.
- Hard probes in Heavy Ion Collisions.
  - Electro-magnetic probes:
    - $e^+e^-$ and direct virtual photon production.
  - Heavy flavor measurements:
    - Photoproduced $J/\psi$ $R_{AA}$.
    - Suppressions of $J/\psi$ and $\Upsilon$.
    - $R_{AA}$ and elliptic flow $v_2$ of D mesons.
  - Jet observable:
    - Jet splitting function --- shared momentum fraction $Z_g$.

- Summary and Outlook
PID: $e$, $\mu$, and hadrons.

HFT: track pointing resolution $\sim 50\ \mu$m at $p_T \sim 0.8\ \text{GeV}/c$. 
e^+e^- production in U+U

- Observed significant excess w.r.t hadronic sources at ρ-like mass region (0.3-0.76 GeV/c^2).

Within STAR acceptance.
Acceptance-corrected excess mass spectra are well described by a model that incorporates a broadened $\rho$ spectral function in various collision systems and energies.
Integrated excess yield, normalized by \( dN_{\text{ch}}/dy \), is proportional to lifetime of fireball from 17.3 – 200 GeV.

Given that total baryon density is nearly constant and emission rate is dominant in the near-\( T_c \) region.

\[ \text{R. Rapp, H. van Hees PLB 753 (2016) 586-590} \]
Extract direct virtual photon yields

The curves represent NLO pQCD prediction:

\[
\frac{T_{AA}d\sigma^{NLO}_{y}(p_T)}{dN_{y}^{\text{inclusive}}(p_T)}
\]


Compared to p+p reference, an excess is observed in low \( p_T \)
Direct virtual photon invariant yields

- $1-3$ GeV/c: dominated by thermal radiation from models.
- Data are consistent with both models for all the centralities except 40-80%.

Paquet: (2+1)D hydrodynamic evolution.
Rapp: Elliptic thermal fireball evolution.

Significant $J/\psi$ signals at very low $p_T (<0.1 \text{ GeV}/c)$ in 40-80%.
No significant centrality dependence --- not from hadronic production.
$J/\psi$ yields in Au+Au and U+U are similar at $p_T<0.1 \text{ GeV}/c$. 
**Nuclear modification factor $R_{AA}$**

- $R_{AA}$ drops from 20 to 1 as centrality changes from peripheral to semi-central.
- Slope from STARLight prediction in UPC is 196 (GeV/c)$^{-2}$, which reflects the size and shape of nucleus.
  - Fit w/o first data point: 199+/-31 (GeV/c)$^{-2}$.
- Possible new probe of QGP!
Results from MTD. $J/\psi$ $p_T$ coverage up to 14 GeV/c.
Transport models with regeneration and dissociation are well consistent with data.

Less regeneration and less dissociation at RHIC.

Data:
JHEP 05 (2016) 179 PRC 84 (2011) 054912
Tsinghua Model:
TAMU model:
X. Zhao, R. Rapp, PRC 82 (2010) 064905, NPA 859 (2011) 114
\[\gamma\] suppression

- Measurement in U+U extends the \(N_{\text{part}}\) coverage.
- Free-energy-based model tends to underpredict the \(R_{\text{AA}}\).
- Internal-energy-based models agree with data.

- Measured difference \(\gamma\) states via dimuon channel.
  - No bremsstrahlung tail.
  - Expect to extract the ratio of \((2S+3S)/1S\) from simultaneous fit to both dielectron and dimuon channel.
  - A factor of 4 improvement of statistics is expected when combining Run11 and Run14.

428 < \(T\) < 443 MeV

\[T = 340\] MeV

Zaochen Ye Sun 08:50
Quarkonia

STAR preliminary

\(\gamma\) states via dimuon channel.

\(\chi^2/\text{ndf} = 22.38/17\) for combined fit.

\(T(1S)\) yield: \(156.7 \pm 23.5\).

\((2S+3S)/1S\) fit: \(0.375 \pm 0.132\).

\(\text{Run14 Au+Au at 200 GeV L} \sim 14.2 \text{ nb}^{-1}\)
First measurement of $D^0 R_{AA}$ using STAR HFT.

$D^0 v_2$ is finite and lower than that of light mesons for $1<p_T<4$ GeV/c in 0-80%.

Suppression is consistent with published result.
DUKE:
• (2+1)-D viscous hydro + hybrid coalescence and fragmentation model
• Input value for diffusion coefficient $2\pi T \times D = 7$ fixed to fit LHC results
• Underestimate the magnitude of $v_2$ in experimental data

D⁰ R_{AA} and v₂

TAMU:
• Full T-matrix treatment, non-perturbative model with internal energy potential
• Good agreement with $D⁰$ meson $v₂$, data favor model including c quark diffusion in the medium.
• Qualitatively describe $R_{AA}$.
• Diffusion coefficient extracted from calculation $2\pi T x D = 3-11$

STAR: PRL 113 (2014) 142301
D^0 R_{AA} and v_2

SUBATECH:
- MC@sHQ calculation with latest EPOS3 initial conditions
- Good agreement between model and experiment for both v_2 and R_{AA} in entire p_T range
- Diffusion coefficient extracted from calculations 2\pi T \times D \sim 2-4

STAR: PRL 113 (2014) 142301

Conclusion for D^0 R_{AA} and v_2:
- Data favor model that charm quark flows.
- D^0 v_2 and R_{AA} can be simultaneously described by models with diffusion coefficient between 2-12, and differences between models need to be resolved.
$D_s R_{AA}$ and elliptic flow $v_2$

- $D_s R_{AA}$ may be higher than $D^0$.
- Higher $D_s/D^0$ ratio wrt. PYTHIA?
- Will follow up with better precision measurements.
Jet splitting function

Soft Drop Condition:

\[ z > z_{\text{cut}} \theta^\beta \]

Based on declustering an angular-ordered tree

“Groomed Momentum Sharing”

\[ z_g = \min \left( \frac{p_T1, p_T2}{p_T1 + p_T2} \right) \]

For \( \beta = 0 \), \( z_g > z_{\text{cut}} \):

\[ \frac{d\sigma}{dz_g} \propto \overline{P}_i(z_g) + O(\alpha_s^2) \]

- \( \sim \) independent of \( p_T \) (in UV limit)
- \( \sim \) independent of \( \alpha_s \)

\( P_i \): Altarelli-Parisi splitting functions (symmetrized)

q\rightarrow qg, g\rightarrow gg, g\rightarrow qg (Kernels in DGLAP)

J. Thaler ALICE Jet Workshop, Yale

Larkoski et al.,
Z_g measurements in p+p and Au+Au

First measurement of z_g at RHIC z_g for di-jets with “hard cores”.

- p+p HT Run6
  Results from trigger and recoil jets are consistent with PYTHIA.

- No significant modification of the splitting function found in Au+Au.

Constrains E-loss models, more theory input needed.

Kolja Kauder Sun 11:00
Jets

CMS observed signification modification in most central, but in quite different kinetic range.
What we learned so far:

• Hot medium modifies $\rho$ meson and emits radiation via lepton pairs.

• Photoproduced $J/\psi$ is observed in the peripheral heavy ion collisions.

• Quarkonium appears suppression and regeneration effects in the medium.

• Charm quark has suppression and collective flow in the QGP.

• Jet splitting function has no significant modification for jet $p_T$ 10-30 GeV/c at RHIC.
• Y2014: with improved HFT efficiency after fixing a decoder issue, a factor of 2-4 improvement is expected in Au+Au.
• Y2015-2016: p+p, p+Au, and Au+Au at 200 GeV.

<table>
<thead>
<tr>
<th>2014-2016</th>
<th>2019-2020</th>
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<tbody>
<tr>
<td>HF and Jet program.</td>
<td>BES-II, dilepton program.</td>
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<td>sQGP properties with precision measurements.</td>
<td>High statistics data in low beam energies will be collected. QCD phase structure including chirality and disappearance of QGP signatures.</td>
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Parallel talks from STAR

**EM probes:**

Chi Yang, Direct virtual photon production.  
Joey Butterworth, $e^+e^-$ production in heavy ion collisions.

**Heavy flavor probes:**

Guannan Xie, $D^0$ production and azimuthal anisotropy.  
Long Zhou, $D_s$ production in Au+Au.  
Long Ma, $D$ meson correlation in $p+p$.  
Yi Yang, $J/\psi$ production in $p+p$ and A+A.  
Yaping Wang, Electron from heavy flavor decays in $p+p$ and Au+Au.  
Zaochen Ye, $\Upsilon$ production in Au+Au.  
Wangmei Zha, Excess of very low $p_T$ $J/\psi$ yield in A+A.

**Jet probes:**

Kun Jiang, Away-side jet background subtraction.  
Kolja Kauder, Shared momentum fraction $z_g$ of Jets in $p+p$ and Au+Au.