Selected highlights from the STAR experiment at RHIC

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Outline

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I Introduction

Lattice QCD prediction:
The Hadron <-> Quark Gluon Plasma (QGP) transition

Goal of ultrarelativistic heavy ion physics:
Study QCD matter under extreme conditions of densities and Temperatures
Map out the QCD phase diagram and measure QGP characteristics

Reproduce a phase transition of the early universe at $10^{-6}$ sec after the Big Bang, between hadrons and quarks and gluons (Quark-Gluon-Plasma)

Beam Energy Scan at RHIC:
* Search for onset of QGP signatures
* Search for signals of the phase boundary
* Search for the QCD critical point
Particle identification mainly via
- $\text{de/dx}$ in the TPC
- topological decay reconstruction in TPC for strange particles and D mesons
- TOF
- Barrel EMCal (used also as fast online trigger)
III Selected physics results

III.1 Open heavy flavor
STAR heavy flavor measurements

STAR measures:

* Charm via direct D meson reconstruction

* Open charm and beauty via electrons from semileptonic decay of charmed hadrons, and e-h and e-D correlations

* Quarkonia via reconstruction of their decay to -> e+ e-

p+p 500 GeV
e-h correlations

Au+Au 62 GeV
Jet quenching and heavy flavour

We compare A+A to expectations from p+p, using the “nuclear modification factor” $R_{AA}$ defined as:

$$R_{AA}(p_T) = \frac{\text{Yield}(A + A)}{\text{Yield}(p + p) \times \langle N_{\text{coll}} \rangle}$$

N coll : Average number of NN collisions in AA collision

Suppression of jets in AuAu: $R_{AA} < 1$

Quarks are expected to exhibit different radiative energy loss depending on their mass (D.Kharzeev et al. Phys Letter B. 519:1999)

Partons interact with the medium and loose energy through eg gluon radiation

B and D separation in p+p 200 and 500 GeV

p+p 200 GeV

* B and D components to non-photonic electrons have been separately measured and are consistent with FONLL predictions
RAA of D0 at high pT:
- unsuppressed for peripheral events
- suppressed for central events
- suppression at high pT similar to pions

Models: bump may be due to radial flow of thermalized light quark which coalesces with charm

He et al, PRC86 014903, arXiv:1204.4442
PB Gossiaux: arXiv: 1207.5445
Flow coefficients $v_n$, $n=1,2,3..$

\[ \frac{dN}{d\phi} \propto 1 + 2 \sum_{n=1}^{\infty} v_n \cos[n(\phi - \Phi_n)] \]

\[ v_n = \langle \cos[n(\phi - \Phi_n)] \rangle \]

* Initial shape of the interaction region ($v2$ - elliptic flow)
Non-photonic electrons (NPE)

R_{AA} of D0 and NPE show similar strong suppression in central Au+Au 200 GeV at high p_T

Models with only radiative energy loss do not describe the data

NPE show nonzero v_2

Increase of v_2 at high p_T's may be due to jet-like correlation and/or path length dependence

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Is $B$ less suppressed than charm?

Hint of possible less suppression of $B$ as compared to $D$ in some cases

New STAR Heavy Flavor Tracker needed
III.2 Quarkonia
Quarkonia: Thermometer of QGP via their suppression pattern

Many effects play a role like dissociation in QGP, cold matter absorption, recombination/coalescence from c, cbar, feeding


A. Mocsy
$p_T$ dependence of J/\(\Psi\) suppression in Au+Au, Cu+Cu 200 GeV

Liu et al, PLB 678 (2009) 72
Zhao et al, PRC 82 (2010) 064905

- J/\(\Psi\) not suppressed at high $p_T$'s in non-central collisions
- J/\(\Psi\) suppressed at all $p_T$'s for most central events
- $R_{AA}$ of J/\(\Psi\) is systematically larger for higher $p_T$
J/Psi $v_2$ consistent with zero for $p_T > 2$ GeV -> Suggests that J/Psi does not originate dominantly from thermalized c and cbar quark coalescence (assuming c and cbar exhibit elliptic flow)
At which energy does J/Psi suppression turn off?

Color Evaporation Model (CEM) estimate for p+p reference used for 39, 62 GeV

$R_{AA}$ of J/Psi is suppressed in similar way at 39, 62 and 200 GeV
Y(1S+2S+3S) in Au+Au collisions at 200 GeV:

* No suppression in most peripheral collisions
* Exhibits suppression in more central collisions increasing with centrality
* The suppression observed is consistent with model assuming Y(2S) and Y(3S) suppression

Assumes $T_0 = 428-442$ MeV and $1/4 \pi < \eta/S < 3/4 \pi$
III.3 Beam Energy Scan
Model used for particle ratio fits: THERMUS by J Cleymans et al

Grand canonical ensemble and strangeness canonical ensemble fits to particle ratios give consistent results for mid-central and central Au+Au collisions and disagree for peripheral collisions.
Directed flow of protons

Directed flow slope is sensitive to a 1st order transition

STAR: $v_1$ slope changes sign from positive to negative between 7.7 and 11.5 GeV

Pions and antiprotons have always negative $v_1$ slopes.

Net-proton $v_1$ slope shows a minimum around 11.5-19.6 GeV

UrQMD model (model without phase transition) cannot explain the data.
Elliptic flow energy dependence

* Difference between baryon and antibaryon elliptic flow coefficient $v_2$ is getting larger in lower energies

PRL 110 (2013) 142301
PRC 88 (2013) 014902
At which energy does jet quenching switch off?

\[ R_{\text{CP}} \text{ suppression measured from } \sqrt{s} = 39 \text{ GeV on} \]
IV Conclusions

- Several sQGP signatures observed in central Au+Au collisions at high energy:

Open Heavy Flavor:
- “Jet quenching” of D mesons and of electrons from charm and beauty quarks in Au+Au 200 GeV
- Elliptic flow of electrons from open charm and beauty in Au+Au 200 GeV further constrain models

Quarkonia suppression:
- J/Psi suppression and elliptic flow
- Upsilon suppression in central Au+Au collisions 200 GeV, consistent with suppression of \( Y(2S+3S) \)

Beam Energy Scan:
- Dissapearance of key QGP signatures at low energies
V Outlook
Short term STAR upgrades

Heavy Flavor Tracker

* HFT pixel prototype with 3 sectors took first data in 2013

* MTD 63% installed and took data in 2013

* Outlook: 2014 full HFT and MTD for Au+Au 200 GeV run

Muon Telescope Detector

J/Psi event in p+p 500 GeV
Outlook
BES-II program (>2017)

BES-II:
* Fine energy scan of region $\sqrt{s} \leq 20$ GeV
* Increased luminosity $\sim$ 3-10 times
* STAR upgrade to extend mid-rapidity coverage

Fixed Target proposal:
* Energy scan of region down to $\sqrt{s} \sim 3$ GeV
* Annular 1% Au target inside STAR beam pipe, and 2 m away from the interaction point center
* Data taking at beginning of each fill in collider mode
Thank you very much for your attention
Upsilon

\[ p+p \sqrt{s_{NN}} = 200 \text{ GeV} \]
\[ |y_{ee}| < 0.5, 0 < p_t < 10 \]

- \( N_+ + N_- \)
- \( N_+ \)

- Comb. Background (CB)
- CB + Drell-Yan + b\bar{b}
- CB + DY + b\bar{b} + \gamma (19, 29, 38)
- Integral of CB + DY + b\bar{b} + \gamma

Counts

\( m_{oo} \) (GeV/c\(^2\))
Table 2. Estimates of the isotropic and anisotropic dissociation scales for the $J/\psi$, $\chi_{c1}$, $\Upsilon(1s)$, $\Upsilon(2s)$, $\Upsilon(3s)$, $\chi_{b1}$, and $\chi_{b2}$. Estimates are taken from Refs. [129, 130].

<table>
<thead>
<tr>
<th>State</th>
<th>Isotropic QGP ($\xi=0$)</th>
<th>Anisotropic QGP ($\xi=1$)</th>
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</thead>
<tbody>
<tr>
<td>$J/\psi$</td>
<td>307 MeV</td>
<td>374 MeV</td>
</tr>
<tr>
<td>$\chi_{c1}$</td>
<td>&lt; 192 MeV</td>
<td>210 MeV</td>
</tr>
<tr>
<td>$\Upsilon(1s)$</td>
<td>593 MeV</td>
<td>735 MeV</td>
</tr>
<tr>
<td>$\Upsilon(2s)$</td>
<td>228 MeV</td>
<td>290 MeV</td>
</tr>
<tr>
<td>$\Upsilon(3s)$</td>
<td>&lt; 192 MeV</td>
<td>&lt; 192 MeV</td>
</tr>
<tr>
<td>$\chi_{b1}$</td>
<td>265 MeV</td>
<td>351 MeV</td>
</tr>
<tr>
<td>$\chi_{b2}$</td>
<td>&lt; 192 MeV</td>
<td>213 MeV</td>
</tr>
</tbody>
</table>

M Strickland et al 1302.2180