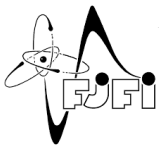
Heavy-ion collisions and Λ hyperon polarization

Bachelor's thesis

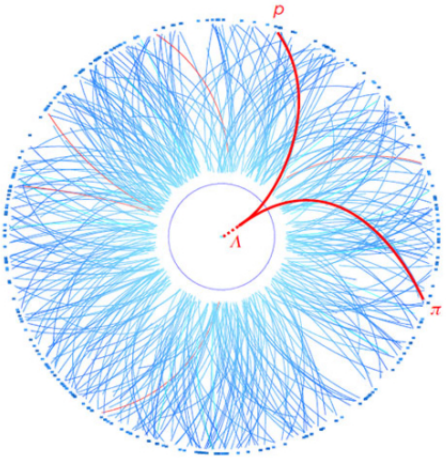
Author: Ondřej Lomický
Supervisor: doc. Mgr. Jaroslav Bielčík, Ph.D.
Advisor: Dr. Barbara Trzeciak

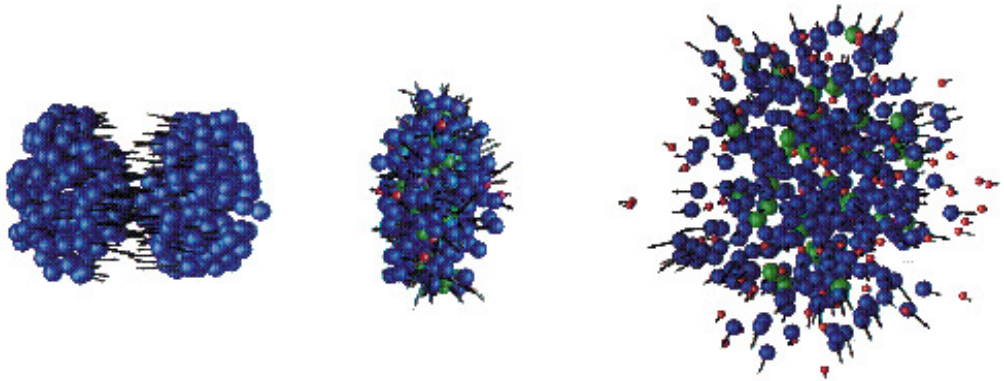
Workshop EJCF 2020
Bílý Potok (u Frýdlantu)



Outline

- Heavy-ion collisions
  - QCD phase diagram
  - Heavy-ion collision
  - Modification factor R_{AA}
  - Jet quenching
- Λ hyperon polarization





QCD phase diagram

Fig.: A water phase diagram [1]

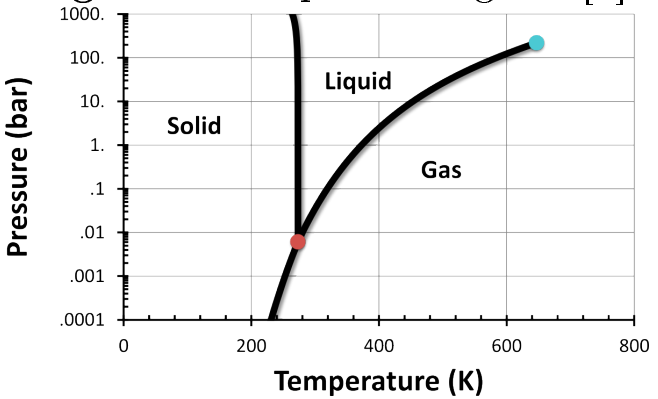
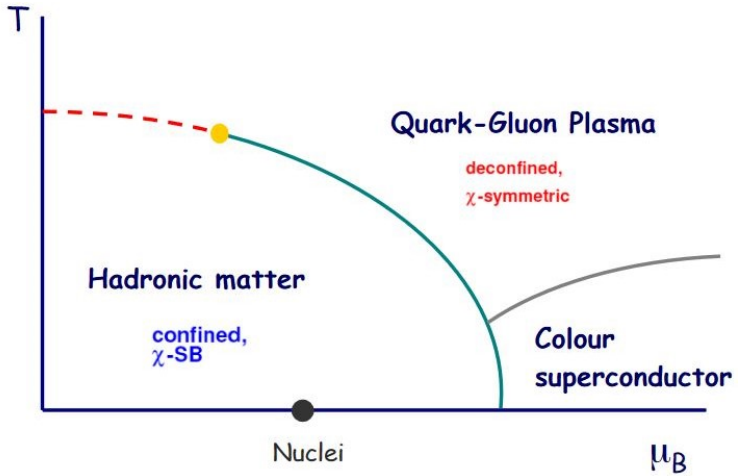


Fig.: A QCD phase diagram [2]

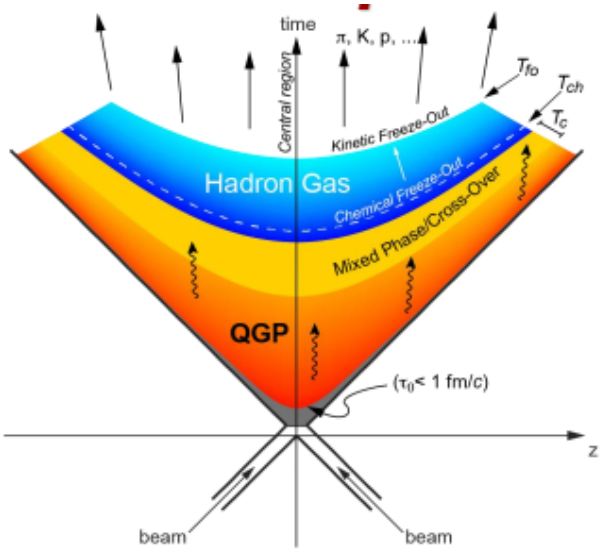


- Critical point for water: 374°C and 22.09 MPa
- Description of behaviour of matter at different conditions
- Baryo-chemical potential μ_B - the energy to increase the baryon quantum number
- Still not sufficiently experimentally explored

Heavy-ion collision

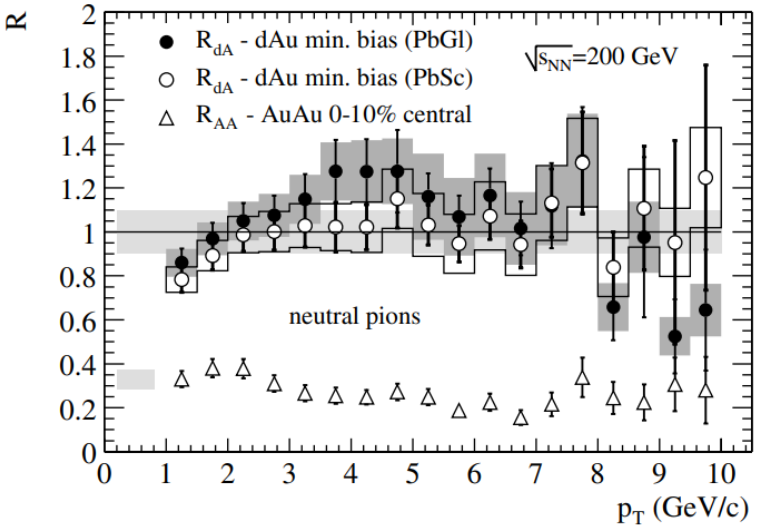
- Pre-equilibrium $t \lessapprox 1$ fm/c
- The QGP can be created due to high energy density
- Critical temperature $T_c \approx (150 - 170)$ MeV
- Freeze-out - quarks are combined back into hadrons, several species
- After kinetic freeze-out, created particles are detected

Fig.: Evolution of a central heavy ion collision in a Minkowski-like plane. [3]



Modification factor R_{AA}

Fig.: R_{AA} for π^0 in d+Au and Au + Au collisions [4]



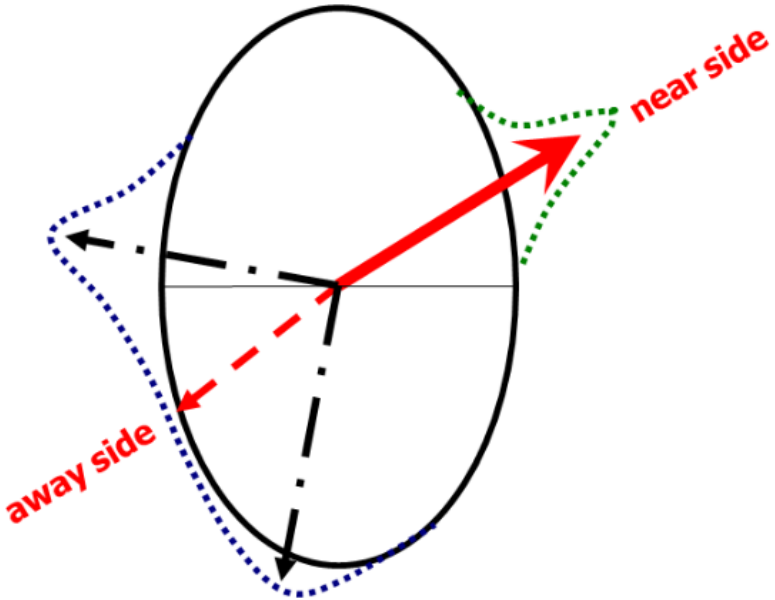
- Medium effects can modify scaling of the yield high p_T particles

$$R_{AA} = \frac{1}{\langle N_{coll}^{AA} \rangle} \frac{\frac{\mathrm{d}^2 N^{AA}}{\mathrm{d}p_T \mathrm{d}\eta}}{\frac{\mathrm{d}^2 N^{PP}}{\mathrm{d}p_T \mathrm{d}\eta}}$$

- $R_{AA} = 1$ - no medium effect
- π^0 ($p_T \geq$ 2-3 GeV) are produced from hard scattering of partons

Jet quenching

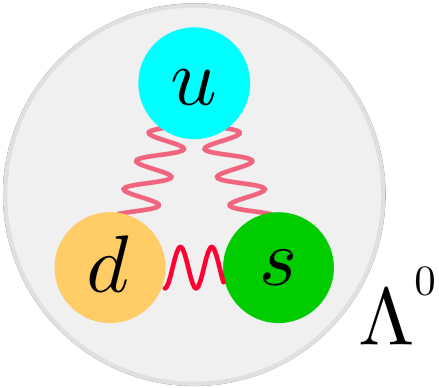
Fig.: Jet and away-side jet [5]



- Jets - particles having small relative distance in momentum space
- Away-side jets - jets in opposite hemisphere
- Di-jet events - away-side jet appears around $\Delta\phi = \pi$
- Au+Au collisions - away-side jet is suppressed
- Jet quenching - jet absorbed in dense medium

Λ hyperon

- Discovered in 1950
- Mean lifetime: $(2.632 \pm 0.020) \times 10^{-10}$ s
- Rest mass: (1115.683 ± 0.006) MeV/c^2
- Neutral electric charge
- Isospin $I = 0$ and $J^P = \frac{1}{2}^+$
- $\overline{\Lambda}$ is consists of $\overline{u}$,$\overline{d}$,$\overline{s}$
- Decay channels:

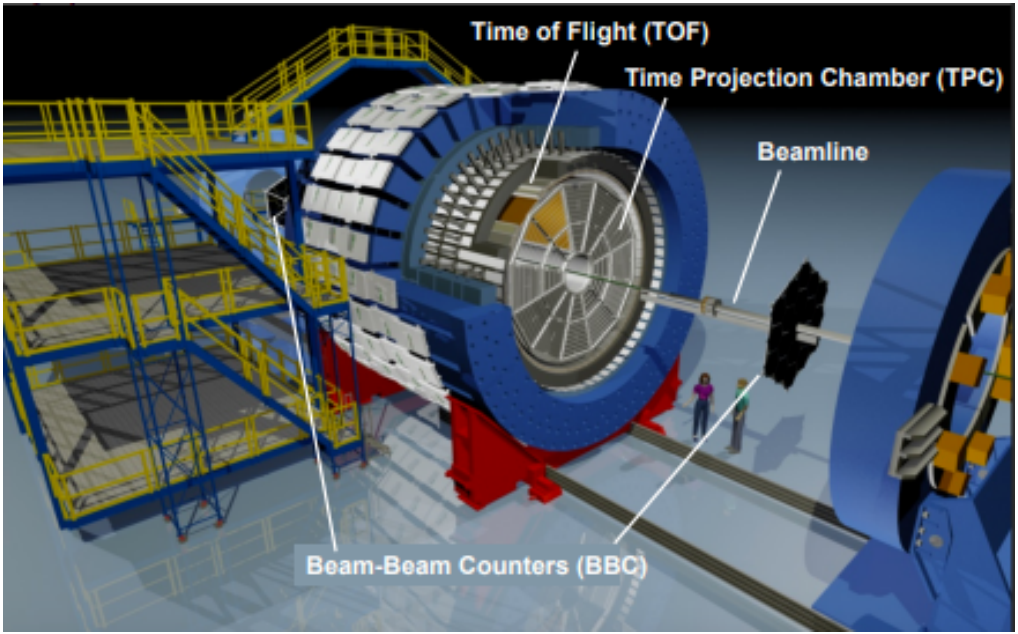


Mode$_\Lambda$	Mode$_{\overline{\Lambda}}$	Fraction (Γ_i/Γ)
$p + \pi^-$	$\overline{p} + \pi^+$	(63.9 ± 0.5) %
$n + \pi^0$	$\overline{n} + \pi^0$	(35.8 ± 0.5) %
$n + \gamma$	$\overline{n} + \gamma$	$(1.75 \pm 0.15) \times 10^{-4}$ %

Tab.: Λ and $\overline{\Lambda}$ decay modes [6]

Data analysis at STAR

Fig.: The STAR detector system. [7]

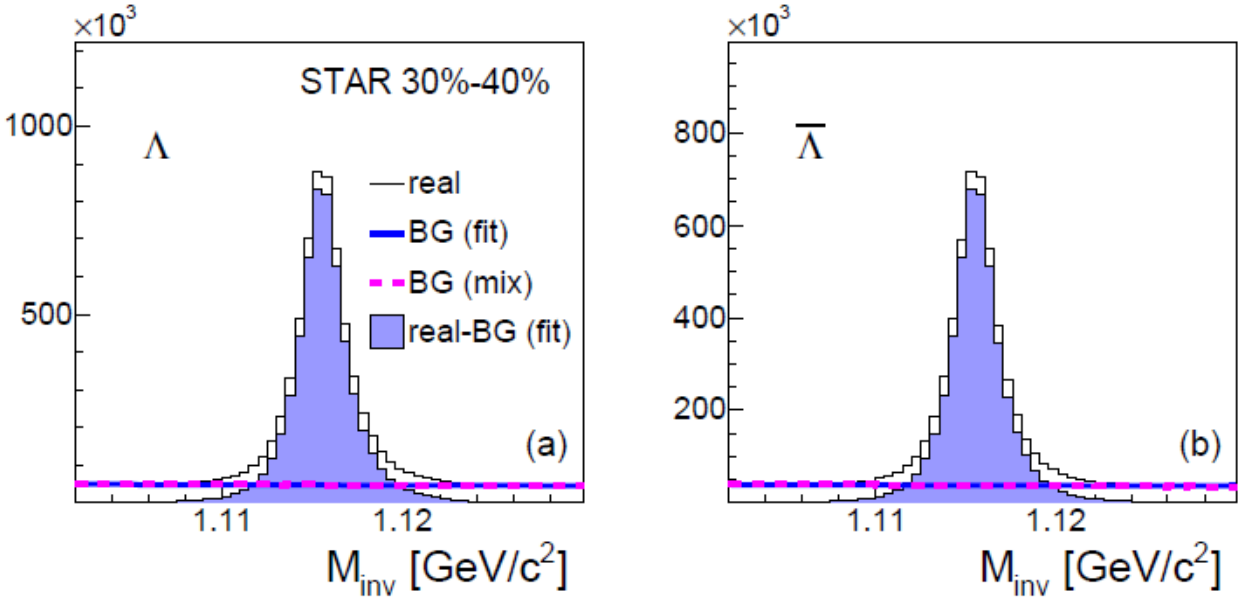


- TPC - identification based on the ionization energy loss
- TOF - timing resolution is $\sim$ 100 ps.

Detection of Λ hyperon

- Daughter p ($\overline{p}$) and π^- (π^+) are identified by $\mathrm{d}E/\mathrm{d}x$ information
- They point away from the primary vertex

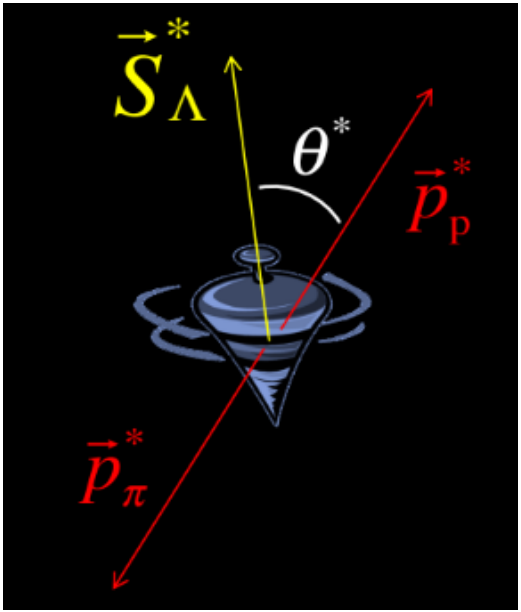
Fig.: Invariant mass distributions of system for Λ and $\overline{\Lambda}$ [8]



Polarization of Λ hyperon

- Polarized particle - spin is aligned with a certain direction (vorticity)
- $\Lambda(\overline{\Lambda})$ is "self-analyzing"
- Vorticity is parallel to angular momentum $\hat{J}_{sys}$
- $\vec{p}^{*}_{p(\pi)}$ - proton (pion) momentum
  $\vec{S}^{*}_{\Lambda}$ - polarization vector in the hyperon rest frame

Fig.: Daughter proton [9]



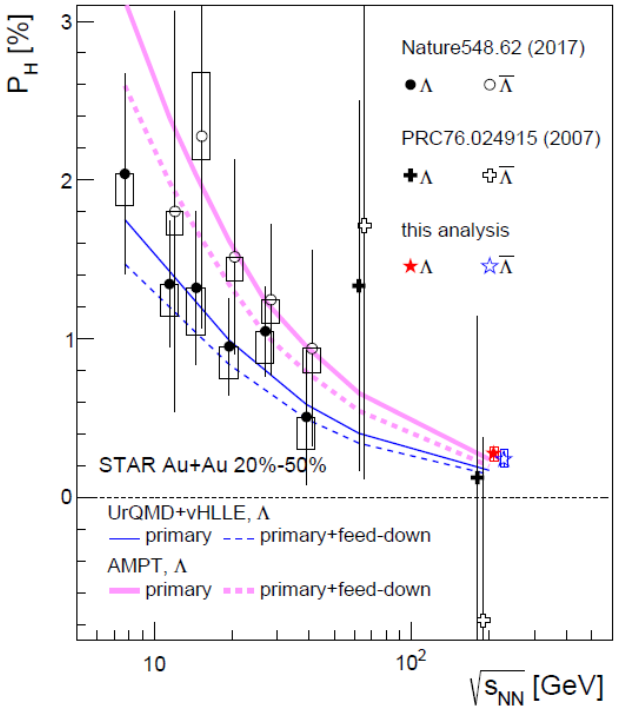
Polarization of Λ hyperon

- P_H polarization projected onto global angular momentum

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

- Ψ_1 - azimuthal angle of the angular momentum of first-order event plane
  ϕ_p^* - azimuthal angle of p momentum in the Λ frame
  $\mathrm{Res}(\Psi_1)$ - resolution of the Ψ_1
- $\alpha_\Lambda = -\alpha_{\overline{\Lambda}} = 0.642 \pm 0.013$

Fig.: The global polarization of Λ and $\overline{\Lambda}$ [8]



Conclusion and motivation

- The QGP is still not thoroughly explored
- R_{AA} and jet quenching can reveal the QGP
- The QGP is the hottest, the least viscous and the most vortical fluid
- Important for studies of chiral symmetry restoration

References I

[1] Physics Soup. (2012). phase diagrams – Physics Soup. [online] Available at: https://physicssoup.wordpress.com/tag/phase-diagrams/ [Accessed 12 Jan. 2020].

[2] Ncatlab.org. (2019). quark-gluon plasma in nLab. [online] Available at: https://ncatlab.org/nlab/show/quark-gluon+plasma [Accessed 12 Jan. 2020].

[3] Ars.els-cdn.com. (2019). [online] Available at: https://ars.els-cdn.com/content/image/1-s2.0-S0375947419300405-gr007.jpg [Accessed 12 Jan. 2020].

[4] Anon, (2003). [online] Available at: https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.91.072303 [Accessed 12 Jan. 2020].

[5] InSPIRE, (2009). [online] Available at: http://inspirehep.net/record/815778/plots [Accessed 12 Jan. 2020].

References II

[6] Pdglive.lbl.gov. (2019). pdgLive. [online] Available at: http://pdglive.lbl.gov/Particle.action?init=0&node=S018&home=BXXX020 [Accessed 12 Jan. 2020].

[7] Arxiv.org. (2017). [online] Available at: https://arxiv.org/pdf/1701.06657.pdf [Accessed 12 Jan. 2020].

[8] Anon, (2018). Researchgate. [online] Available at: https://www.researchgate.net/publication/325118641_Global_polarization_ [Accessed 12 Jan. 2020].

[9] Google Docs. (2019). LisaQM2019.pdf. [online] Available at: https://drive.google.com/file/d/1ASuo0Ih7shaLKIf2CVmzuVVYChiF50qK/v [Accessed 12 Jan. 2020].