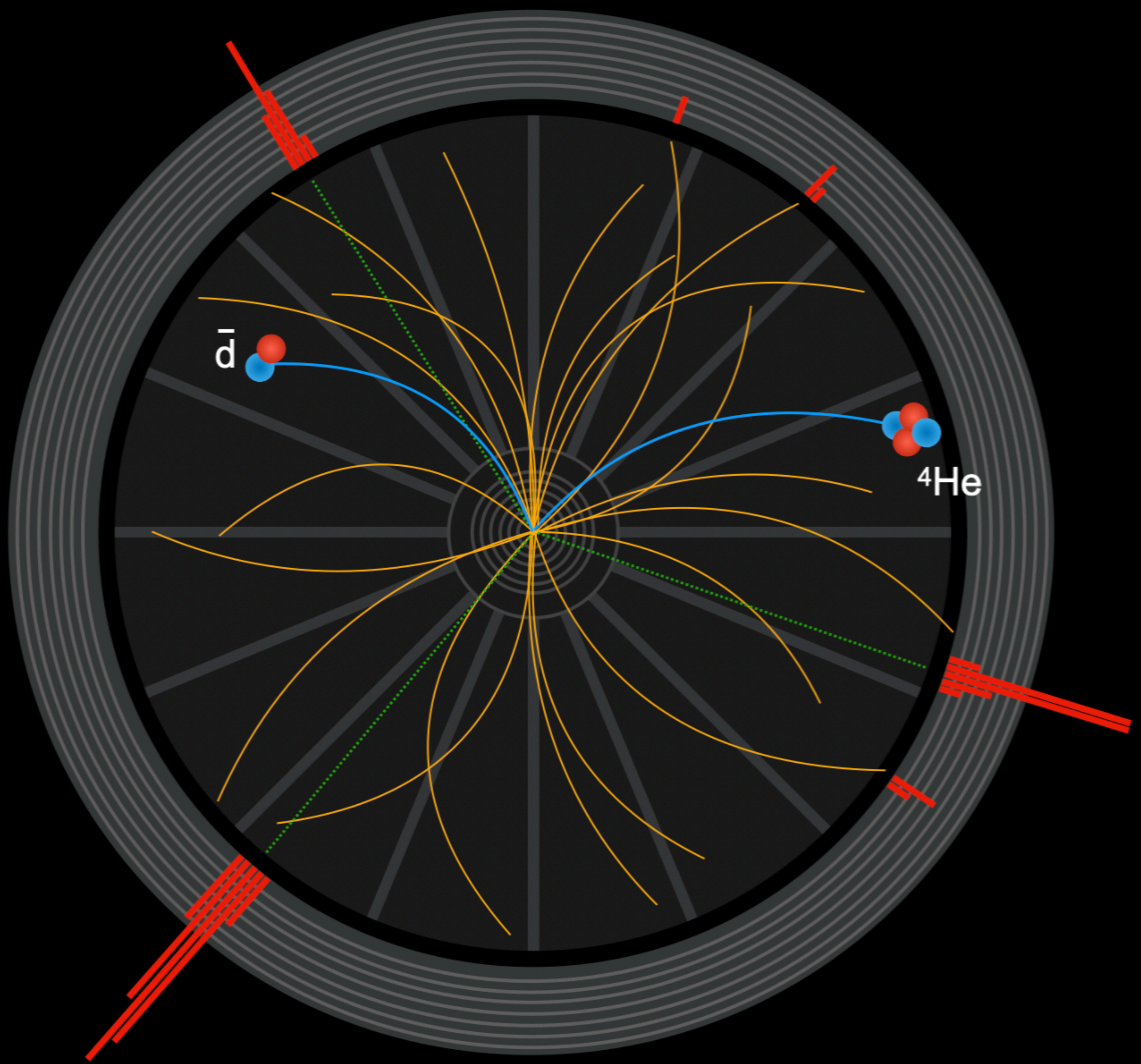
Rapid Reaction Task Force on

Understanding the production of light (anti)nuclei at RHIC and LHC

8 – 12 April, 2024



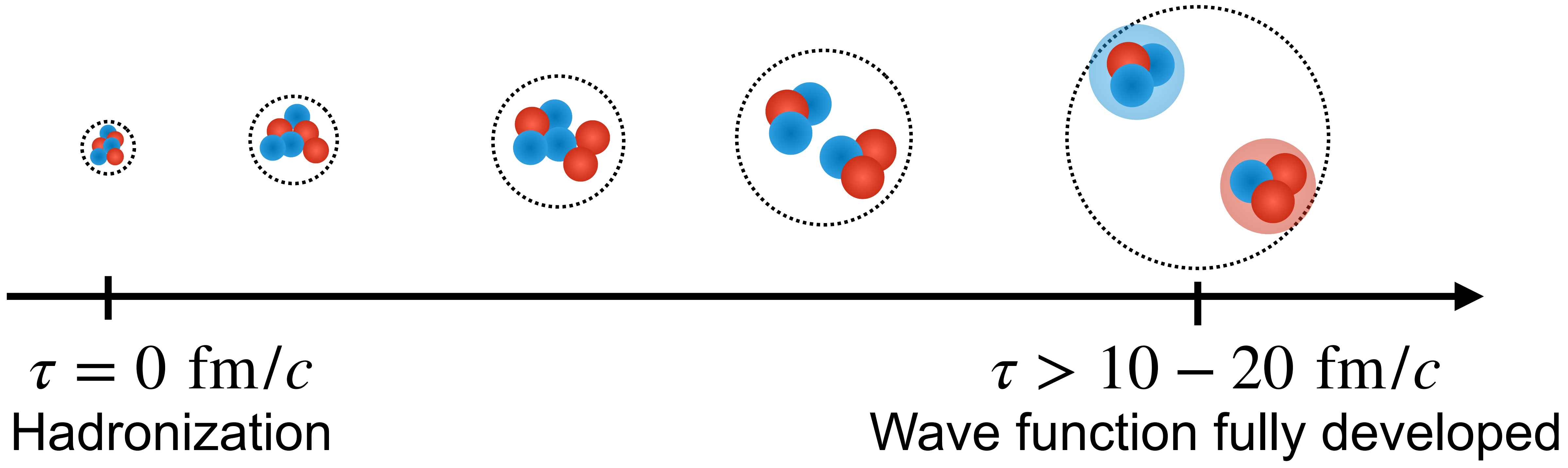
Organizers: A. Caliva, H. Elfner, J. Schukraft, K. Blum

Discussion on selected topics from the symposium

The compact multi-quark systems

Assumption:

- Light nuclei produced as compact (colorless) quark systems
  > Negligible interaction with hadrons
- Formation time > $\tau_{\text{hadronic phase}}$



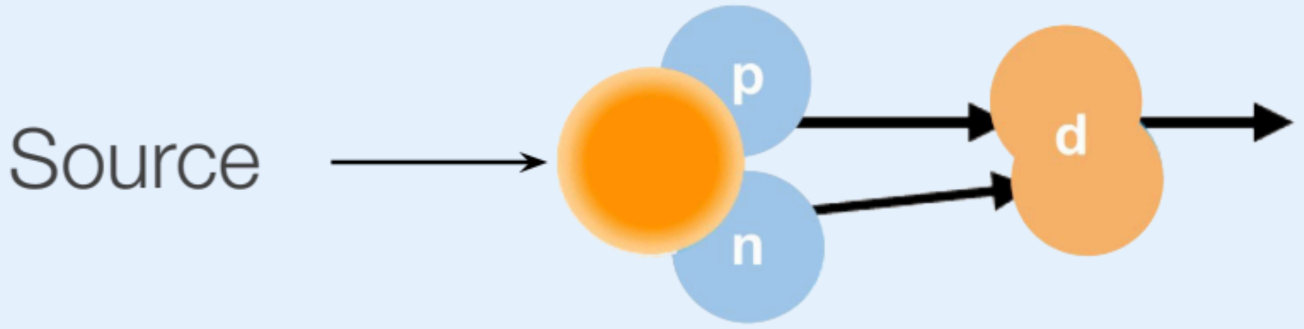
> The detailed production mechanism for loosely bound states remains an open question. One, admittedly speculative, possibility is that such objects, at QGP hadronization, are produced as compact, colorless droplets of quark matter with quantum numbers of the final state hadrons. The concept of possible excitations of nuclear matter into colorless quark droplets was considered already in [65]. In our context, these states should have a lifetime of 5 fm or longer, excitation energies of 40 MeV or less, for evolution into the final state hadrons which are measured in the detector. Since by construction they are initially compact they would survive also a possible short-lived hadronic phase after hadronization. This would be a natural explanation for the striking observation of the thermal pattern for these nuclear bound states emerging from Figs. 1 and 2. Note that the observed thermal

Coalescence probability

The coalescence model

Wigner function formalism

What do we need for coalescence?



$q = (p_p - p_n)/2$

$r = r_p - r_n$

p,n-pair   deuteron

Quantum mechanics:

$$d^3N/dP^3 = \mathrm{Tr}(\rho_d \rho_{Nucl})$$

$$d^3N/dP^3 = \int d^3q \int d^3r_p \int d^3r_n \; \textit{Deuteron Density} \; \textit{Nucleon Density}$$

$$d^3N/dP^3 = S \int d^3q \int d^3r_p \int d^3r_n \, W(q,r) \; W_{pn}(p_p,p_n,r_p,r_n)/(2\pi)^6$$

Spin-Isospin statistics factor (=⅜ for deuterons)

Wigner function of deuteron

Wigner function of p-n state

Kachelriess et al. EPJA 57 (5) 167, 2021

Coalescence probability

$$P_{\mathrm{coal}} \propto \langle W_d | pn \rangle \text{ or } P_{\mathrm{coal}} \propto \langle W_d | \hat{H} | pn \rangle \text{ ?}$$

Reaction-based model [1], (anti)deuterons are generated by ordinary nuclear reactions between nucleons produced in the collision with parametrized energy-dependent cross sections tuned on available experimental data

- $p + n \to d + \gamma$
- $p + n \to d + \pi^0$
- $p + n \to d + \pi^0 + \pi^0$
- $p + n \to d + \pi^+ + \pi^-$
- $p + p \to d + \pi^+$
- $p + p \to d + \pi^+ + \pi^0$
- $n + n \to d + \pi^-$
- $n + n \to d + \pi^- + \pi^0$

[1] https://arxiv.org/abs/2203.11601

Formation time of bound states

Bound State Formation in Time Dependent Potentials

Jan Rais,* Hendrik van Hees, and Carsten Greiner
Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität,
Max-von-Laue-Str. 1, D-60438 Frankfurt am Main, Germany
(Dated: July 12, 2022)

We study the temporal formation of quantum mechanical bound states within a one-dimensional attractive square-well potential, by first solving the time-independent Schrödinger equation and then study a time dependent system with an external time-dependent potential. For this we introduce Gaussian potentials with different spatial and temporal extensions, and generalize this description also for subsequent pulses and for random, noisy potentials. Our main goal is to study the time scales, in which the bound state is populated and depopulated. Particularly we clarify a likely connection between the uncertainty relation for energy and time and the transition time between different energy eigenstates. We demonstrate, that the formation of states is not delayed due to the uncertainty relation but follows the pulse shape of the perturbation. In addition we investigate the (non-)applicability of first-order perturbation theory on the considered quantum system.

Jan Rais, Hendrik van Hees, and Carsten Greiner
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