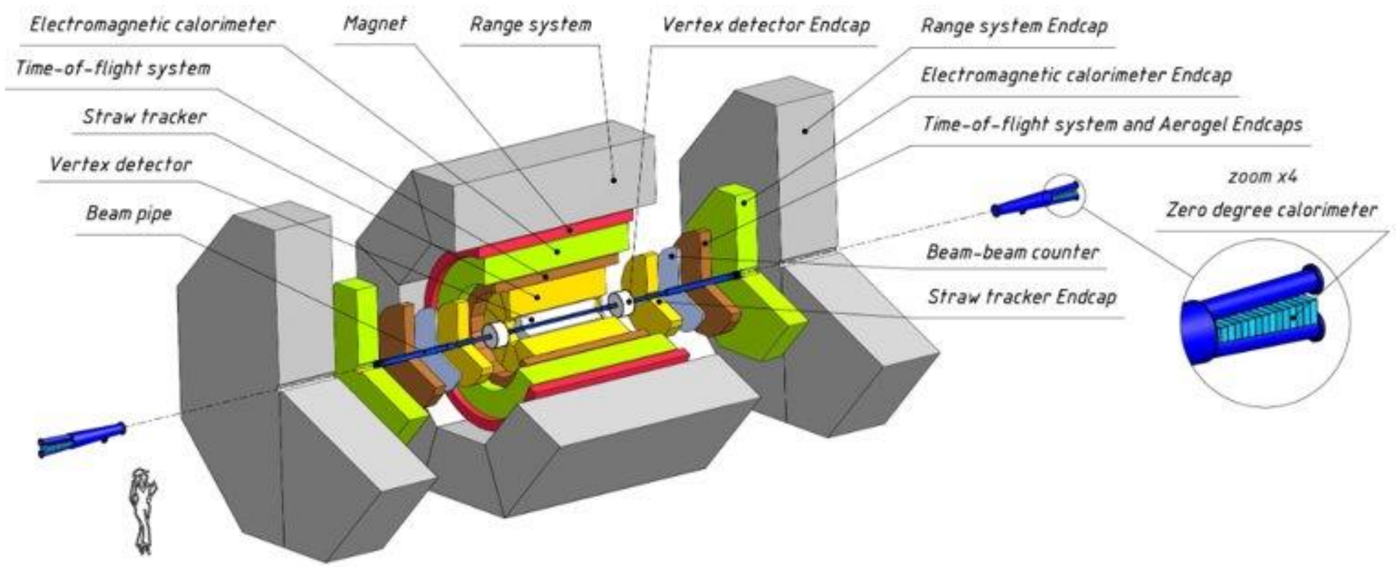


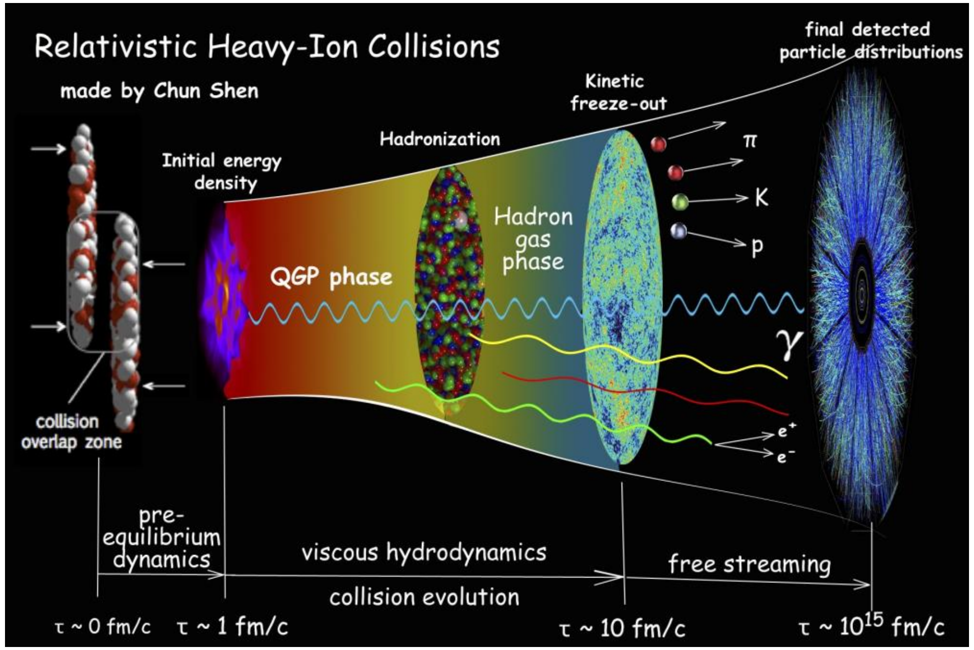
Relativistic ion-ion physics program at SPD

Grigory Nigmatkulov

National Research Nuclear University MEPhI

SPD Physics and MC. May 24, 2023

Relativistic Heavy-Ion Collisions

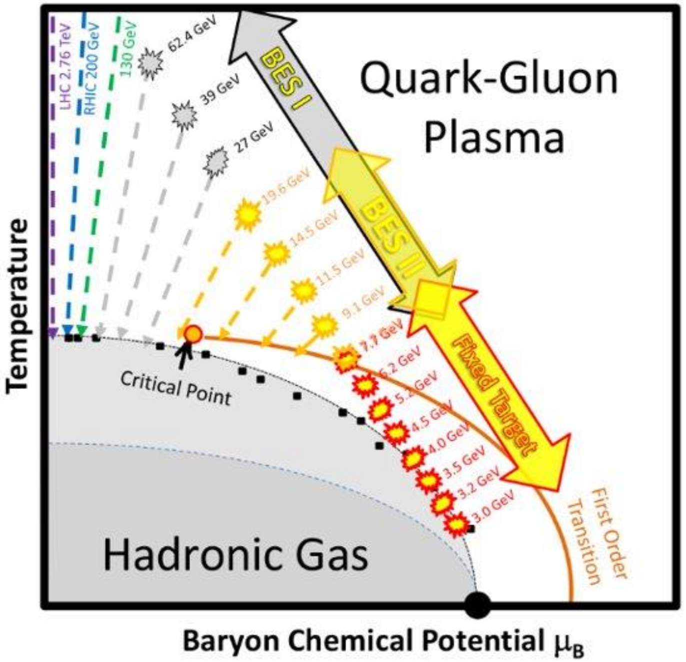


Physics questions:

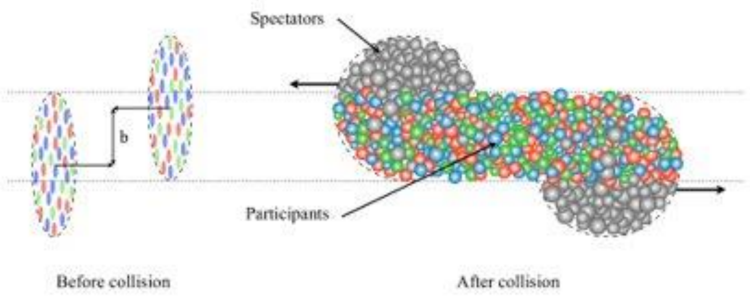
- Nuclear matter properties at extreme temperatures and densities
- Change of nuclear Equation-of-State
- How to describe the nuclear matter at different baryon chemical potentials?
  - Almost perfect liquid (LHC)
  - Mixture of
  - Hadron gas (low energies $\sqrt{s_{NN}}$<3-5 GeV)
- Propagation of particles through matter (e.g. nuclear matter effects)
- Chiral magnetic and vortical effects
- And many more

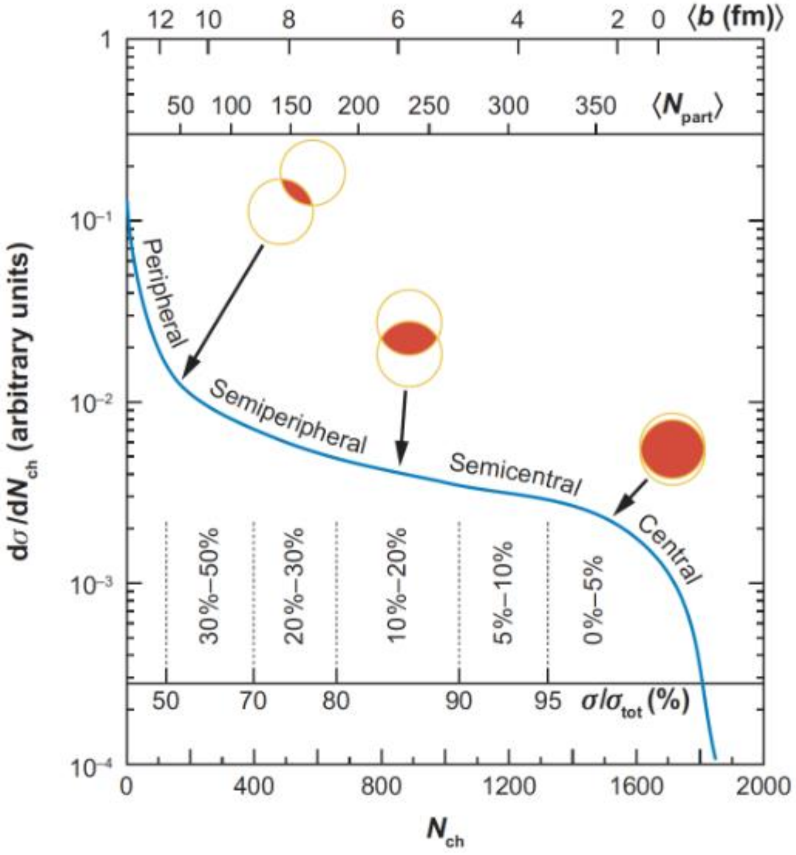
System properties can be probed via:

- Transverse momentum particle spectra
- Momentum and angular correlations
- Azimuthal anisotropies
- Global and local polarization of particles
- Etc...

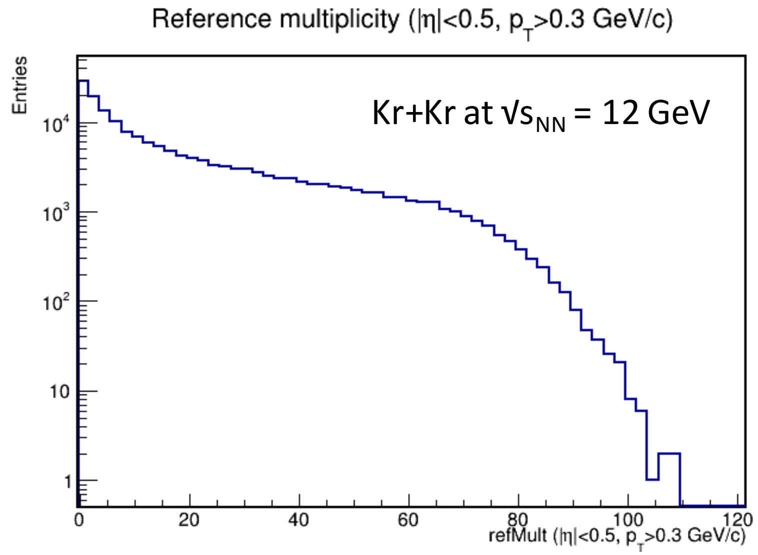


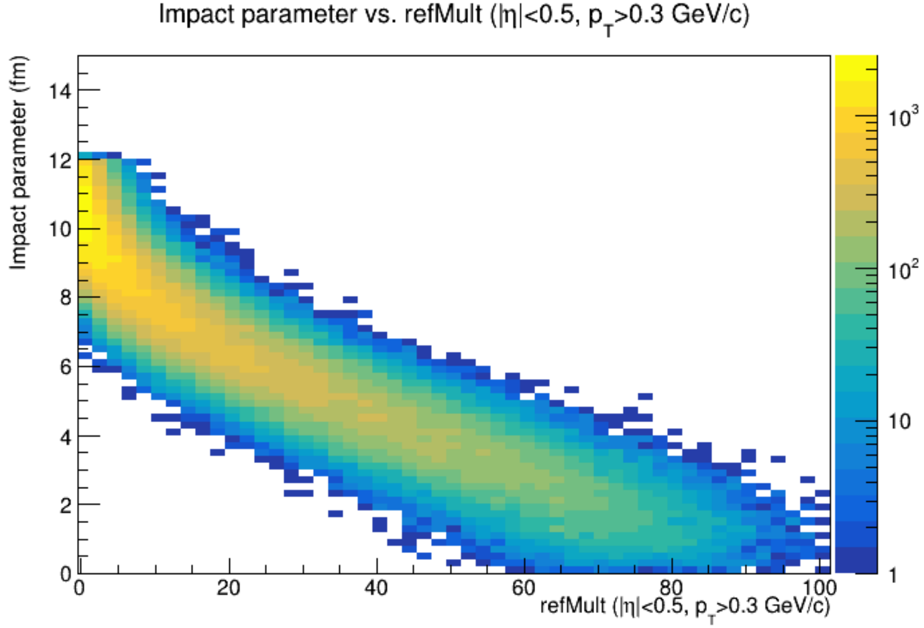
Collision Centrality and Charged Particle Density





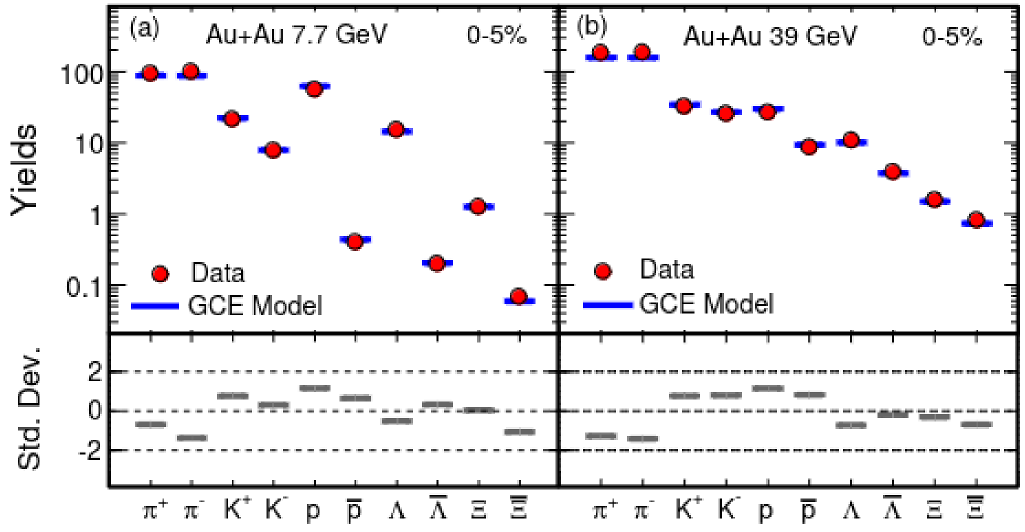
Good correlation between charged particle multiplicity and impact parameter for the SPD acceptance

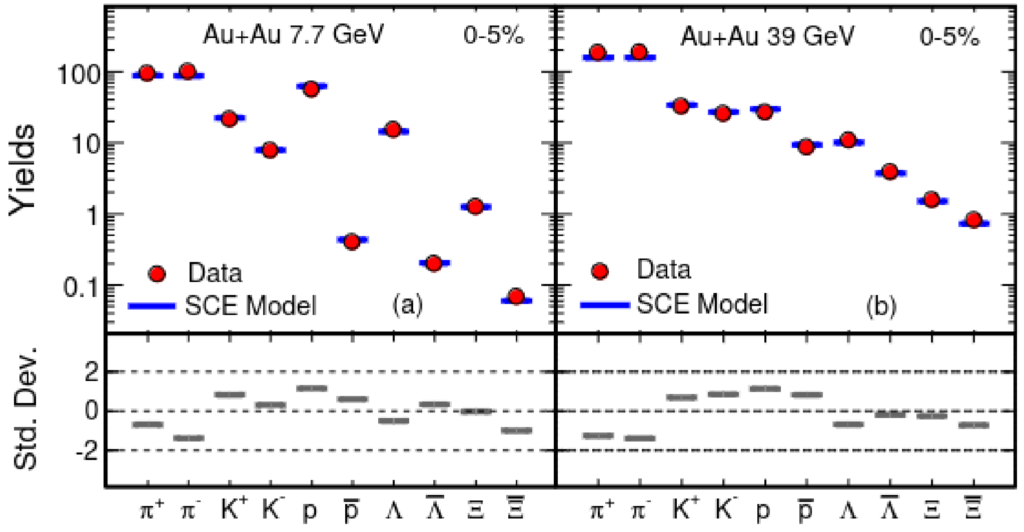




Mapping the QCD Phase Diagram

Phys. Rev. C 96 (2017) 44904



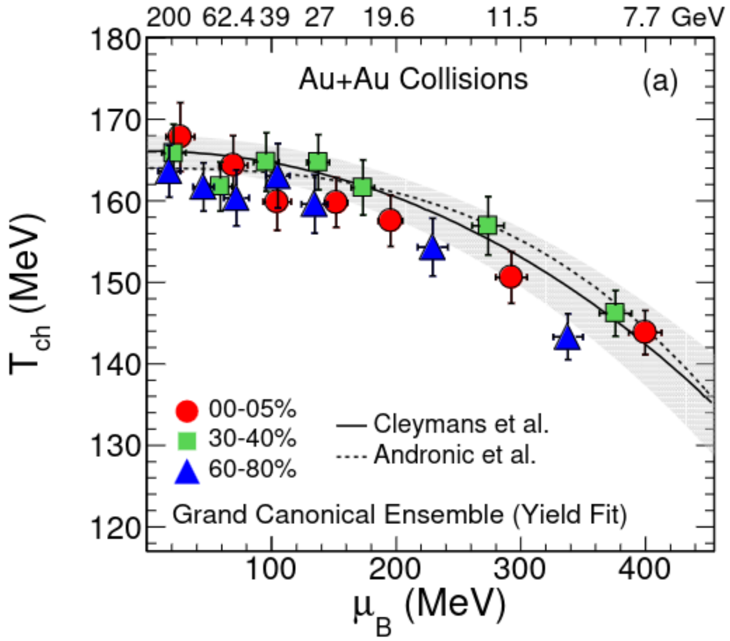


Grand Canonical Ensemble – B, Q and S are conserved on average

Canonical Ensemble – exact conservation of B, Q and S

Strangeness Canonical Ensemble – exact conservation of S

THERMUS model: S. Wheaton, J. Cleymans, and M. Hauer, Comput. Phys. Commun. 180, 84 (2009)



Mapping QCD Phase Diagram

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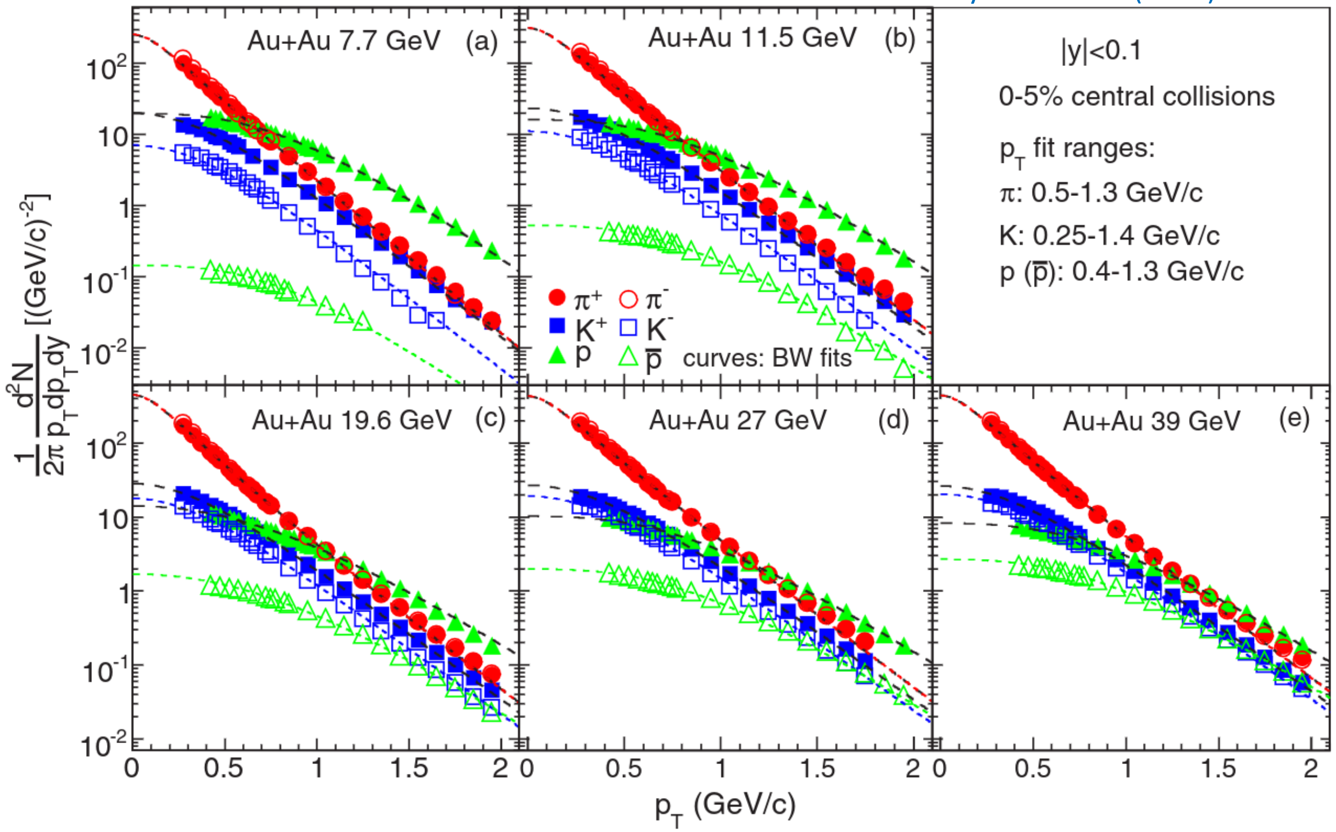
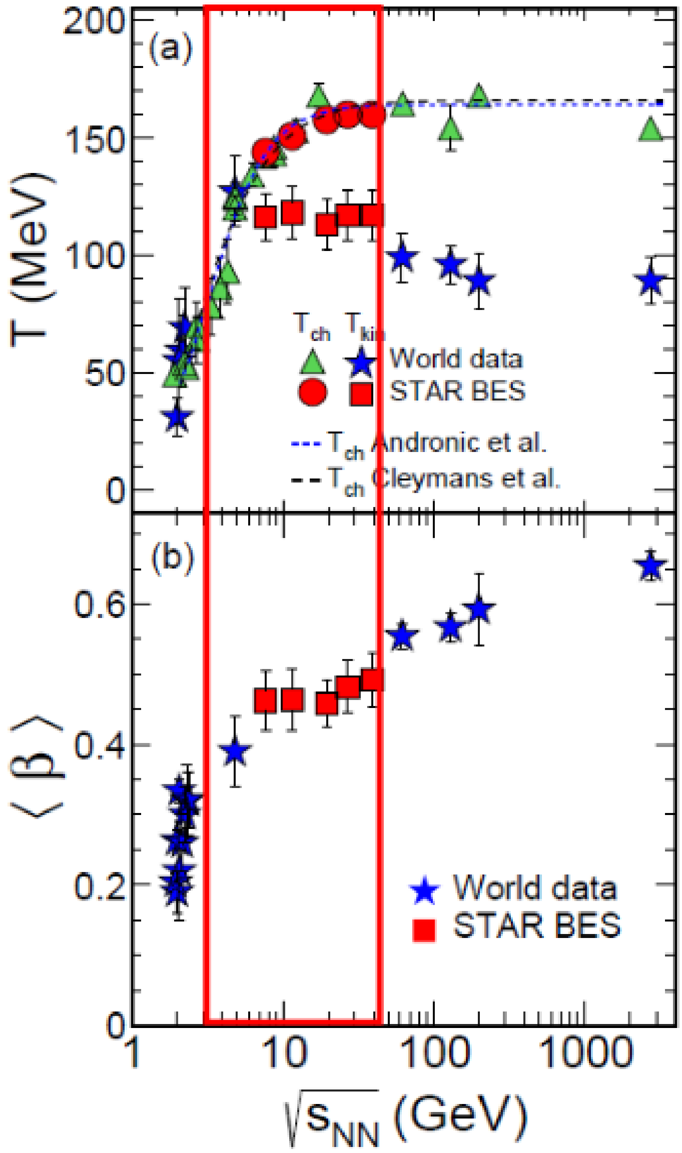


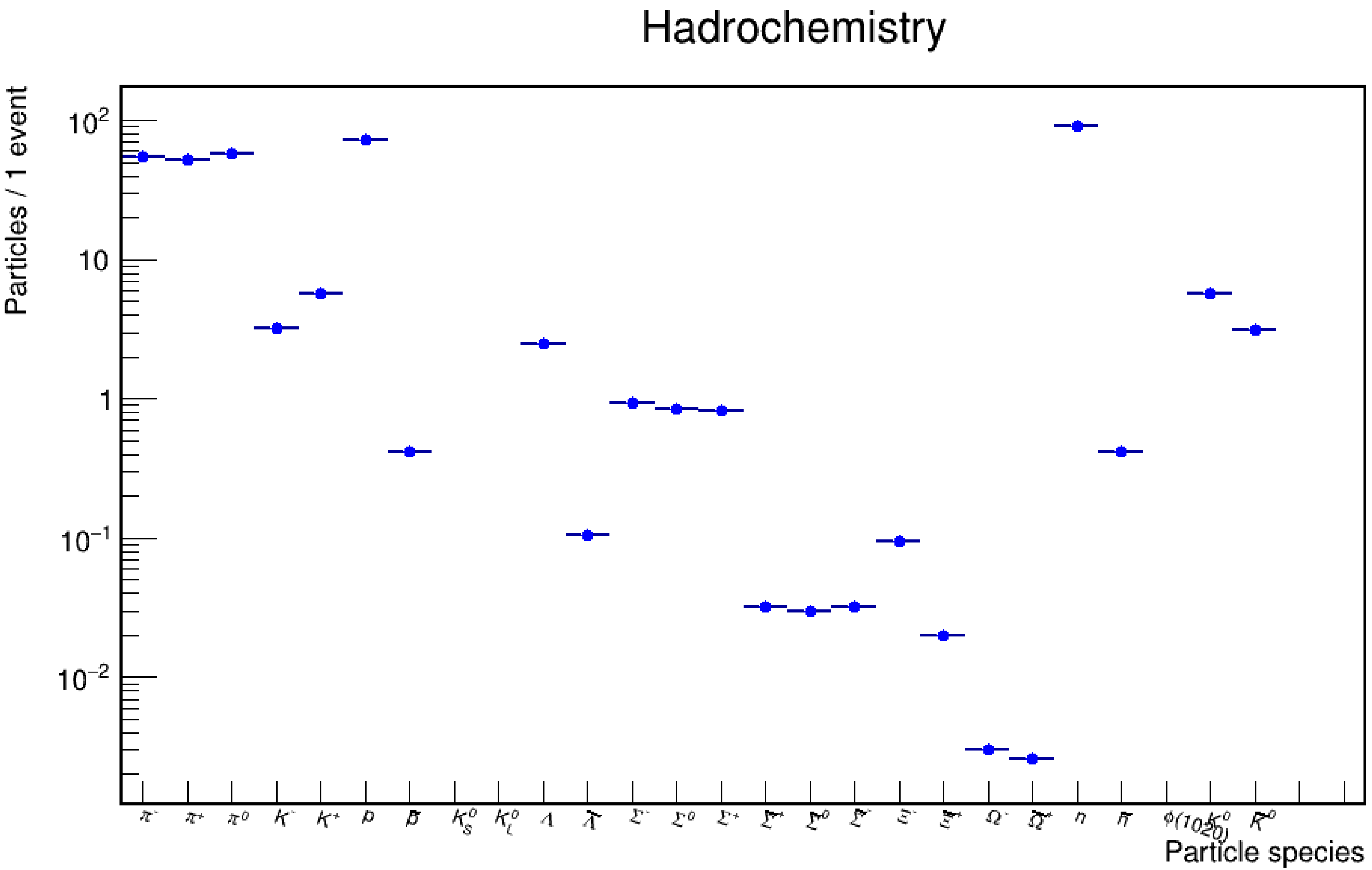


Parameters: Temperature (T_{kin}) and transverse radial velocity (β) obtained by fitting the momentum distribution of particles

Blast-wave fits for particle spectra

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh \rho(r)}{T}\right) \times K_1\left(\frac{m_T \cosh \rho(r)}{T}\right)$$

Raw Particle Yields Estimation for SPD



Good coverage for most of the particles

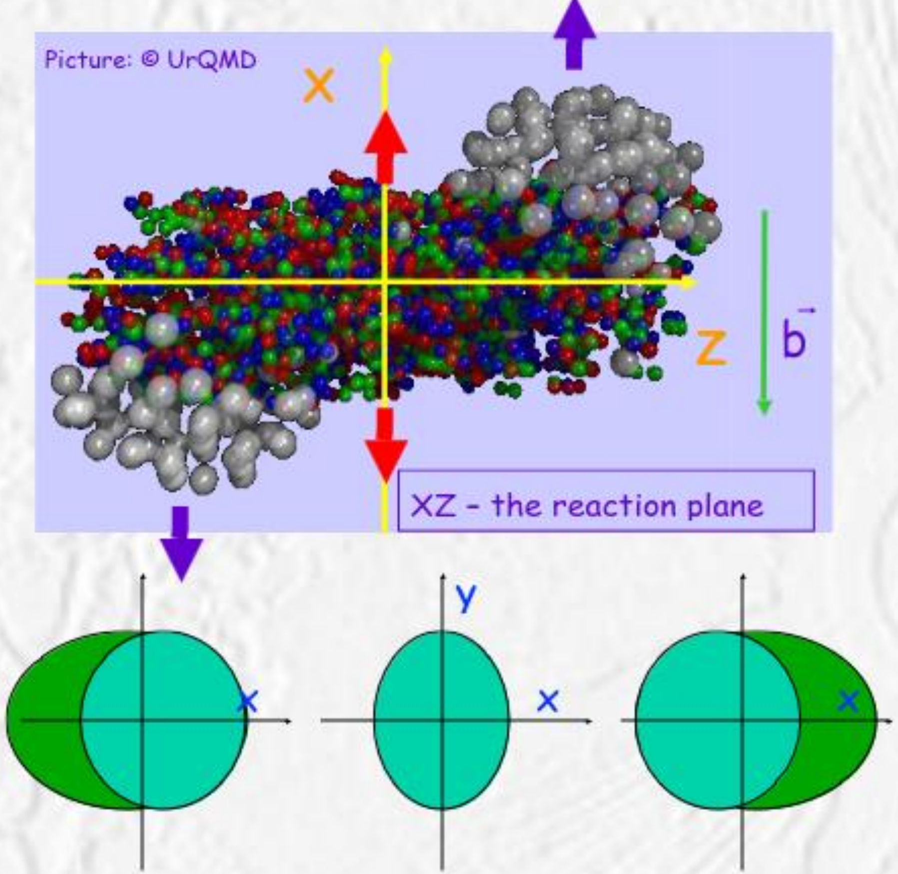
SPD should be able to detect particles that MPD, STAR and ALICE cannot measure (i.e., neuterons, kinks, etc)

Measurements can be extended to the charmed particles (e.g., J/ψ)

Anisotropic flow

Anisotropic flow ≡ correlations with respect to the reaction plane, system response to azimuthally asymmetric initial conditions

Term “flow” does not mean necessarily “hydro” flow – used only to emphasize the collective behavior
←→ multiparticle azimuthal correlation.



$$E\frac{d^3n}{d^3p} = \frac{1}{2\pi\, p_T}\frac{d^2n}{dp_t\, dy}\left(1 + \sum_n 2v_n \cos[n(\phi - \Psi_{RP})]\right)$$

$$v_n(p_T, y) = \langle \cos[n(\phi_i - \Psi_{RP})]\rangle$$

Advantages:

- Describes different kind of anisotropies in a common way
- Possibility to “fully” correct the results and compare directly to theory and other experiments

Flow study in relativistic nuclear collisions by Fourier expansion of Azimuthal particle distributions #14

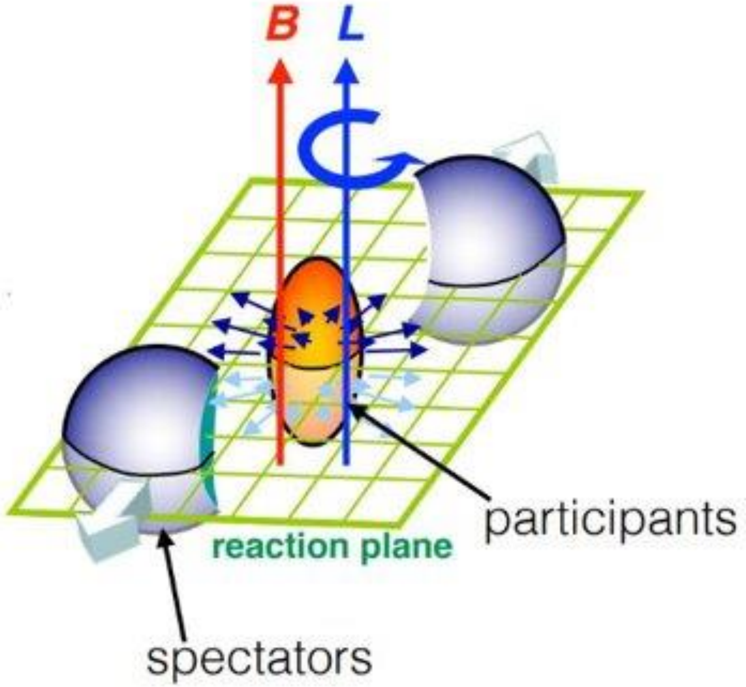
S. Voloshin (Pittsburgh U.), Y. Zhang (SUNY, Stony Brook) (Jun, 1994)

Published in: *Z.Phys.C* 70 (1996) 665-672 • e-Print: hep-ph/9407282 [hep-ph]

pdf DOI cite claim reference search 945 citations

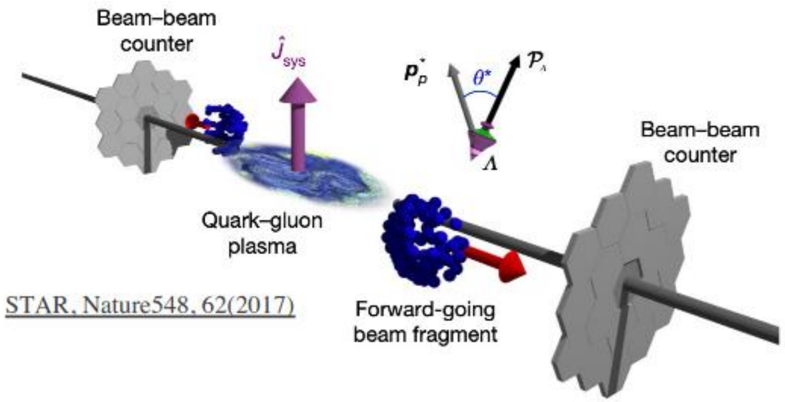
Global Hyperon Polarization

- The Quark-Gluon Plasma (QGP) formed in non-central nucleus-nucleus collisions is associated with large angular momentum, that leads to vorticity in the medium
- Spin-orbit coupling aligns spin directions of produced particles with the direction of vorticity
  - Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)
  - S. A. Voloshin, arXiv:nucl-th/0410089
- Another possible source of particle polarization is magnetic field, created in non-central collisions in the initial stage
  - D. Kharzeev, L. McLerran, and H. Warringa, Nucl.Phys.A803, 227 (2008)
  - McLerran and Skokov, Nucl. Phys. A929, 184 (2014)



Global Hyperon Polarization

The average vorticity points along the direction of the angular momentum of the $\hat{J}_{sys}$



Global polarization is measured from the angular distributions of hyperon decay product:

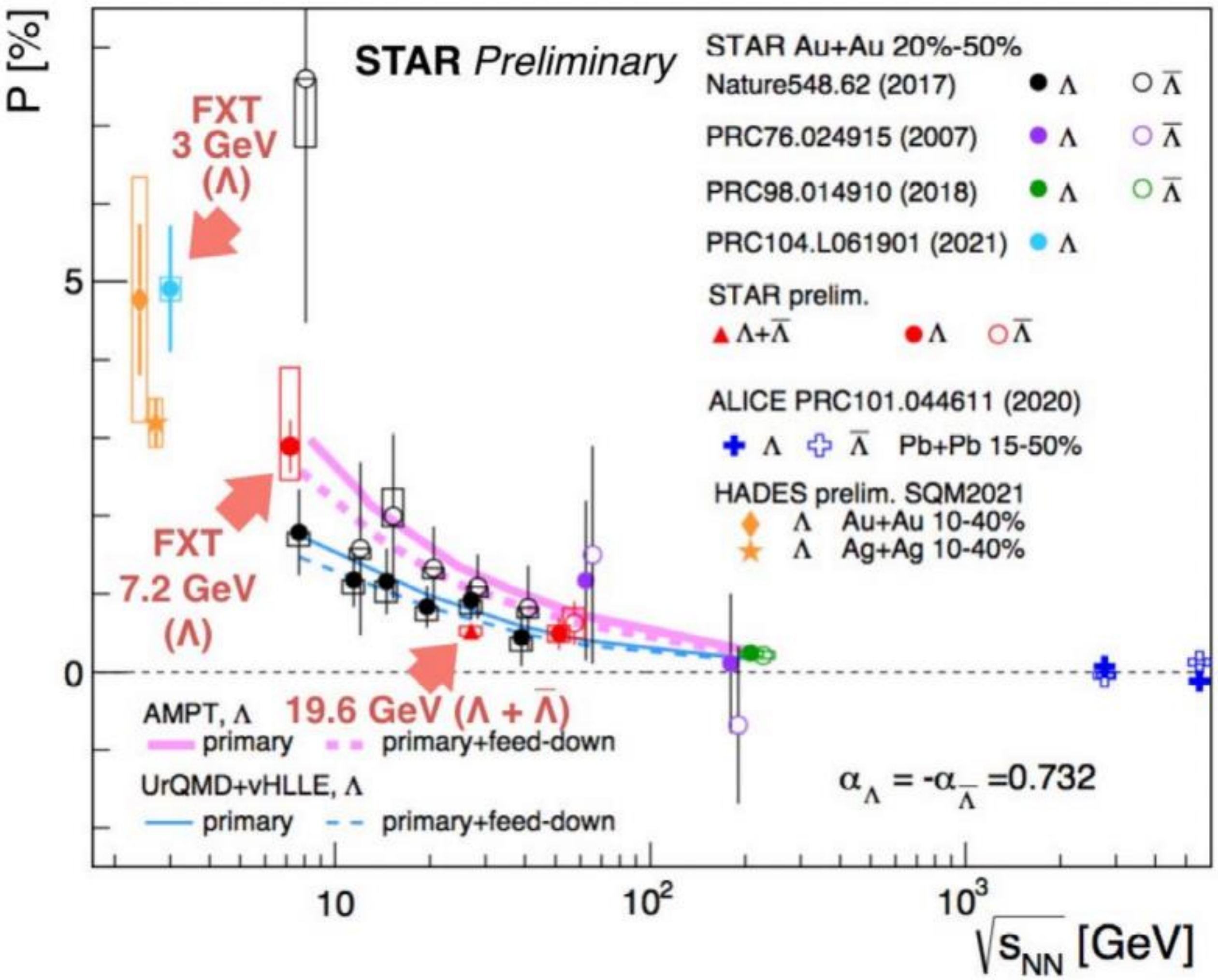
$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin(\Psi_1 - \phi_d^*) \rangle}{\mathrm{Res}(\Psi_1)}$$

Thermal vorticity:

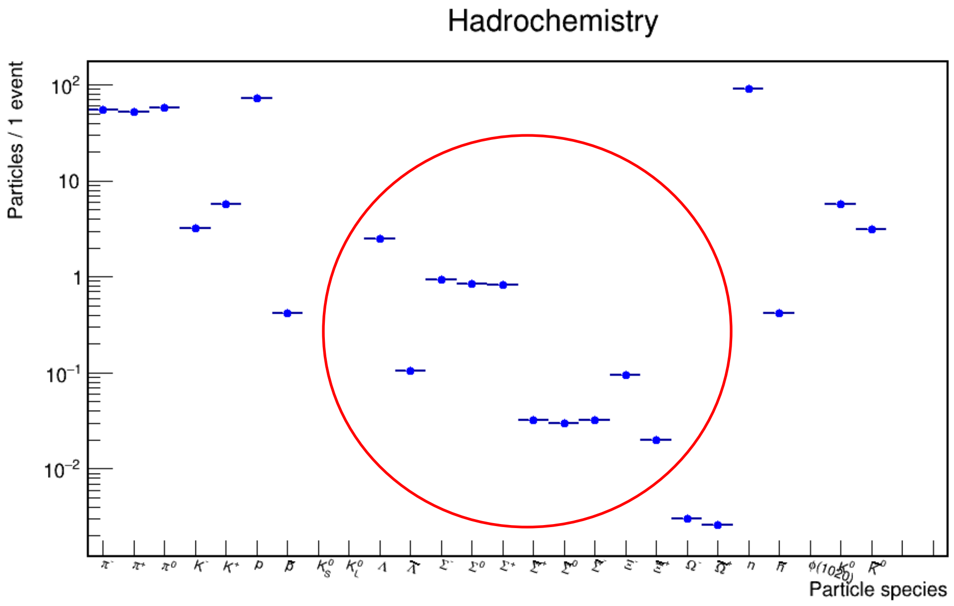
$$\omega = k_B T (P_\Lambda + P_{\bar{\Lambda}})/\hbar \qquad \omega \sim (9 \pm 1) \times 10^{21} s^{-1}$$

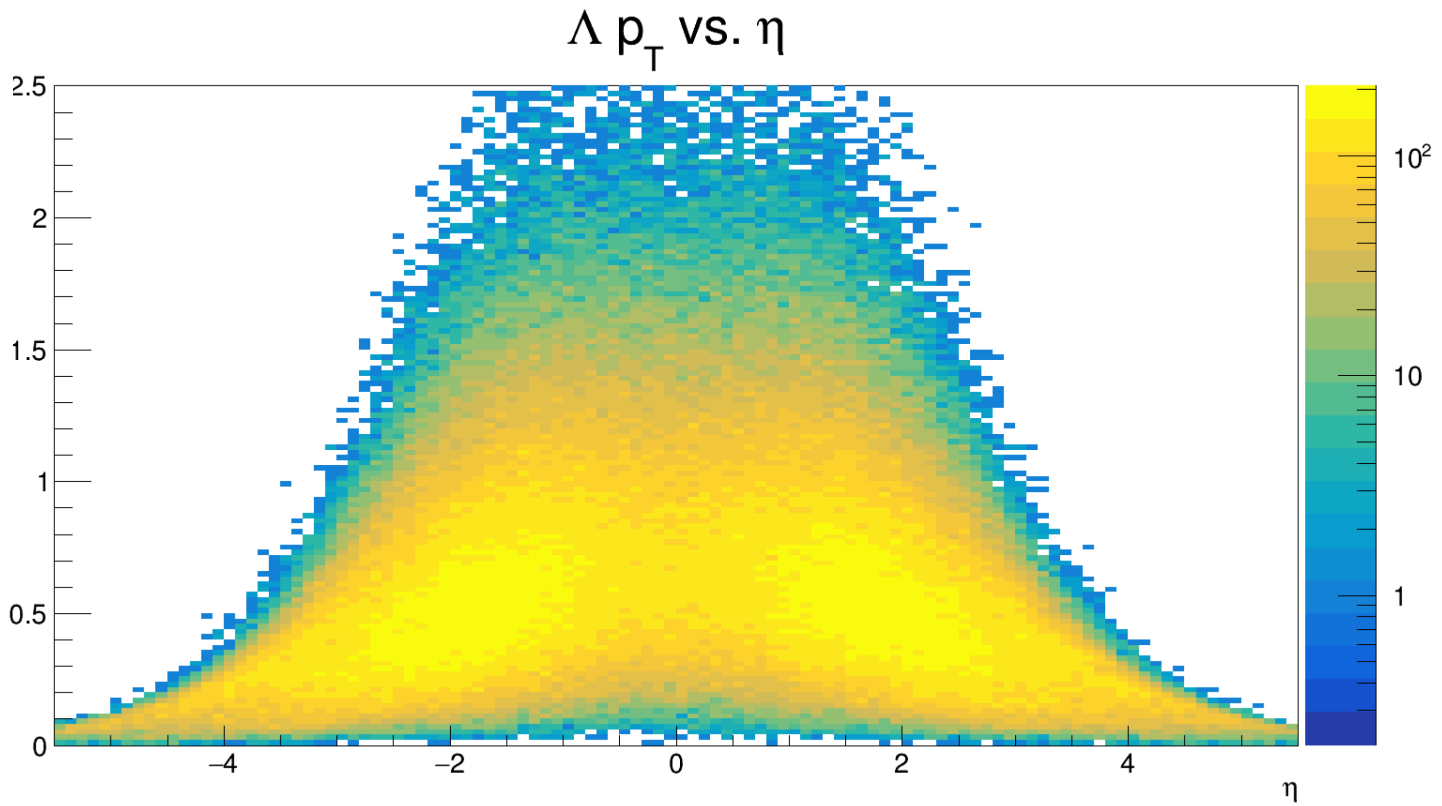
F. Becattini et al., PRC95, 054902(2017)

Nature 548 (2017) 62, PRC 104 (2021) 061901, arXiv: 2204.02302



Hyperon Yields and Kinematics (First Look)





Good coverage for forward/backward rapidity regions where transferred polarization expects to grow

Summary

- First look at measurements of heavy ion collisions at the SPD acceptance
- Many topics that will compliment ongoing heavy-ion program at NICA
- More precise calculations are ongoing