Highlights from STAR

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STAR Heavy Ion Program

1) QCD in cold nuclear matter
2) QCD in hot nuclear matter
   • sQGP properties
   • QCD phase structure
STAR Detector

- Large & uniform acceptance at mid-rapidity
- Excellent particle identification
- Fast data acquisition

Barrel TOF, MTD, Barrel EMC, Endcap EMC, FMS, HLT, HFT, TPC, DAQ1000, COMPLETE, Ongoing.
Recorded Datasets

- AuAu 200 mb
- AuAu 200 cen
- AuAu 62
- UU 193
- CuAu 200
- dAu 200
- AuAu 39
- AuAu 27
- AuAu 19
- AuAu 11
- AuAu 7
- CuCu 200
- CuCu 62
- CuCu 22

Integrated # of events ($\times 10^8$) vs. Year
Integrated Lum (nb$^{-1}$)

STAR Presentations at this QM

1) Initial Condition – Search for CGC
   • Forward triggered correlations
   • Vector meson photoproduction in Ultra-peripheral collisions

2) sQGP Properties
   • Anisotropic flow: identified particle $v_2$, $v_n$; nonflow/flow fluctuation
   • CME observables: $A_\pm$ dependency of $\pi^\pm v_2$, charge separation signal in U+U
   • Dielectrons: differential studies, energy dependence
   • Jet $v_2$: jet azimuthal corr. w.r.t. the reaction plane
   • Triggered and untriggered particle correlations
   • Heavy Flavor: improved precision on $R_{AA}$ of $D^0$, NPE, $J/\psi$, Upsilon
   • Exotic particles: hypertriton
   • Identified particle HBT

3) Beam Energy Scan
   • Freeze-out parameters
   • Turn-off of sQGP signatures: NCQ-scaling, $R_{cp}$, charge separation signal
   • Search for 1st order phase transition: $v_1$, asHBT
   • Search for critical point: higher moments, particle ratio fluctuations
Initial Condition
Forward Triggered Correlations

- Pion(FMS) – Pion(FMS) correlation
  - Away side width broadening consistent with CGC expectations.
  - Evolution of width vs. rapidity ($x_g$): the smaller $x_g$, the larger broadening consistent with a smooth transition from dilute parton system to CGC.

Li, 4D, Wed.
sQGP Properties
Precision measurements on identified particle $v_2$ from high statistics Au+Au 200 GeV.

0-30%: baryon-meson grouping / NCQ scaling holds.
30-80%: Multi-strange hadron $v_2$ deviate from NCQ scaling at $m_T-m_0>1$ GeV/c$^2$.

Precision identified particle $v_2$ data provide constraints to study the sQGP properties.
Charge Asymmetry Dependence of $\pi^{+/−} v_2$

Chiral Magnetic Effect + Chiral Separation Effect
→ Chiral Magnetic Wave → electrical quadrupole

Theoretical calculations consistent with data.

Wang, IVB, Thu.; Ke, poster #387
Charge Separation w.r.t. EP in U+U

- Charge separation – motivated by search for LPV + CME.
  - Other interpretations involving $v_2$ background.
- $v_2$ in U+U is higher than that in Au+Au at the same uncorr. $dN/d\eta$.
- In 0-1% central collisions, with the magnetic field “turned off”, the charge separation signal ($\gamma_{os}$-$\gamma_{ss}$) disappears while $v_2$ is still ~2.5%.
  - Consistent with no signal in the LPV + CME expectation.

$$\gamma = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_r) \rangle$$
Low mass enhancement in Au+Au 200 GeV is accounted for by theoretical calculations of in-medium $\rho$ broadening.

Data in central/minbias show hints of charm modifications/other sources in IMR.

Systematic studies on dielectron production:
- $p_T$ and centrality dependence at 200 GeV
- elliptic flow measurements

Geurts, IV, Thu.; Huang, 3C, Wed.

Zhao, poster #153
Cui, poster #322
Energy Dependent Dielectron Production

- Systematic measurements of dielectron mass spectra over a broad energy range.
- LMR enhancement persists down to 19.6 GeV.
- Theoretical calculations of in-medium \( \rho \) broadening with similar baryon densities from 19.6 - 200 GeV reproduce LMR excesses well.

In-medium \( \rho \) broadening
R. Rapp: private communications

Huck, Huang, poster #113, 269

Geurts, IV, Thu.
Huang, 3C, Wed.

STAR Preliminary
Reconstructed Jet $v_2$

$Jet v_2 = \text{correlation between recon. jets and the event plane.} \neq \text{Jet flow}$
- to probe path-length dependence of the jet quenching.

$|\eta_{jet}|<0.6$

$FTPC: \quad 2.8<|\eta|<3.7$

- Non-zero jet $v_2\{FTPC\}$ in mid-central collisions.

**pathlength dependent parton energy loss.**

Ohlson, 4B, Wed.
Open Charm Hadrons

Combined year 2010 and 2011 statistics.
• Charm production cross section follows $N_{\text{bin}}$ scaling $\rightarrow$ improved precision.
• Small hump structure in $D^0$ $R_{\text{AA}}$ in low $p_T$ – similar in theoretical calculation.
• $R_{\text{AA}}$ in Au+Au collisions suppressed at $p_T > 3$ GeV/c.

Xie, IIB, Tue.; Tlusty, 6A, Fri.
Non-photonic electrons

High statistics data @ 200, 62.4, 39 GeV

- Significant suppression in 200 GeV central collisions.
- Finite NPE $v_2$ at 200 GeV.

Mustafa, 7A, Fri.; Kikola, poster #459
Exotics: Hypertriton Production

\[ {^3}_{\Lambda}H + {^3}_{\Lambda}\bar{H} \text{ produced: } 602 \pm 63 \quad \text{significance: } 9.6\sigma \]

- Combined various datasets: x 3 more statistics compared to the Science publication.

**Lifetime significantly lower than that of free \( \Lambda \).**

Zhu, 5A, Thu.
Beam Energy Scan

0) Turn-off of sQGP signatures
1) Search for the signals of phase boundary
2) Search for the QCD critical point

BES Phase-I

<table>
<thead>
<tr>
<th>Year</th>
<th>$\sqrt{s_{NN}}$ (GeV)</th>
<th>Events ($10^6$)</th>
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<tbody>
<tr>
<td>2010</td>
<td>39</td>
<td>130</td>
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<td>2011</td>
<td>27</td>
<td>70</td>
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<td>2011</td>
<td>19.6</td>
<td>36</td>
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<td>2010</td>
<td>11.5</td>
<td>12</td>
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<tr>
<td>2010</td>
<td>7.7</td>
<td>5</td>
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</tbody>
</table>

Kumar, VA, Fri.
Breakdown of NCQ-scaling

- Significant difference between baryon-antibaryon $v_2$ at lower energies.
- No clear baryon/meson grouping for anti-particles at $\leq 11.5$ GeV.

NCQ scaling is broken!

Shi, 6B, Fri; Schmah, poster #141
Disappearance of $R_{cp}$ Suppression

- Baryon-meson splitting reduces and disappears with decreasing energy.
- $\Omega/\phi$ ratio falls off at 11.5 GeV.
- $R_{cp} \sim 1$ at 11.5, 7.7 GeV. - Cronin effect?
- $R_{cp}$ suppression NOT seen at lower energies!

Zhang, 5A, Thu. Sangaline, 5C, Thu. Horvat, poster #94
• Motivated by search for local parity violation. Require sQGP formation.
• The splitting between OS and LS correlations (charge separation) seen in top RHIC energy Au+Au collisions.

This charge separation signal disappears at lower energies (<= 11.5 GeV)!
Directed Flow of Protons

• Directed flow ($v_1$) slope: sensitive to 1st order phase transition.

• Proton $v_1$ slope changes sign from + to – between 7.7 and 11.5 GeV and remains small but negative up to 200 GeV.

• $v_1$ slopes for other particles are all negative.

• “net-proton” $v_1$ slope shows a minimum around 11.5-19.6 GeV.

• AMPT/UrQMD models cannot explain data.
Evolution of the initial shape depends on the pressure anisotropy.
- Freeze-out eccentricity sensitive to the 1st order phase transition.

Measured freeze-out eccentricity parameters show a smooth decrease from low to high energies.
Higher Moments of Net-protons

\[ \sigma^2 = \langle (N - \langle N \rangle)^2 \rangle \]
\[ S = \langle (N - \langle N \rangle)^3 \rangle / \sigma^3 \]
\[ \kappa = \langle (N - \langle N \rangle)^4 \rangle / \sigma^4 - 3 \]

- Higher moments - more sensitive to Critical Point induced fluctuations.
- Deviation from Poisson baseline in 0-5% collisions at >7.7 GeV.
- Above Poisson baseline in peripheral collisions below 19.6 GeV.
- UrQMD shows monotonic behavior.
- Need precision measurements at low energies.

Net-proton/Net-charge/Net-kaon

Luo, 7B, Fri.; McDonald, 7B, Fri.
Li/Sahoo/Sarkar, poster #215/557/394
Summary of BES Phase-I at RHIC

1) Several key sQGP signatures NOT seen at low energies.

Hadronic interactions become more important in the system created at low collision energies.

2) Deviations from the Poisson baseline in net-proton higher moment analysis.

BES-II with significantly improved statistics focusing on beam energies <= 20 GeV.
Outlook

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<tr>
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<td>BES-I</td>
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**HFT/MTD: Heavy Flavor / Dileptons**

**BES-II ($\sqrt{s_{NN}} \leq 20$GeV)**

- **pA/eA program**

- **Precision measurements on HF and dileptons:** Quantify the sQGP properties (hot QCD)

- **Precision measurements on focused energies:** Map out the QCD phase structure

- **Precision measurements on pA and eA:** Study QCD in cold matter

*Huang, 6C, Fri.*
### Plenary Presentations:

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<tr>
<th>Title</th>
<th>Speaker</th>
<th>Session</th>
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<tr>
<td>Azimuthal Anisotropy Results from STAR</td>
<td>Daniel Cebra</td>
<td>IC, Mon 15:55</td>
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<tr>
<td>Heavy Flavor Results from STAR</td>
<td>Wei Xie</td>
<td>IIB, Tue 11:15</td>
</tr>
<tr>
<td>Di-lepton Physics Program at STAR</td>
<td>Frank Guerts</td>
<td>IVA, Thu 8:30</td>
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<tr>
<td>Search for Chiral Magnetic Effect in High Energy Nucleus Collisions</td>
<td>Gang Wang</td>
<td>IVB, Thu 12:20</td>
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<tr>
<td>STAR Results from RHIC Beam Energy Scan</td>
<td>Lokesh Kumar</td>
<td>VA, Fri 8:30</td>
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### Parallel Presentations:

1. **Initial cond.**
   - Forward azimuthal correlations in p+p and d+Au collisions at $\sqrt{s} = 200\text{GeV}$ at STAR
     
     - **Xuan Li**, 4D, Wed 12:20

2. **Bulk probes**
   - Systematic Investigation on Partonic Collectivity through Centrality Dependence of Elliptic Flow for Multi-strange Hadrons in STAR at RHIC
     
     - **Md. Nasim**, 3A, Wed 10:10
   
   - Two- and Multi-particle cumulant measurements of $v_{\langle n\rangle}$ and isolation of flow and nonflow in 200 GeV Au+Au collisions by STAR
     
     - **Li Yi**, 3A, Wed 9:30
   
   - Di-electron differential cross section in Au+Au collisions at different beam energies at STAR
     
     - **Bingchu Huang**, 3C, Wed 9:10

3. **Hard probes**
   - Measurements of Non-photonic Electrons Production and Elliptic Flow in sNN = 39, 62.4 and 200 GeV Au+Au Collisions from STAR at RHIC
     
     - **Mustafa Mustafa**, 7A, Fri 16:50
   
   - Open charm hadron production in $p+p$ and Au+Au collisions at STAR
     
     - **David Tlusty**, 6A, Fri 14:20
   
   - Quarkonia production in the STAR experiment
     
     - **Barbara Trzeciak**, 1D, Tue 15:35
   
   - Measurements of the Correlation between Jets and the Reaction Plane in STAR at RHIC
     
     - **Alice Ohlson**, 4B, Wed 11:40
Full List of Oral Presentations

9) Centrality dependence of freeze-out parameters from the Beam Energy Scan at STAR
   Sabita Das, 6B, Fri 15:00

10) $R_{CP}$ and $R_{AA}$ Measurements of Identified and Unidentified Charged Particles at High $p_{T}$ in Au+Au Collisions at $\sqrt{s_{NN}}=$7.7, 11.5, 19.6, 27, 39, and 62.4 GeV in STAR
   Evan Sangaline, 5C, Thu 15:00

11) Beam Energy Dependence of Strange Hadron Production from STAR at RHIC
    Xiaoping Zhang, 5A, Thu 15:00

12) Event anisotropy $v_2$ in Au+Au collisions at $\sqrt{s_{NN}}=$ 7.7 - 62.4 GeV with STAR
    Shusu Shi, 6B, Fri 15:20

13) Beam Energy Dependence of First and Higher-Order Flow Harmonics from the STAR Experiment at RHIC
    Yadav Pandit, 1A, Tue, 14:55

14) Femtoscopy of identified particles at STAR
    Neha Shah, 1C, Tue 14:35

15) Beam Energy Dependence of Hypertriton Production and Lifetime Measurement at STAR
    Yuhui Zhu, 5A, Thu 15:40

16) Search for QCD Phase Transitions and the Critical Point Utilizing Particle Ratio Fluctuations and Transverse Momentum Correlations from the STAR Experiment
    Prithwish Tribedy, 2C, Tue 16:45

17) Search for the QCD Critical Point by Higher Moments of Net-proton Multiplicity Distributions at STAR
    Xiaofeng Luo, 7B, Fri 17:30

18) Beam energy and centrality dependence of the statistical moments of the net-charge multiplicity distributions in Au+Au collisions at STAR
    Daniel McDonald, 7B, Fri 16:50

19) Study of the Sixth Order Cumulant of Net-proton Distributions Measured in STAR at RHIC
    Lizhu Chen, 2C, Tue 17:25

20) STAR Upgrade Plan for the Coming Decade
    Huang Z. Huang, 6C, Fri 14:00