Charm production at CBM experiment

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Outline

1. Phase diagram
2. Phase transitions
3. Heavy-ion collisions
4. Charm quark
5. Charm production at high collision energies
6. Charm production at low collision energies
7. Sub-threshold charm production
8. CMB experiment at FAIR
9. Micro Vertex Detector

Motivation

Electromagnetic interaction is well described by QED.

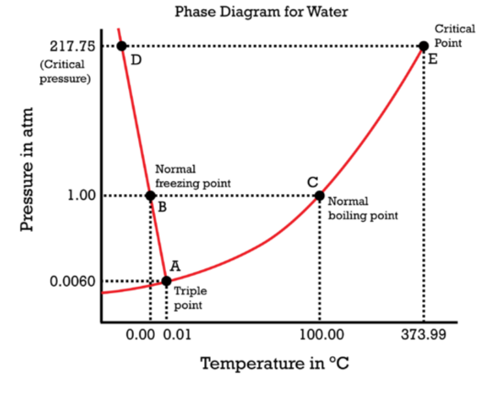

Fig.: A water phase diagram. [1]

What about strong interaction?

QCD phase diagram

QCD is yet to be explored more properly.

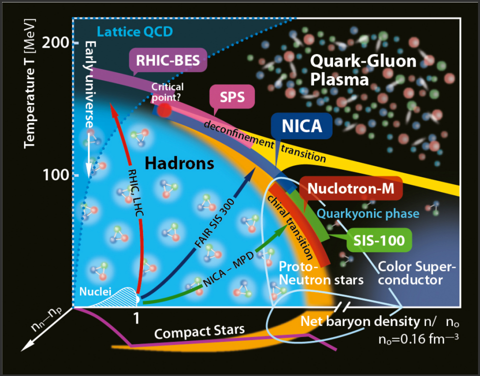

Fig.: Phase diagram of nuclear matter. [2].

- temperature T increases with higher energy of the collision
- conjugate variable to the net-baryon density is baryo-chemical potentional μ_B
- μ_B is an expression of the imbalance between matter and antimatter

At which temperature critical point for nuclear matter can be found?

Critical point

Predictions of the exact position of the CP vary depending on the calculations.

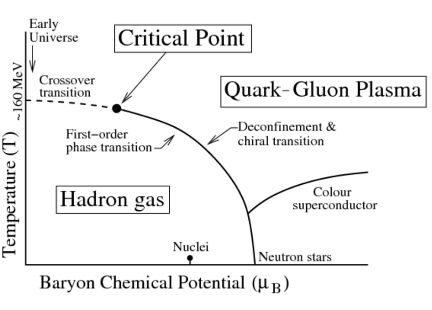

Fig.: Nuclear matter phase diagram. [3].

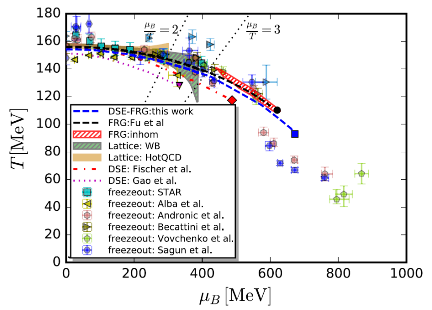

Fig.: Phase diagram combining phenomenological freeze-out data and theoretical results. [4].

Heavy-ion collisions

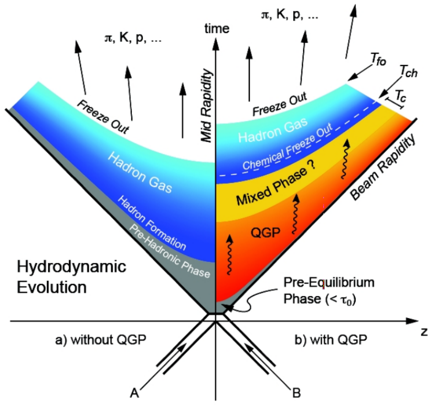

Fig.: Hydrodynamic space-time evolution after the collision when QGP is (not) present. [**5**].

- experiments can simulate some of extreme conditions
- left scenario: the energy is not high enough for QGP to occur, this form of matter is very dense
- right scenario: QGP is created

Charm quark

- discovered in 1974
- rest mass: (1.275 ± 0.020) GeV
- electric charge: $+\frac{2}{3}$e
- isospin I $= 0$ and $\mathrm{J^P} = \frac{1}{2}^+$

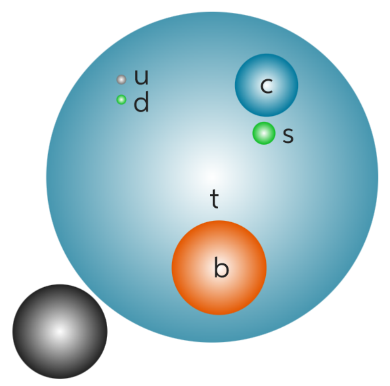

Fig.: Size comparison of 6 quarks and a proton (grey). [**6**].

Charm reconstruction

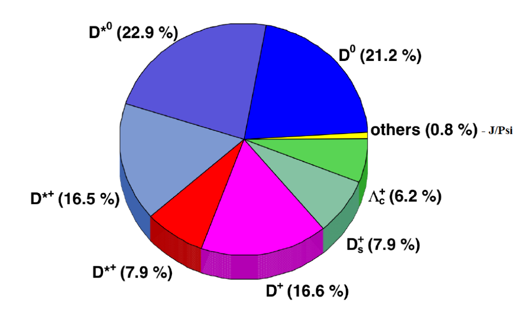

Fig.: Relative abundance of charm quark fragmenting to hadrons averaged over data collected in pp, e^+e^- and $pe^\pm$ collisions. [7]

	composition	rest mass [MeV/c^2]
D^0	$c\bar{u}$	1864.84 ± 0.05
D^{*0}	$c\bar{u}$	2006.85 ± 0.05
D^+	$c\bar{d}$	1869.66 ± 0.05
D^{*+}	$c\bar{d}$	2010.26 ± 0.05
D_s^+	$c\bar{s}$	1968.35 ± 0.07
Λ^+	udc	2286.46 ± 0.14
J/Ψ	$c\bar{c}$	3096.900 ± 0.006

- 16.5 % of D^{*+} from $D^0\pi^+$ reconstruction
- 7.9 % of D^{*+} from $D^+\pi^0$ or $D^+\gamma$ reconstruction

Open charm as a probe to QGP

- ultra-relativistic energies at RHIC or LHC
- in traditional scenario charm is only produced during the collision in hard processes
- it carries information about the very early stage of nuclear collision (too heavy to be affected)
- initial state is well defined, it is possible apply QCD perturbative calculations
- mechanism of energy loss, transport coefficients
- energy loss increases with temperature
- medium effects can modify the yield of high p_T particles
  $\rightarrow$ modification factor R_{AA}
- $R_{AA} = \frac{1}{N_{coll}^{AA}} \frac{\frac{d^2 N^{AA}}{dp_T d\eta}}{\frac{d^2 N^{PP}}{dp_T d\eta}}$
  for $R_{AA} = 1$ no medium effects present

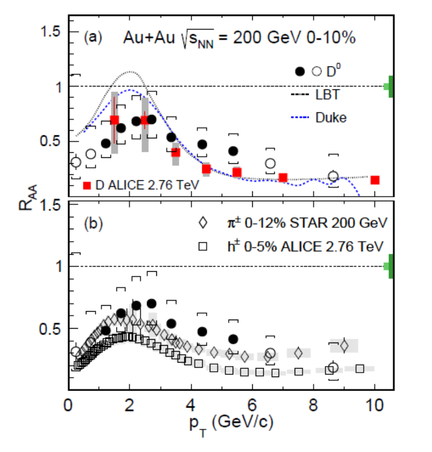

Fig.: Strong suppression of D^0 a) in model calculations and b) in data from ALICE and STAR. [16]

Open charm as a probe to QGP 2

- v_2 is similar to that of lighter quarks

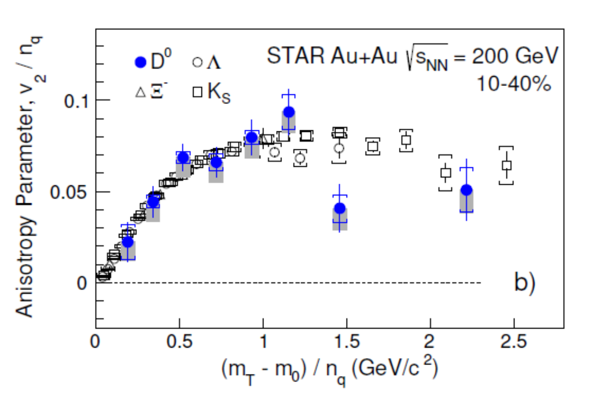

Fig.: STAR data: charm flow is very similar to that of lighter quarks. [**16**]

Heavy ion collisions at lower collision energies

- motivation: exploration of other parts of phase diagram
  - system created at low energies is close to the transition between hadronic phase and QGP with very high baryo-chemical potential and net baryon density and lower temperatures

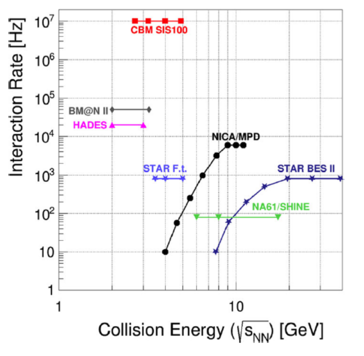

Fig.: Worldwide high-density experiments and their rate handling abilities. [10]

FAIR, The Accelerator Facility

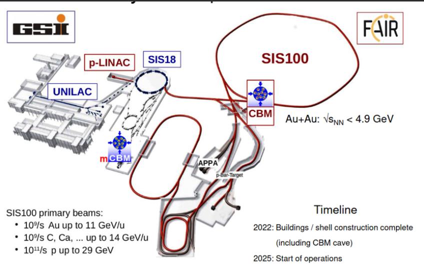

Fig.: The map of FAIR accelerating facility - blue is finished, red is under construction. [11]

SIS-100 - chwerIonen Synchrotron (heavy ion synchrotron)

- circumference 1.1 km
- acceleration of both very light ions (like H) and heavy ones (Pb, Au...) possible
- charm: propagation in nuclear matter, production mechanisms at threshold beam energies
  → observables: D-mesons and charmonium in p-p and p-A collisions

Storage rings

- to capture produced rare particles
- new experiments with these particles every time they fly past
- repeated use of those particles is indirectly equivalent to a further increase in intensity without having to use the accelerator facility

FAIR and its experiments

FAIR (Facility for Antiproton and Ion Research)

- end of construction planned for 2027
- 4 planned experiments
  - NUSTAR - NUclear STructure Astrophysics and Reactions (stars and nuclei)
  - PANDA - antimatter research, antiproton annihilation
  - APPA - Atomic Plasma Physics and Application - macroscopic effects for tissues and materials (medical use and engineering)
  - **CBM - Compressed Baryonic matter (it can simulate conditions inside supermassive objects like neutron stars)**

Charm production at FAIR

- multi-step scatterings of nucleons and their resonance states accumulates sufficient energy for production of J/Ψ and $\Lambda_c + \overline{\mathrm{D}}$
- SIS100 acceleration - energy below the charm production threshold in elementary collisions

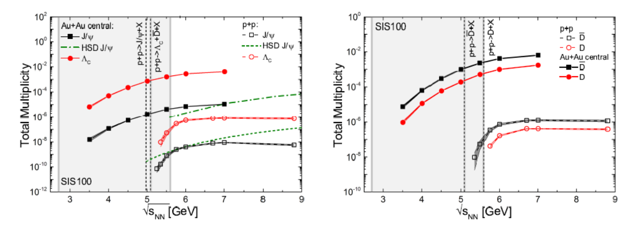

Fig.: Production yields of J/Ψ, Λ_c, D and $\overline{\mathrm{D}}$ in p-p and Au-Au central reactions as a function of collision energy. Vertical dashed lines indicate threshold center-of-mass energies and grey area corresponds to the beam energy range expected at SIS100. [**12**]

CBM experiment at FAIR

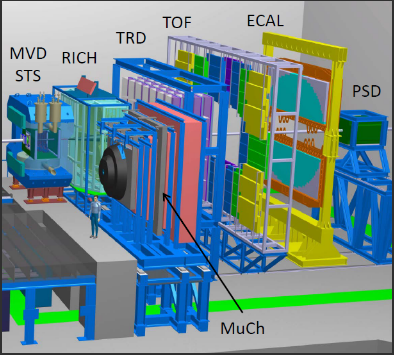

Fig.: CBM experiment and its detectors. [13]

- **MVD (Micro Vertex Detector) - primary and secondary vertex reconstruction with very high precision**
- STS (Silicon Tracking system) - vertex, track and momentum reconstruction
- RICH (Ring Imaging Cherenkov detector) - electron identification
- MuCh (Muon Chamber system) - muon identification
- TRD (Transition Radiation Detector) - global tracking, electron identification
- TOF (Time-Of-Flight) - time-of-flight measurements and hadron identification
- ECAL (Electromagnetic CALorimeter) - electron and neutral particles identification
- PSD (Projectile Spectator Detector) - centrality determination and reaction plane

Micro Vertex Detector

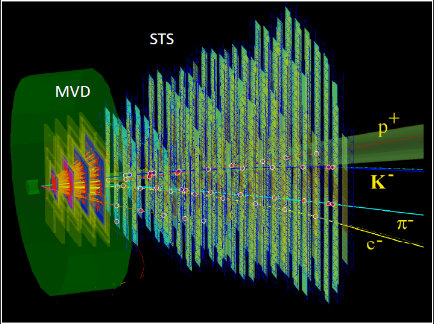

Fig.: MVD and STS detectors with tracks from p-Ni collision at 15 AGeV. [**13**]

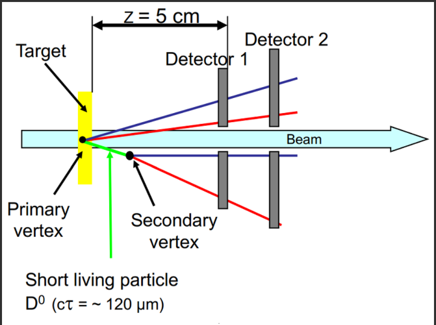

Fig.: Basic principle of MVD. [**14**]

Thank you for your attention.

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