Recent results on Light Flavor from STAR

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Introduction

RHIC Top Energy
p+p, p+Al, p+Au, d+Au, 3He+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 the 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

- Initial conditions: flow results
- Phase transition and critical point:
  \( v_1 \), net fluctuations, deuteron, triton, strangeness
- Hypertriton
- Medium effect and dynamics:
  \( K^* \) and \( \phi \), low-\( p_T \) dilepton
- Chirality, vorticity and polarization effects:
  \( \Lambda \) polarization, CME
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Flow and Fluctuations in Multiple Systems

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.
Collectivity in Small Systems

- Different $V_{2,2}$ from different methods to correct for non-flow background in p/d+Au collisions, positive $v_2$ at high multiplicity
- $v_2$ from subtraction method is negative at lower collision energies
- $v_2$ from template fit increases with multiplicity
- Initial state effect vs. final state effect? Hydrodynamics or anisotropic escape?
Stronger longitudinal flow decorrelation at RHIC than at LHC.

Hydrodynamic calculations can not simultaneously describe LHC and RHIC data.
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Higher moments

Mapping the **freeze-out curve** and probing the possible **critical point** through fluctuations of conserved quantum numbers:

New measurements of net-proton cumulants for Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV

The $C_6/C_2$ for central Au+Au collisions at 54.4 GeV is positive while that for 200 GeV is negative (with large uncertainties). These have consequences vis-à-vis chiral criticality in QCD.
Higher moments of Net-$\Lambda$ distributions

Net-Lambda fluctuations provide a more complete strangeness proxy together with net kaons and compare with HRG predictions for sequential hadronization

The net-Lambda cumulant ratios can be described by the latest HRG model, no non-monotonic behavior vs. energy

The net-Lambda variance vs. $y$: small deviations from NBD for larger rapidity coverage, could be attributed to the effect of baryon number and strangeness conservation

works if B and S conservation are treated additive

Rene Bellwied’s talk

SQM2019, Italy J. Zhao
Directed Flow ($v_1$)

Probe of the softening of the Equation of State
- strong softening: consistent with the 1st-order phase transition
- weaker softening: more likely due to crossover
Directed Flow of Identified Particles

(N:\users\jzhao\atc\star\publications\STAR-DIR-2018-012.pdf)


10 - 40% Au+Au
STAR preliminary

\[ (v_1)_{\text{trans.}u(d)} = \frac{[(v_1)_{\text{net}p} - (3 - N_{\text{trans.}u(d)})v_1(\bar{u}(\bar{d})]/N_{\text{trans.}u(d)} \]

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

- 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
Fixed-Target Test Run for Au+Au at 4.5 GeV

- First $\pi_1$ measurement in this energy range, $\pi_1$ slope turning up towards lower energies
- Dedicated FXT runs (3.0-7.7 GeV) in 2019+ to explore high baryon density regime
$B_2(d)$ are smaller than that of $B_2(d)$, indicate antibaryon freeze-out at a larger source. $B_2$ decreases with collision energy. A minimum at $\sqrt{s_{NN}} \sim 20$ GeV: change of EOS?!

$B_2$ and $\sqrt{B_3}$ are consistent within uncertainties except 200 GeV.
Neutron density fluctuation, $\Delta n$, shows a non-monotonic behavior on collision energy. Peak $\sim 20$ GeV.
Strange hadron production

\[ \langle m_T \rangle - m_0 \text{ of antibaryons and baryons significantly deviate from each other towards lower collision energies, especially for anti-}\Lambda \text{ and } \Lambda. \]

- The \( K_0^0 \) \( R_{CP} \) no suppression for \( p_T \) 3.5 GeV and particle type independence at \( \leq 11.5 \text{ GeV}. \)
- Partonic energy loss effect less significant at low energies. The cold nuclear matter effect take over?
- Further investigation of the deconfinement phase transition below 19.6 GeV
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(Anti-)Hypertriton Masses

- Excellent S/B with HFT, precise determination of the binding energy:
  \[ m_d + m_\Lambda - m_\Lambda^3 = 0.44 \pm 0.10 \text{ (stat.)} \pm 0.15 \text{ (syst.) MeV} \]

- Providing insight on Hyperon-Nucleon interaction, thus neutron star structure

- The mass difference between \( _\Lambda^3\text{H} \) and anti-\( _\Lambda^3\text{H} \)
  
  \[
  (\Delta m/m)_{_\Lambda^3\text{H}} = (1.0 \pm 0.9 \text{ (stat.)} \pm 0.7 \text{ (syst.)}) \times 10^{-4}
  \]
  is the first test of the CPT symmetry in the light hypernuclei sector

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STAR, arXiv:1904.10520
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**Highlights from STAR**

Zhenyu Ye for the STAR Collaboration

University of Illinois at Chicago

**J. Zhao**

SQM2019, Italy

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**K*0 and φ resonance production**

- K*0/K- decreases with centrality
- φ/K- ratio is independent of centrality

- Dominance of hadronic re-scattering at RHIC and LHC
- More re-scattering in central collisions

Small hadronic interaction cross section for φ

- More re-scattering in central collisions
Low-\(p_T\) \(e^+e^-\) enhancement

Can not be explained by in-medium broadened \(\rho\) model

Compared to hadronic production, excess yield exhibits a much weaker centrality dependence

Need additional source(s)

Initial magnetic field?

May provide insights on the chiral effects?
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- First observation of finite $\Lambda$ global polarization at 200 GeV
- First observation of quadrupole structure of $\Lambda$ local polarization along beam direction
H-J Xu, et al., CPC 42 (2018) 084103

- **ψ<sub>PP</sub>(TPC) vs. ψ<sub>RP</sub>(ZDC)**

- **Invariant mass dep. of the Δγ**

- **Isolate possible CME signal in inclusive Δγ by different methods**

- **These estimates indicate:**
  - possible CME signal is small in inclusive Δγ, within 1-2σ from zero with the current precision

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STAR preliminary

Au+Au \( \sqrt{s_{NN}} = 200 \text{ GeV (20-50%)} \)

- \( \psi_{RP}/\psi_{PP} \) (TPC full)
- \( \psi_{RP}/\psi_{PP} \) (TPC sub-evt)
- \( m_{inv} > 1.5 \text{ GeV/c}^2 \) (TPC full)
- Low \( m_{inv} \) + ESE (TPC sub-evt)

**Possible CME Δγ / inclusive Δγ**

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