# Charm in heavy ion collision

Charm means here a property of strongly interacting elementary particles, hadrons, build out of their sub-elementary fundamental components – quarks and gluons. These components, with a generic name partons, carry specific charges called colors – red, green and blue. Colors are sources of strong interactions binding partons into nucleons - protons and neutrons - and them into nuclei. The theory describing strong interaction is called Quantum Chromodynamics (QCD). Hadrons are constructed out of partons in such a way that they do not carry any color - so they are called colorless. In other words - colors of partons are not inherited by hadrons. Colors are not observable. These are different from other charges carried by partons, as e.g. electric charge, isotopic spin and flavors. Flavor means here *strangeness* possessed by the quark $s$, *charm* possessed by the quark $c$, *true* (called also *top*) by the quark $t$, and *beauty* (called also *bottom*) by the quark $b$. Quarks $s, c, t, b$, ordered by the masses, are preceded by the lightest quarks $u$ (up) and $d$ (down) having the same mass, but different components of the isotopic spin $\pm 1/2$. Gluons are just massless, appearing in eight coloring combinations. Any quark $q$ has its antiquark $\bar{q}$ – the same mass, all charges opposite. All hadrons can be systematized as they are built out of pair quark-antiquark $\bar{q}q$ (mesons) or three quarks $qqq$ (baryons) – with quarks glued by gluons.

Almost all hadrons of the Universe are build out of light quarks $u$ and $d$. Higher flavors $s, c, t, b$ are formed only under special conditions, when "normal" hadrons collide at high energy. Then the excitation energy is transformed ($E = mc^2$) into production of new particles, and if it is high enough, into production of heavy flavor hadrons – i.e. composed also out of heavy flavor quarks. Such conditions appear – when Big Bang ignited the Universe, in the cores of stars, and when beam of particles accelerated in the accelerator hits the target (fixed target experiment) or collides with the opposite beam coming out of accelerator (collider experiment). Such experiments give the unique possibility to research in a controlled way processes and forces on the most fundamental partonic level, to imitate conditions inside star's core, not excluding some Big Bang conditions.

Particularly interesting situations appear when colliding objects are not single hadrons but nuclei. There is a theoretical possibility, based on QCD suggestions, that within such collisions a new form of matter would appear, a kind of hot and dense partonic soup – called Quark Gluon Plasma (QGP). Hot means here a temperature of the order $10^{12}$ °K, dense means 3-15 times normal nuclear matter density. Similar QGP existed during first milliseconds of Bing Bang, it can appear also at supernovae explosions. The main physical problem here, beyond all technological challenges, is to recognize signatures of the QGP appearance. The QGP, composed of deconfined quarks and gluons cools down within $10^{-14}$s, partons pass into confined phase and freshly created hadrons find their way into detectors system. Now, one should decipher out of these experimental data if some signatures of QGP appeared.

NA61/SHINE, CERN SPS (Super Synchrotron) experiment is fixed target heavy ion collision experiment. Different sizes nuclei, from Be+Be till Pb+Pb, are colliding as beam-target at different energies. The main goal of present project, submitted by Polish-Norwegian Consortium participating in the experiment, is upgrade of the main detector parts – the Time Projection Chambers to make possible detection of open charm D mesons made of charm/no-charm quarks pair. There is a well-established hypothesis that the dumping in the production of hidden charm $J/\Psi$ mesons, made out of $\bar{c}c$ charm pair, as compared to the direct charm production is attributed to the QGP medium. Unambiguous evidence of the QGP state is still missing, however. The rich and precise results from RHIC and LHC heavy ion programs did not change the conclusion. The new state of matter found in heavy ion collisions features many of the characteristics of the theoretically predicted quark-gluon plasma.

The NA61/SHINE charm program requires a tenfold increase of the data taking rate. This charm program is a natural extension of the previous studies of the phase transition to the quark-gluon plasma. It addresses the question of the validity and the limits of statistical and dynamical models of high energy collisions in the new domain of quark mass. The objective of charm hadron production measurements in Pb+Pb collisions is to obtain the first data on the mean number of $\bar{c}c$ pairs produced in the full phase space in heavy ion collisions. Moreover,first results on the collision energy and system size dependence will be provided. This, in particular, should significantly help to answer the questions:

- What is the mechanism of open charm production?
- How does the onset of deconfinement impact open charm production?
- How does the formation of a quark-gluon plasma impact $J/\Psi$ production?