Spin polarization in relativistic heavy-ion collisions (at NICA)

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JOINT INSTITUTE FOR NUCLEAR RESEARCH

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Vortical motion of nuclear matter

Relativistic nuclear collision

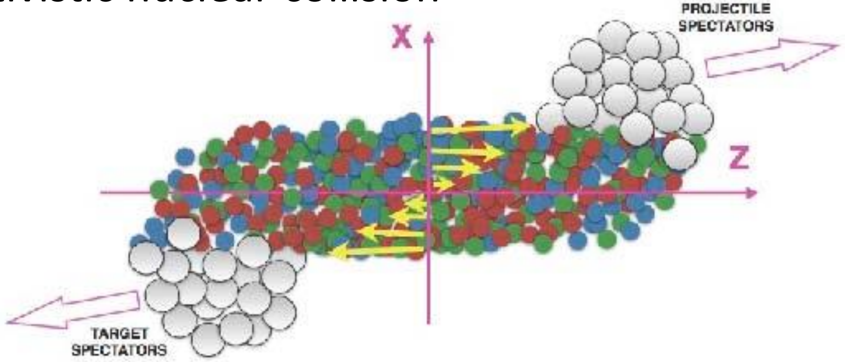


Fig. from Becattini, et al., PRC 95, 54902 (2017)

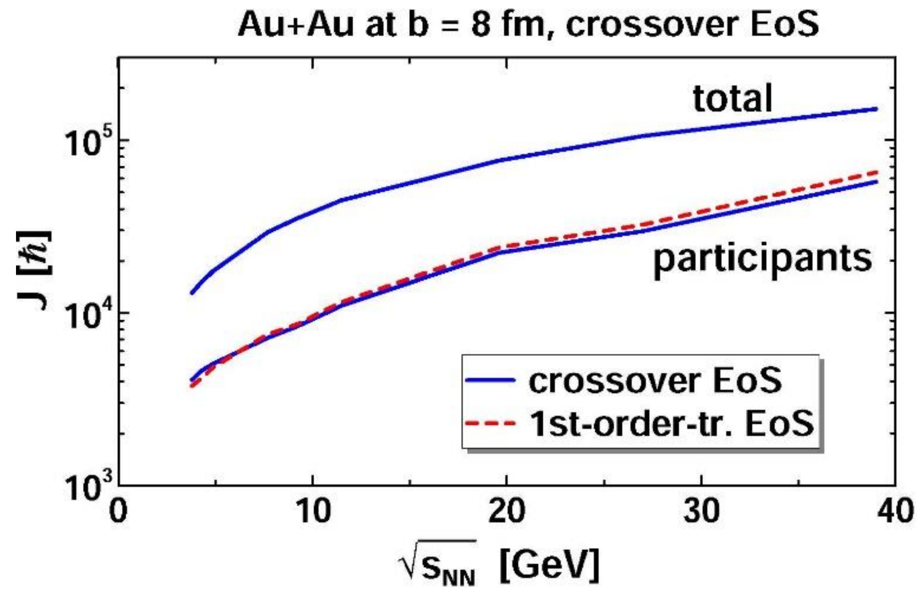
Vortical motion: $\vec{\omega} = (1/2)\vec{\nabla} \times \vec{v}$ = **Vorticity**

Relativistic Kinematic Vorticity

$$\omega_{\mu\nu} = \frac{1}{2}(\partial_\nu u_\mu - \partial_\mu u_\nu)$$

where u_μ = collective local 4-velocity of the matter

Large angular momentum



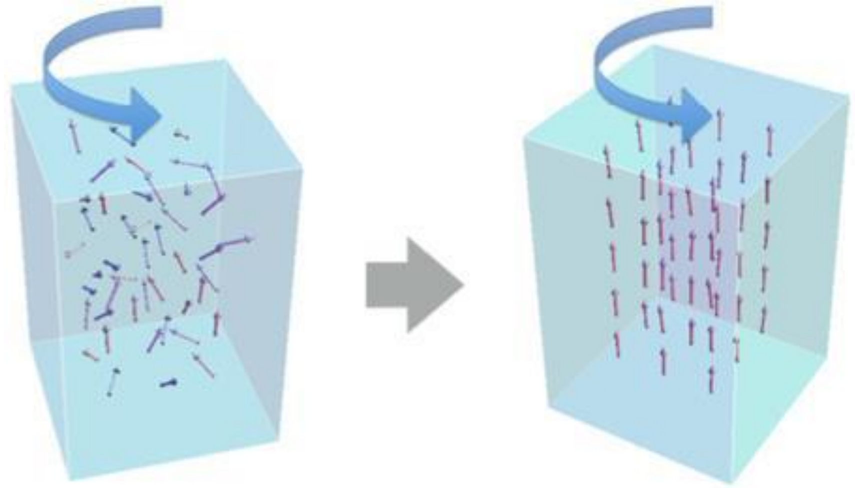
Yu B. Ivanov, V.D. Toneev, A.A. Soldatov, Phys. Rev. C 100 (2019), 014908

Observation of vortical motion

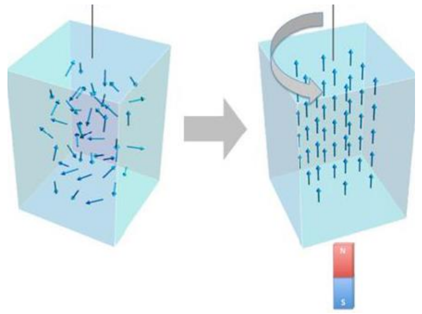
Vorticity induces alignment of particle spin along its direction

This global polarization is analog of
Barnett effect (1915): magnetization by rotation

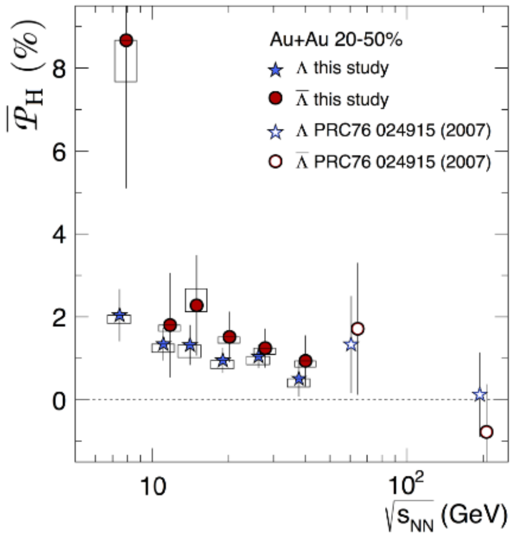
A fraction of orbital momentum of body rotation
is transformed into spin angular momentum



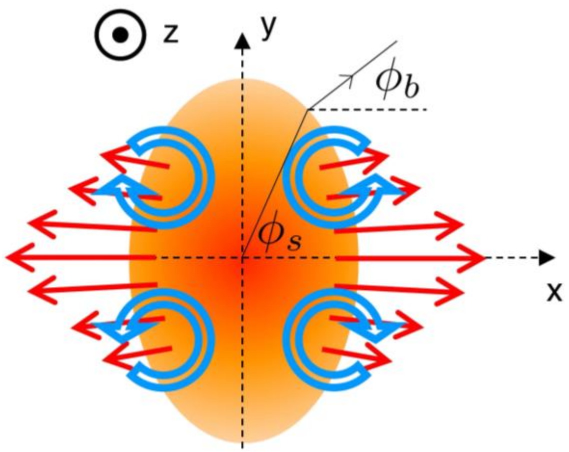
Reverse effect:
Einstein-de Haas effect (1915): rotation by magnetization

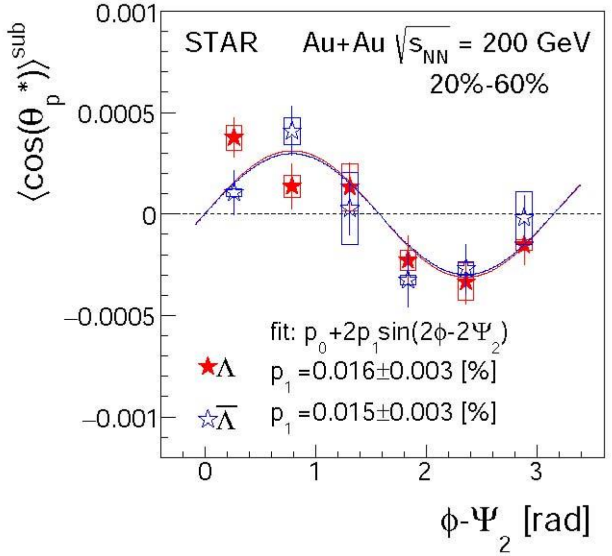


Observation of polarization in HIC



Global Λ and $\bar{\Lambda}$ polarization was measured by STAR collaboration
[Nature 548, 62 (2017)]





Polarization of Λ and $\bar{\Lambda}$ hyperons along the beam direction in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
J. Adam et al. [STAR], Phys. Rev. Lett. 123, 132301 (2019)

Measurement of **global spin alignment of K^{*0} and φ vector mesons** using the STAR detector at RHIC
S. Singha [STAR], arXiv:2002.07427 [nucl-ex].
also
S. Acharya, et al., [ALICE Collaboration], Phys. Rev. Lett. 125, 012301 (2020).

Global Λ and $\bar{\Lambda}$ polarization

Two approaches can explain these data

✓Thermodynamic approach [F. Becattini, et al., Annals Phys. 338, 32 (2013)]

Spins are distributed according to thermal equilibrium in rotating system

✓Approach based on axial vertical effect (AVE) [Baznat Gudima Sorin Teryaev PRC 88 (2013) 061901 Sorin and Teryaev, PRC 95, 011902 (2017)]

The system is thermally equilibrium but spin polarization is dynamically determined by AVE.

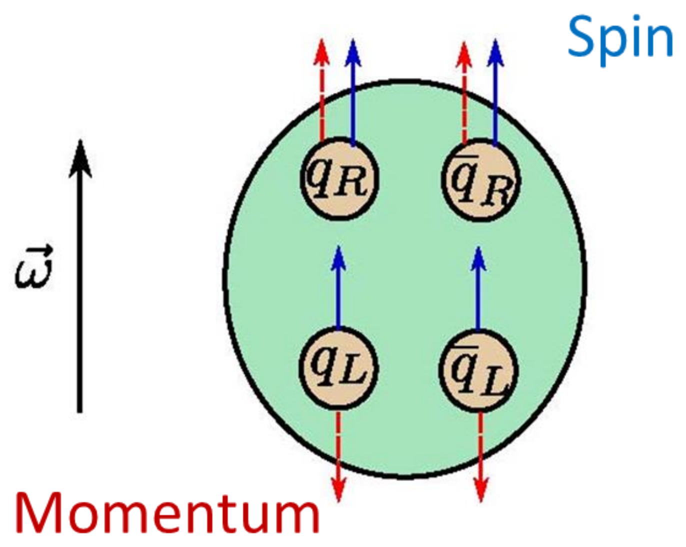


Fig. from Gao, et al., PRL 109 (2012) 232301

Polarization increases with $\sqrt{s_{NN}}$ decrease

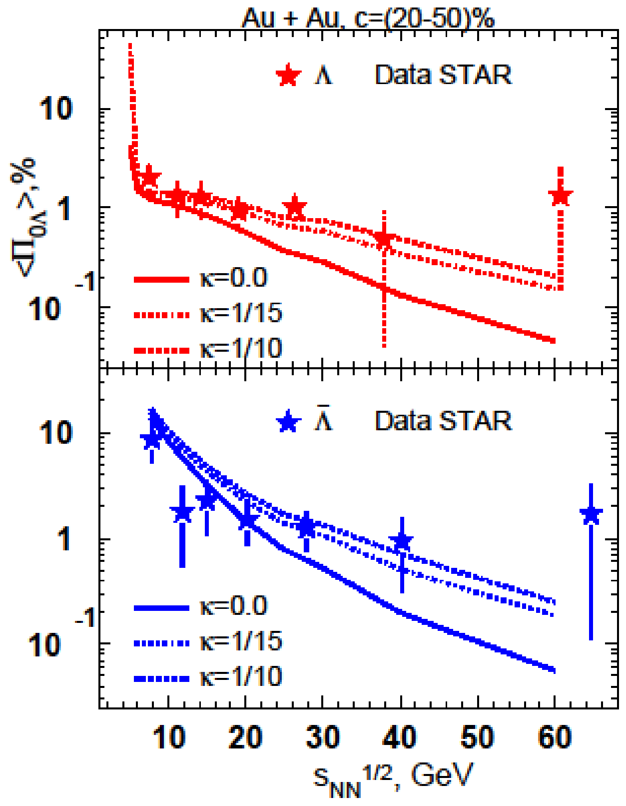
first predicted in [Rogachevsky, Sorin, Teryaev, PRC 82 (2010) 054910]

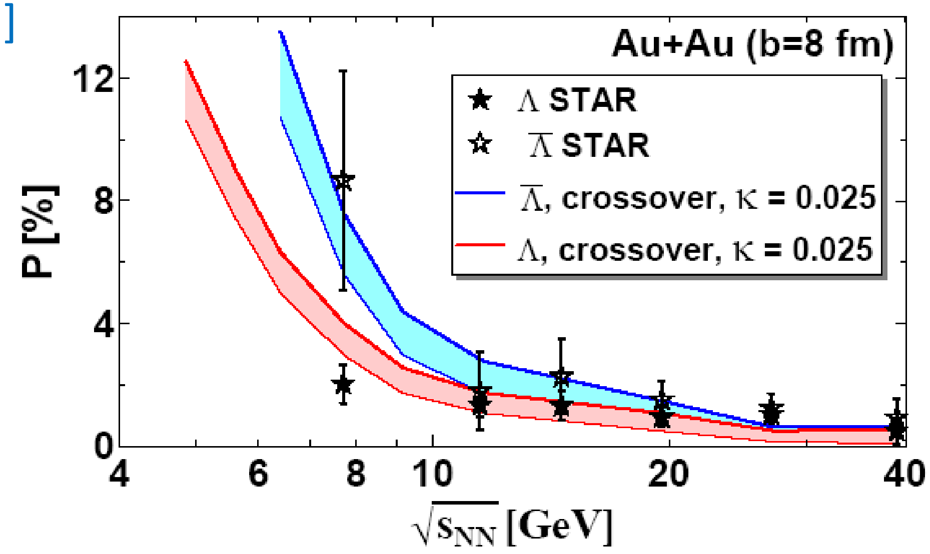
AVE approach predicts higher polarization at low energies than **thermodyn. one**

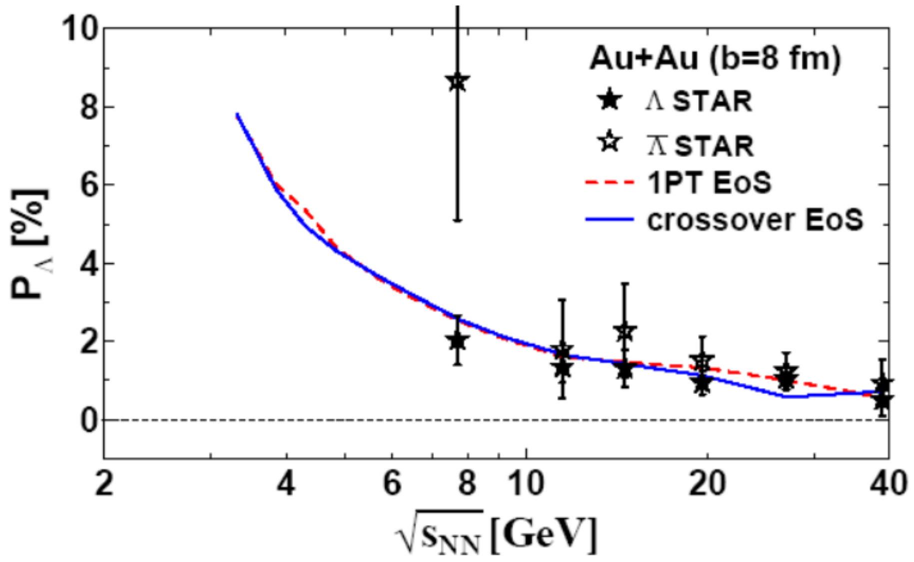
Baznat, Gudima, Sorin, Teryaev, PRC 97, 041902 (2018) [QGSM]

Ivanov, PRC 102 (2020) 044904

Ivanov, Soldatov, PRC 102, 024916 (2020)
+ 10 other publications





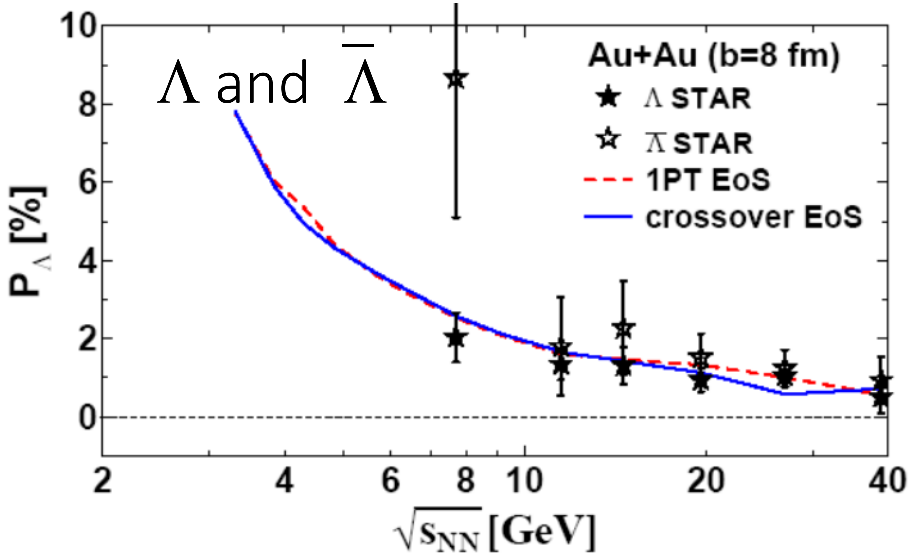


NICA data will distinguish between AVE and thermodynamic predictions

Λ -- $\bar{\Lambda}$ polarization splitting (1)

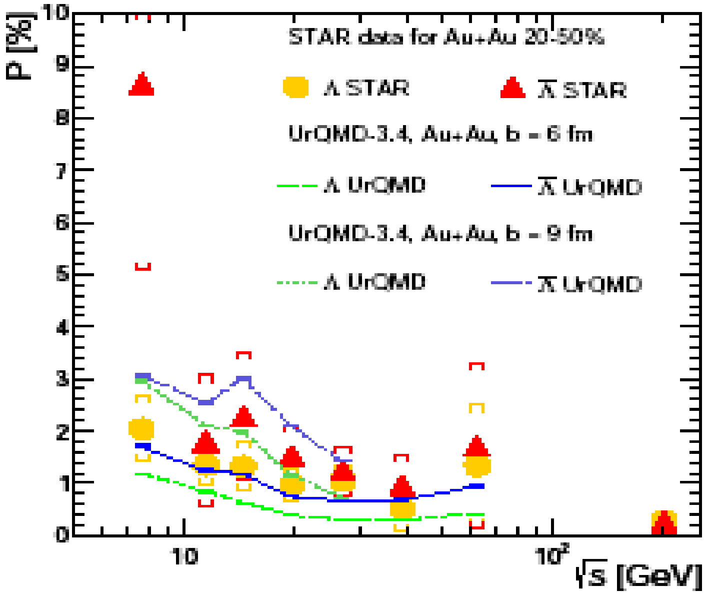
In the standard thermodynamic approach this splitting is either very small

Ivanov, Soldatov, PRC 102, 024916 (2020)



or simply small, if different freeze-out for Λ and $\bar{\Lambda}$ is taken into account,

Vitiuk, Bravina and Zabrodin, Phys. Lett. B 803, 135298 (2020)



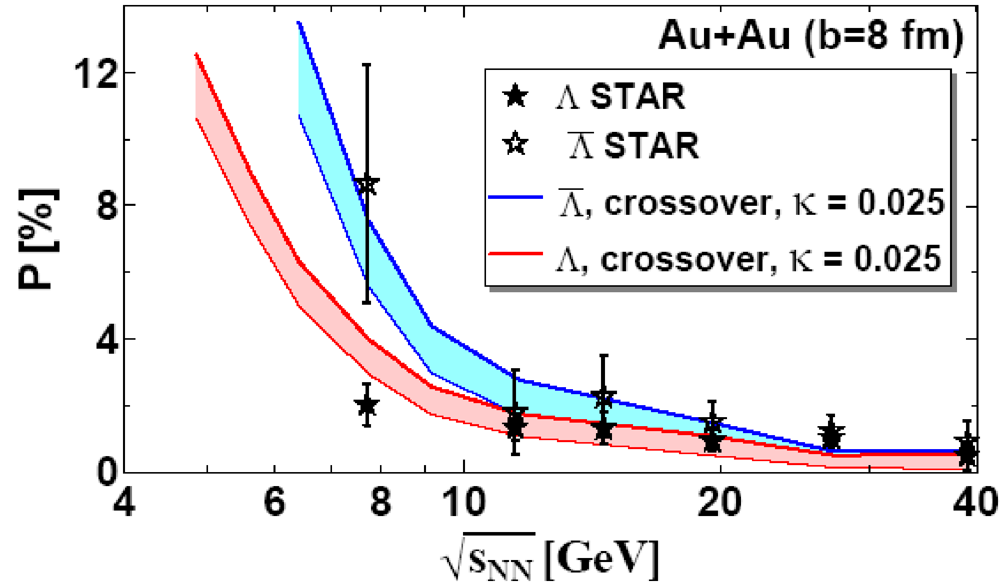
while exp. difference is large at 7.7 GeV, although error bars for $\bar{\Lambda}$ are also large.

Λ -- $\bar{\Lambda}$ polarization splitting (2)

AVE approach naturally predicts the Λ -- $\bar{\Lambda}$ polarization splitting

Baznat, Gudima, Sorin, Teryaev, PRC 97, 041902 (2018)

Ivanov, PRC 102 (2020) 044904



Measurements at NICA can refine the data at 7.7 GeV and extend them down to 5 GeV

and thus clarify the nature of the Λ -- $\bar{\Lambda}$ polarization splitting

Other approaches to Λ -- $\bar{\Lambda}$ polarization splitting

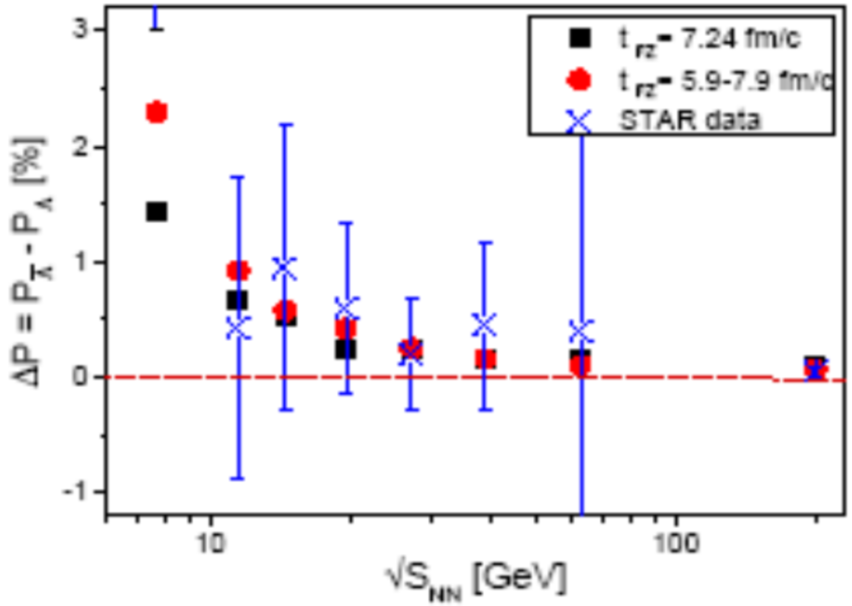
✓Presence of a strong magnetic field

Still open question:

if the required strong magnetic field is generated in collisions?

✓ Interaction mediated by massive vector and scalar bosons (Walecka-like model)

Csernai, Kapusta, Welle, PRC 99, 021901 (2019)

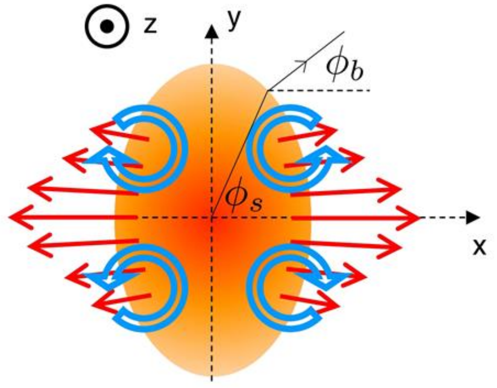


Xie, Chen, Csernai, arXiv:1912.00209

Other remaining problems

Straightforward application of the thermodynamic approach does not explain data on

Local polarization of Λ and $\bar{\Lambda}$ hyperons along the beam direction (sign problem)



and

too high **global spin alignment of K^{*0} and φ vector mesons**

These are subjects of active discussion

Calculations of polarization at NICA energies

Many calculations at $7.7 \le \sqrt{s_{NN}} \le$ 11.5 GeV (top NICA = low BES-RHIC energies)

Only few calculations at $\sqrt{s_{NN}} <$ 7.7 GeV

✓Within thermodynamic approach by *Becattini et al.*

Deng, Huang, Ma, Zhang, PRC 101, 064908 (2020) [UrQMD, in terms of mean vorticity]

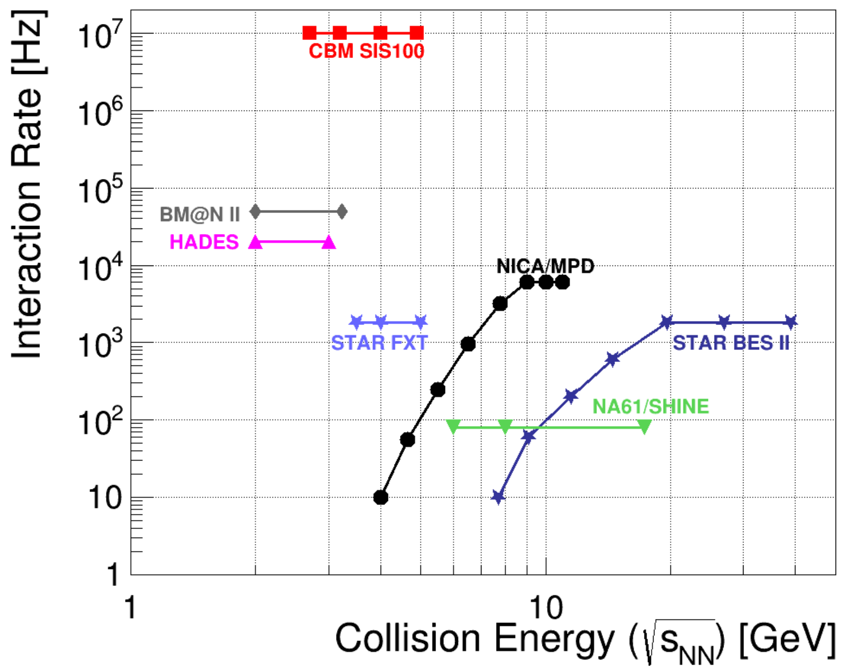
Ivanov, et al., PRC 100, 014908 (2019), PRC 102, 024916 (2020) [3FD model]

✓Within axial-vertical-effect approach *[Sorin&Teryaev, PRC 95, 011902 (2017)]*

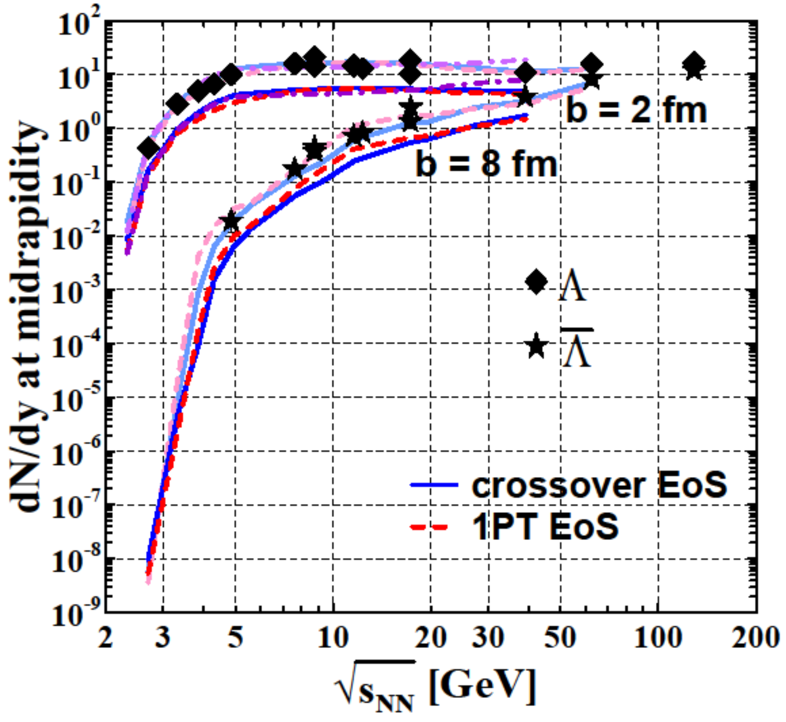
Baznat, Gudima, Sorin, Teryaev, PRC 97, 041902 (2018) [QGSM model]

Ivanov, 2006.14328 [nucl-th] [3FD model]

Feasibility of polarization measurements at NICA



CBM, Eur.Phys.J.A 53 (2017) 3, 60



3FD simulations

To be published

STAR experience

global polarization: (dN/dy)(interaction rate) ≥ 1 s

local polarization: (dN=dy)(interaction rate) ≥ 10^4 s

Therefore, at NICA polarization measurements are feasible at

$\sqrt{s_{NN}} \geq$ 4 GeV for global Λ,

$\sqrt{s_{NN}} \geq$ 5 GeV for global $\bar{\Lambda}$,

$\sqrt{s_{NN}} \geq$ 6 GeV for local Λ,

infeasible for local $\bar{\Lambda}$

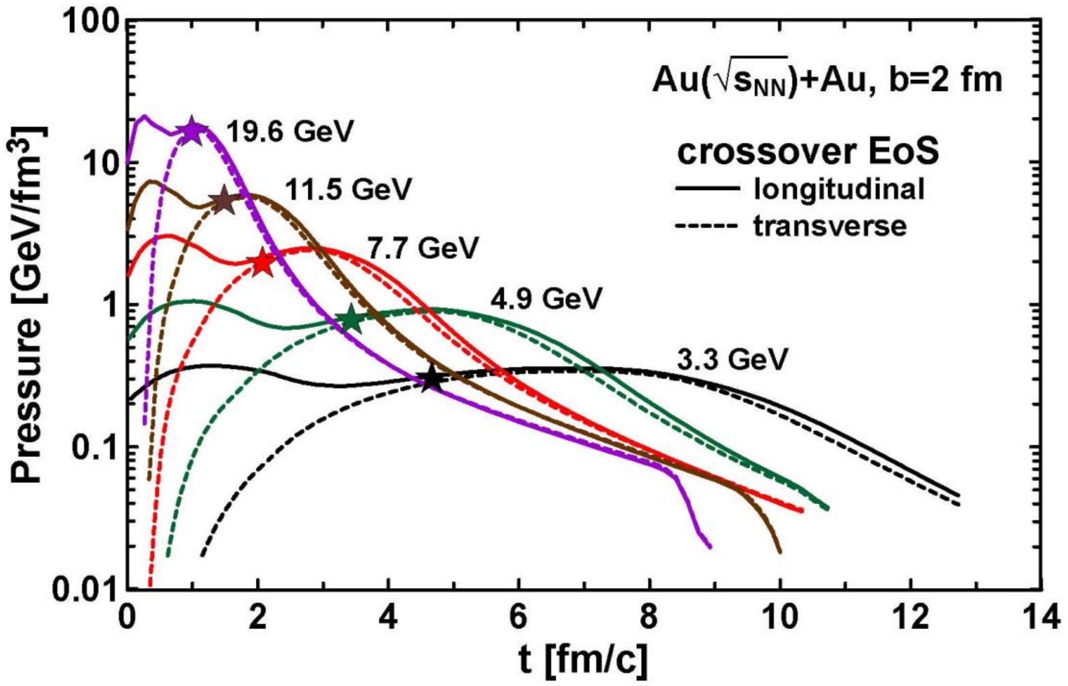
Equilibration at NICA energies

Longitudinal and transverse pressure in the center of colliding nuclei

Mechanical equilibration time is comparatively long

Freeze-out is mechanically equilibrium

Ivanov, Soldatov, PRC C 101, 024915 (2020)



Chemical equilibration takes even longer time

Bravina et al., PRC 78, 014907 (2008); De et al., PRC 94, 054901 (2016);

M. Teslyk, L. Bravina, O. Panova, O. Vitiuk, E. Zabrodin, PRC 101, 014904 (2020)

Summary

- ✓ **NICA data will distinguish between AVE and thermodynamic predictions**

- ✓ **Measurements at NICA can clarify the nature of the Λ -- $\bar{\Lambda}$ splitting**

- ✓ **Measurements of local longitudinal Λ polarization are also possible at $\sqrt{s_{NN}} \geq$ 6 GeV**

- ✓ The authors are grateful to the RFBR for support within the Grants No. 18-02-40084 and No. 18-02-40085

- ✓ Key publications within the RFBR Grants No. 18-02-40084 and No. 18-02-40085

- ❑ Y. B. Ivanov and A. A. Soldatov, Phys. Rev. C 101, 024915 (2020)
- ❑ Y. B. Ivanov, V. D. Toneev and A. A. Soldatov, Phys. Rev. C 100, 014908 (2019)
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- ❑ M. Teslyk, L. Bravina, O. Panova, O. Vitiuk, E. Zabrodin, Phys. Rev. C 101, 014904 (2020)
- ❑ O. Vitiuk, L.V. Bravina, E.E. Zabrodin, Phys. Lett. B 803, 135298 (2020)
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