Highlights from STAR
Zhenyu Ye for the STAR Collaboration
University of Illinois at Chicago
• Tracking and PID (full $2\pi$)
  TPC: $|\eta| < 1$
  TOF: $|\eta| < 1$
  BEMC: $|\eta| < 1$
  EEMC: $1 < \eta < 2$
  HFT (2014-2016): $|\eta| < 1$
  MTD (2014+): $|\eta| < 0.5$

• MB trigger and event plane reconstruction
  BBC: $3.3 < |\eta| < 5$
  EPD (2018+): $2.1 < |\eta| < 5.1$
  FMS: $2.5 < \eta < 4$
  VPD: $4.2 < |\eta| < 5$
  ZDC: $6.5 < |\eta| < 7.5$

• On-going/future upgrades
  iTPC (2019+): $|\eta| < 1.5$
  eTOF (2019+): $-1.6 < \eta < -1$
  FCS (2021+): $2.5 < \eta < 4$
  FTS (2021+): $2.5 < \eta < 4$
Introduction

**RHIC Top Energy**
- p+p, p+Al, p+Au, d+Au, $^3$He+Au, Cu+Cu, Cu+Au, Ru+Ru, Zr+Zr, Au+Au, U+U
- QCD at high energy density/temperature
- Properties of QGP, EoS

**Beam Energy Scan**
- Au+Au $\sqrt{s_{NN}} = 7.7$-62 GeV
- QCD phase transition
- Search for critical point
- Turn-off of QGP signatures

**Fixed-Target Program**
- Au+Au $\sqrt{s_{NN}} = 3.0$-7.7 GeV
- High baryon density regime with $\mu_B \sim 420$-720 MeV
## Outline

1. Open heavy flavor - $D^0 \nu_1, D^0 R_{AA}$ and $R_{CP}, \Lambda_c$
2. Quarkonium - $\Upsilon R_{AA}$
3. Jet modification and high-$p_T$ hadrons - di-jet imbalance, di-hadron correlation
4. Chirality, vorticity and polarization effects - $\Lambda$ polarization, $\phi$ polarization, CME, CMW
5. Initial state physics and approach to equilibrium - $\nu_2$ and $\nu_3$ fluctuations
6. Collectivity in small systems - $\nu_2$ in p+Au and d+Au
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12. Upgrades - BES-II and forward upgrades
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$D^0$ Directed Flow in 200 GeV Au+Au Collisions

- First evidence for non-zero $D^0 \nu_1$ from 2014+2016 Heavy Flavor Tracker (HFT) data:
  
  $D^0 + \overline{D}^0 \ dv_1/dy = -0.081 \pm 0.021 \ _{\text{(stat.)}}^{+0.017} \ _{\text{syst.}}^{-0.017}$

  probe the initial tilt of the source and the initial EM field

\[ \text{STAR Preliminary} \]

- $D^0$ (\text{\textsc{uc}})
- $\overline{D}^0$ (\text{\textsc{uc}})
- $K^+ + K^-$ (\text{\textsc{us} + \text{\textsc{us}}})

$D^0$ points x-axis shifted by 0.04
$\Lambda_c$ Enhancement in 200 GeV Au+Au Collisions

- $\Lambda_c$ enhancement increases towards more central Au+Au collisions
- Large $\Lambda_c$ contribution to the total charm cross-section in HI collisions

**STAR Preliminary**

Au+Au, $\sqrt{s_{NN}} = 200$ GeV, $3 < p_T < 6$ GeV/c

ALICE, p+p, $\sqrt{s} = 7$ TeV, $3 < p_T < 4$ GeV/c

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

Sooraj Radhakrishnan
#546 May 15, 15:40
$D^0$ Nuclear Modification Factors in 200 GeV Au+Au Collisions

- Significant suppression at low $p_T$ with no strong centrality dependence
- Suppression at high $p_T$ decreases towards more peripheral collisions

Sooraj Radhakrishnan
#546 May 15, 15:40
Nuclear Modification Factors in 200 GeV Au+Au Collisions

- Error found in previous 2010/11 analysis\(^1\). Corrected results consistent with 2014 (HFT) data
- Erratum for 2010/11 and a separate paper for 2014 data to be submitted soon

\(^1\) PRL 113, 142301 (2014)
Upsilon Suppression in 200 GeV Au+Au Collisions

- Improved precision by combining 2011 di-electron, 2014+2016 di-muon
- $\Upsilon(2S + 3S) R_{AA}$ smaller than $\Upsilon(1S)$ in 0-10%, "sequential melting" at RHIC

CMS PLB 04, 031 (2017)
Di-Jet Imbalance in 200 GeV Au+Au Collisions

• First measurement of centrality dependence of $A_J$ at RHIC
• Smaller di-jet imbalance in more peripheral collisions

Run7 0-20%: STAR PRL 119, 062301 (2017)
Di-hadron Correlations in 200 GeV Au+Au Collisions

Event Shape Engineering

- \( q_2 \) top 20%
- \( q_2 \) bottom 20%

- \( \Delta \phi = \phi_{asso} - \phi_{trig} \)

- ① \(-4\pi/8 < \phi_s < -3\pi/8\) out-of-plane
- ② \(-4\pi/8 < \phi_s < -3\pi/8\) out-of-plane
- ③ \(-\pi/8 < \phi_s < 0\) in-plane
- ④ \(-\pi/8 < \phi_s < 0\) in-plane

\[ \frac{1}{N_{trig}} \frac{dN_{pair}}{d(\Delta \phi)} \]

\( p_T^t = 4-10 \text{ GeV/c} \), \( p_T^a = 1-2 \text{ GeV/c} \)

- Di-hadron correlations depend on the angle of trigger particle w.r.t. event plane, and on \( q_2 \) : path-length dependence of jet-medium interaction

Quark Matter 2018, Venice, Italy

Zhenyu Ye for STAR Collaboration

Ryo Aoyama #551
May 15 16:40
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First observation of $\Lambda$ global polarization at 200 GeV
First observation of $Λ$ global polarization at 200 GeV
First observation of quadrupole structure of $Λ$ local polarization along beam direction

S. Voloshin, sQM2017
F. Becattini and I. Karpenko, PRL120, 012302 (2018)
Spin Alignment of $\phi$ Mesons in 200 GeV Au+Au Collisions

$\rho_{00}$ deviates from 1/3 in non-central collisions, probe vorticity induced by initial angular momentum and particle production.

\[ \frac{dN}{d(\cos\theta^*)} = N_0 \times \left[ (1 - \rho_{00}) + (3\rho_{00} - 1)\cos^2\theta^* \right] \]

Au+Au 200 GeV
1.2 < $p_T$ < 5.4 GeV/c
$\phi$ meson (1st order EP)

STAR preliminary

Chensheng Zhou
#731, May 16, 18:10
Possible CME $\Delta \gamma$ / inclusive $\Delta \gamma$

- Isolate possible CME signal in inclusive $\Delta \gamma$ by different methods

H.-J. Xu et al. arXiv:1710.07265
J. Zhao et al. arXiv:1705.05410
Isolate possible CME signal in inclusive $\Delta \gamma$ by different methods
• New observable $R_{\Psi_2}(\Delta S)$ shows difference between $p(d)+Au$ and peripheral $Au+Au$ collisions
• Dedicated isobar run this year completed, blind analyses for CME studies being conducted
• Differences in slope (r) among p/d+Au, Au+Au and U+U consistent with CMW expectation
• Difference between normalized $\Delta \nu_2$ and $\Delta \nu_3$ in most central and peripheral collisions

\[ A_{\text{ch}} = \frac{\bar{N}_+ - \bar{N}_-}{\bar{N}_+ + \bar{N}_-} \]

\[ \Delta \nu_2 = v_2^- - v_2^+ \approx r A_{\text{ch}} \]

\[ \text{Norm. } \Delta \nu_n = 2 \frac{v_n^- - v_n^+}{v_n^- + v_n^+} \]
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Ratio of $v_n\{4\}/v_n\{2\}$ is sensitive to flow fluctuations. The ratio for elliptic flow depends on collision system while that for triangular flow is independent.
- Ratio of $v_n\{4\}/v_n\{2\}$ is sensitive to flow fluctuations. The ratio for elliptic flow depends on collision system while that for triangular flow is independent.

- $v_2\{2\}$ scales with $\varepsilon_2\{2\}$ - similar viscous effect in these collisions.
Different $V_{2,2}$ from different methods to correct for non-flow background in p/d+Au collisions. Be careful about the assumptions of the methods.
Longitudinal Flow Decorrelation in 200 GeV Au+Au Collisions

• Stronger longitudinal flow decorrelation at RHIC than at LHC
• Hydro calculations can not simultaneously describe LHC and RHIC data
Directed Flow of Identified Particles in Beam Energy Scan


$\langle v_1 \rangle_{\text{trans.}u(d)} = \left[ (v_1)_{\text{net} \, p} - \left( 3 - N_{\text{trans.}u(d)} \right) (v_1)_{\bar{u}(d)} \right] / N_{\text{trans.}u(d)}$

$N_{\text{trans.}u(d)} = 3 \left[ 1 - \exp \left( -2 \mu_{u(d)} / T_{ch} \right) \right] / (1 - r_{p/p})$

- 10 species & 8 energies allow a detailed study of constituent-quark $v_1$. In most cases, the coalescence picture works for both “produced” particles and “net” particles
- “Transported quark” $v_1$ has a local minimum at ~14.5 GeV
• First $\pi$ $v_1$ measurement in this energy range, $v_1$ slope turning up towards lower energies
• Dedicated FXT runs (3.0-7.7 GeV) in 2019+ to explore high baryon density regime.
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Femtoscopy with Identified Particles in Beam Energy Scan

- Energy and centrality dependence of HBT radius studied with BES data
- Lighter particles emitted closer to the center of the source than heavy particles

Sebastian Siejka
#590, May 16, 15:40
Cumulants of Net-Particle Distributions in Beam Energy Scan

- Significant correlation in $Q$-$k$ and $Q$-$p$ is observed that cannot be explained by thermal (HRG) or non-thermal (UrQMD) model calculations.

\begin{align*}
C_{p,k}(\sigma_{p,k}^2) &= \left(\frac{\sigma_{p,k}}{\sigma_{N,k}^2}\right)
\end{align*}

\begin{align*}
C_{Q,k}(\sigma_{Q,k}^2) &= \left(\frac{\sigma_{Q,k}}{\sigma_{N,k}^2}\right)
\end{align*}

\begin{align*}
C_{Q,p}(\sigma_{Q,p}^2) &= \left(\frac{\sigma_{Q,p}}{\sigma_{N,p}^2}\right)
\end{align*}

\begin{align*}
\sqrt{s_{NN}} \text{ (GeV)}
\end{align*}

Toshihiro Nonaka
#585, May 16, 12:50

STAR Preliminary
Cumulants of Net-Particle Distributions in Beam Energy Scan

- Significant correlation in Q-k and Q-p is observed that can not be explained by thermal (HRG) or non-thermal (UrQMD) model calculations.

- Net-Lambda cumulant ratio $C_2/C_1$ closer to HRG calculations with freeze-out condition of kaon than charge/proton.
• Non-monotonic energy dependence of neutron density fluctuation $\Delta n = \langle \delta_n^2 \rangle / \langle n \rangle^2$

$N_t \cdot N_p / N_d^2 \approx g(1 + \Delta n)$, with $g = 0.29$

STAR Preliminary

STAR Au+Au Collisions (0-10%)
Measurement of (Anti-)Hypertriton Masses

• Excellent S/B ratio from the HFT data, allowing for precise determination of the hypertriton binding energy:
\[ m_d + m_\Lambda - m_{^3\Lambda H} = 0.44 \pm 0.10 \text{ (stat.)} \pm 0.15 \text{ (syst.)} \text{ MeV} \]
providing insight on Hyperon-Nucleon interaction and thus neutron star structure,
and the mass difference between \(^3\Lambda H\) and \(^3\bar{\Lambda}H\)
\[ (\Delta m/m)^{^3\Lambda H}_{^{3\bar{\Lambda}H}} = (1.0 \pm 0.9 \text{ (stat.)} \pm 0.7 \text{ (syst.)}) \times 10^{-4} \]
is the first test of the CPT symmetry in the light hyper-nuclei sector.
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Beam Energy Scan Phase II and Forward Upgrades

The STAR Forward Calorimeter and Forward Tracking System

A Tale of Initial State: Nucleon to Nuclei

<table>
<thead>
<tr>
<th>Beam Energy Scan Phase II (2019+)</th>
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<tbody>
<tr>
<td>Collider + FXT at 3.5-19.6 GeV</td>
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<tr>
<td>with iTPC, EPD, eTOF</td>
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<tr>
<td>Look for 1st order phase transition</td>
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<tr>
<td>Look for QCD critical point</td>
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<tr>
<td>Turn-off of QGP signatures</td>
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<th>Forward Upgrade (2021+)</th>
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<tbody>
<tr>
<td>p+p, p+A, A+A at top energies</td>
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<tr>
<td>(3+1)D correlations</td>
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<tr>
<td>Initial state &amp; hadronization in nucl. collisions</td>
</tr>
<tr>
<td>Subprocess driving large $A_N$ at high $x_F$ and $\eta$</td>
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<tr>
<td>Signature and A-dependence of saturation</td>
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<tr>
<td>TMDs at low and high $x$, $\Delta g(x)$ at low $x$</td>
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Qian Yang
#23, May 15, 10:00
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19 oral and 32 poster presentations from STAR (listed in the following slides)
Parallel Talks from STAR

Thermodynamics and hadron chemistry

#556 Precise measurement on hypertriton and anti-hypertriton masses and lifetimes with the Heavy Flavor Tracker and the production of triton in Au+Au collisions at STAR, by Peng Liu, May 15 15:40

Initial state physics and approach to equilibrium

#588 Collision System Dependence of Anisotropic Flow, Flow Fluctuations and Mixed Harmonic Correlations at STAR Energies, by Niseem Magdy, May 15 11:30

Correlations and fluctuations

#551 Event Plane Dependence of Di-hadron Correlations with Event Shape Engineering at the STAR Experiment, by Ryo Aoyama, May 15 16:40

#590 Geometry and Dynamics in Heavy-ion Collisions Seen by the Femtoscopy in the STAR Experiment, by Sebastian Siejka, May 16 15:40

Collective dynamics

#591 Measurement of Longitudinal Decorrelation of Anisotropic Flow v2 and v3 in 54 and 200 GeV Au+Au Collisions at STAR, by Maowu Nie, May 15 12:50

#587 Directed Flow of Quarks from the RHIC Beam Energy Scan Measured by STAR, by Gang Wang, May 16 11:50

Chirality, vorticity and polarisation effects

#584 Global Polarization of Lambda Hyperons in Au+Au Collisions at 200 GeV from STAR, by Takafumi Niida, May 15 9:00

#848 Measurements of the Chiral Magnetic Effect with Background Isolation in 200 GeV Au+Au Collisions at STAR, by Jie Zhao, May 16 9:40

#592 Search for the Chiral Magnetic Wave with Anisotropic Flow of Identified Particles at RHIC-STAr, by Qiye Shou, May 16 17:30

Open heavy flavor

#546 Measurements of Open Charm and Bottom Production in Au+Au Collisions at 200 GeV with the STAR Experiment at RHIC, by Sooraj Radhakrishnan, May 15 15:40

#540 Measurements of D0 Meson Directed, Elliptic and Triangular Flow Using the STAR Detector at RHIC, by Subhash Singha, May 16 9:40

Quarkonia

#544 Upsilon Measurements in Au+Au Collisions at √sNN = 200 GeV with the STAR Experiment, by Pengfei Wang, May 15 11:10

Phase diagram and search for the critical point

#585 Recent Results and Methods on Higher Order and Off-diagonal Cumulants of Identified Net-particle Multiplicity Distributions in Au+Au Collisions at STAR, by Toshihiro Nonaka, May 16 12:50

High baryon density and astrophysics

#558 Recent Results from the STAR Fixed-Target Program, by Yang Wu, May 15 16:00

Collectivity in small systems

#734 Long-range Collectivity in Small Collision Systems with Two- and Four-particle Correlations at STAR, by Shengli Huang, May 15 11:30

Future facilities, upgrades and instrumentation

#23 The STAR BES II and Forward Rapidity Physics and Upgrades, by Qian Yang, May 15 10:00
### Thermodynamics and hadron chemistry
- #450 Collision Energy and Centrality Dependence of Light Nuclei (Triton) Production at RHIC with the STAR Experiment, by Dingwei Zhang
- #559 Strangeness Production in U+U Collisions at STAR, by Srikanta Kumar Tripathy

### Initial state physics and approach to equilibrium
- #733 Directed Flow Due to the Initial Source Tilt and Density Asymmetry in Cu+Au and Au+Au Collisions at STAR, by Takafulmi Niida

### Correlations and fluctuations
- #453 Effect of Volume Fluctuation and Non-binomial Efficiency on the Cumulants of Net-proton Multiplicity Distributions at the STAR Experiment, by Toshihiro Nonaka
- #467 Angular Correlations Study of Identified Hadrons in the STAR Beam Energy Scan Program, by Andrezj Lipiec
- #528 Energy Dependence of the Fluctuations of Net-Lambda Distributions at STAR, by Nalinda Peipei Li
- #532 Measurement of the Sixth-order Cumulant of Net-charge Distributions in Au+Au Collisions at sNN = 200 GeV by the STAR Experiment, by Tetsuro Sugiiura
- #579 Femtoscopic Measurements for Shape-engineered Events in Au+Au Collisions at STAR, by Benjamin Schweid

### Collective dynamics
- #124 D0-meson Elliptic Flow Measurement in Au+Au Collisions at sNN = 200 GeV from STAR, by Yue Liang
- #527 Charged Particle Yields and Anisotropic Flow at Forward Rapidities from Au+Au Collisions at 54GeV Using the STAR Event Plane Detector, by Isaac Upsal

### Chirality, vorticity and polarisation effects
- #452 The Azimuthal Angle Dependence of Lambda (anti-Lambda) Polarization in Au+Au Collisions from STAR, by Biao Tu
- #593 Beam Energy and Collisions System Dependence of Charge Separation Relative to the Second-, Third- and Fourth-order Event Planes and the Implications for the Search for Chiral Magnetic Effects in STAR, by Nisem Madgy

### Jet modifications and high-pT hadrons
- #375 Performance of Heavy-flavor Tagged Jet Identification in STAR, by Saehanseul Oh

### Open heavy flavor
- #81 Centrality and Transverse Momentum Dependences of D0-meson and Dz-meson Production at Mid-rapidity in Au+Au Collisions at sNN = 200 GeV, by Guannan Xie
- #83 Topological Cut Optimization for Lambda_cbar Reconstruction Using the Supervised Learning Algorithm in TMVA at STAR, by Chuan Fu
- #84 Production of Dz Mesons in Au+Au Collisions at sNN = 200 GeV Measured by the STAR Experiment, by Jan Vanek
- #85 Extraction of Bottom Production via the Semi-leptonic Decay Channel in Au+Au Collisions at sNN = 200 GeV by the STAR Experiment, by Yifei Zhang
- #87 D*+ Production in Au+Au Collisions at sNN = 200 GeV Measured by the STAR Experiment, by Yuanjing Ji
- #100 Measurement of Lambda_cbar- /Lambda_c+ Ratio in Au+Au Collisions at sNN = 200 GeV with the STAR Experiment, by Miroslav Simko
- #541 Measurements of Open Bottom Hadron Production via Displaced J/psi, D0 and Electrons in Au+Au Collisions at sNN = 200 GeV at STAR, by Xiaolong Chen

### Quarkonia
- #80 Measurement of J/psi Polarization in p+p Collisions at vs = 200 GeV through the Di-muon Channel at STAR, by Zhen Liu
- #110 Measurements of the Upsilon Meson Production in Au+Au Collisions at sNN = 200 GeV by the STAR Experiment, by Oliver Matonoha

### Electromagnetic and weak probes
- Dimuon Invariant Mass Spectra with the Muon Telescope Detector at STAR in p+p collisions at 200 GeV, by James Brandenburg
- #534 Off-diagonal Cumulants of Net-charge, Net-proton, and Net-kaon Multiplicity Distributions in Au+Au collisions at STAR, by Arghya Chatterjee
- #535 Cumulants of Net-Proton Multiplicity Distributions in Cu+Cu Collisions at sNN = 22.4, 62.4 and 200 GeV from STAR, by Zhenzhen Yang

### Collectivity in small systems
- #851 STAR Measurements of Elliptic Flow in Small Collision Systems, by Maria Sergeeva 15

### Future facilities, upgrades and instrumentation
- #14 Performance of the STAR Event Plane Detector, by Justin Ewigleben
- #20 Construction of the STAR Event Plane Detector, by Joseph Adams
- #25 The STAR Mid-Rapidity Physics Program after the BES-II, by Qian Yang
- #26 The STAR Forward-Rapidity Physics Program after the BES-II, by Li Yi