Charm correlations

XVI Polish Workshop on Relativistic Heavy-Ion Collisions

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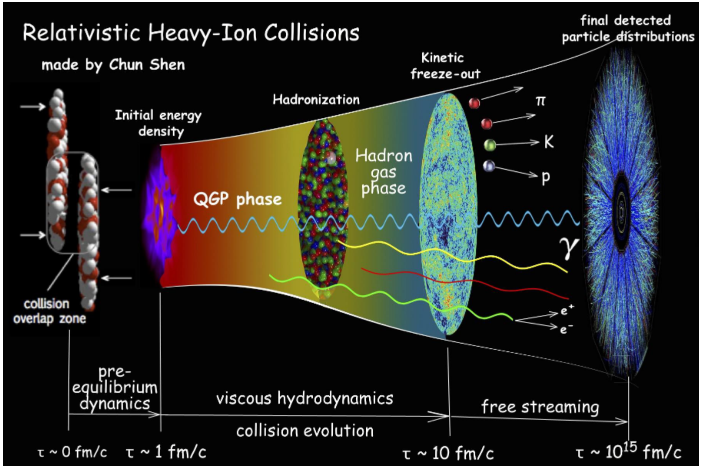
Overview

1. Standard picture of heavy-ion collission
2. Probing QGP
3. Simplified model
   - Three pictures of emission
4. Fisibility of the measurement
   - Requirements
   - Results of modeling
   - Fisibility

Standard picture of heavy-ion collission

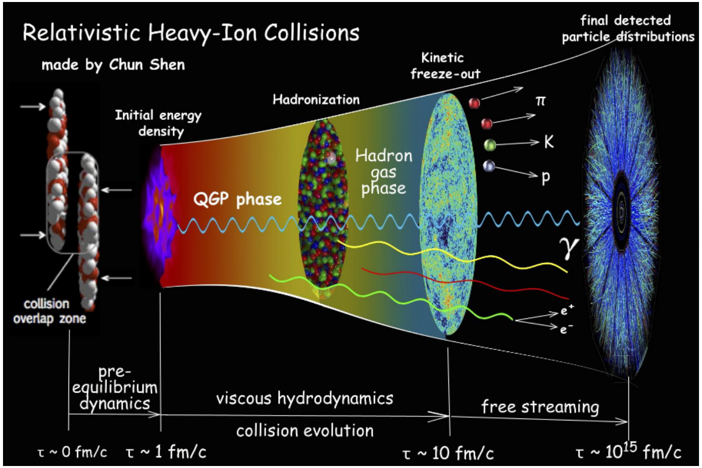
1. *Initial state*
   A hot dense medium, called as qurk-gluon plasa (QGP) is created.
2. *Expansion stage*
   The plasma expands, reaching hadronisation temperature $T_H \approx 150 Mev$.
3. *Hadronisation*
   The plasma is converted to hadrons and resonanses.
4. *Free-streaming stage*
   Resonances decay; non-interacting hadrons freely stream in the vacuum to a detector.



Standard picture of heavy-ion collission

Heavy quarks in heavy-ion collission

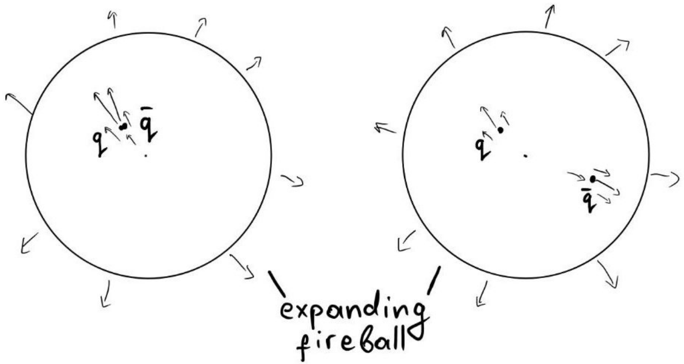
1. *Initial state*
   A hot dense medium, called as qurk-gluon plasa (QGP) is created.
   The $q\bar{q}$ pairs are produced locally and in a limited number due to high energy threshold.
2. *Expansion stage*
   The plasma expand, reaching hadronisation temperature $T_H \approx 150 Mev$.
   The $q\bar{q}$ pair termalise with the medium.
3. *Hadronisation*
   The plasma is converted to hadrons and resonanses.
   The flow and hadronisation (local statistical process) contributions give the momenta of charm hadrons.
4. *Free-streaming stage*
   Resonances decay; non-interacting hadrons freely stream in the vacuum to a detector.
   Hadrons carrying the heavy quarks soon decay.



Probing QGP

⇒ Heavy quarks can be used as a probe to study both formation and evolution of the QGP medium.

- Azimuthal correlations in heavy-ion collisions at high energies were already addressed theoretically and applied by RHIC and LHC, e.g. study mechanism of jet supperssion, study of charm energy loss mechanism
- ...
- This idea steems back to 1986 (J/*Psi* melting), maybe even earlier.
- → We want to investigate a "locality" of $q\bar{q}$ pair production via momentum correlations between final state hadrons.

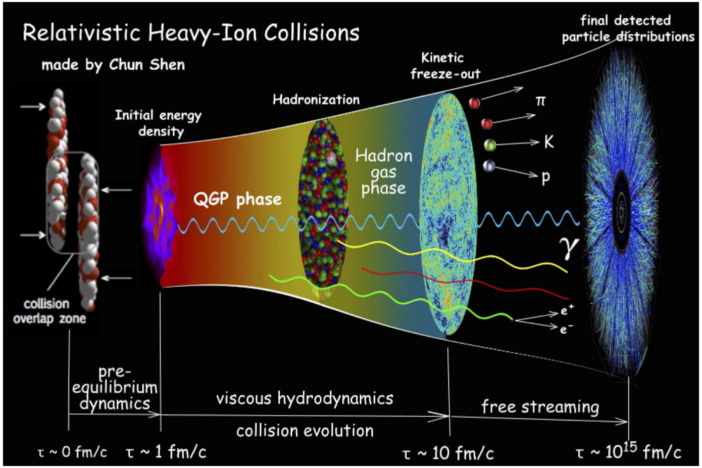


Probing QGP

Describing heavy-ion collisions / What we do

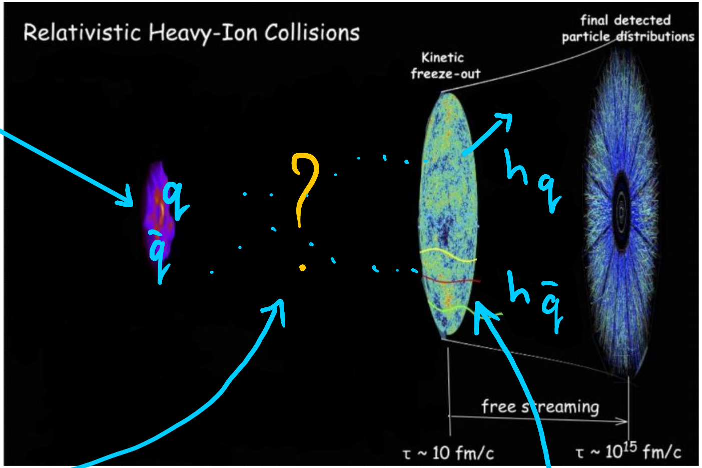
- Initial state (Glauber, Color glass, ...)
- Expansion of the QGP with hydrodynamics
  Classical approach, some of the inital correlations may be lost.
- Statistical hadronisation
  Similar: usually done vai relativistic Wigner, which depends on the one-particles reduced density matrix, no two-particles or higher orders.
- Hadron gass

$\Rightarrow$ *Might not fit our purposes*



Simplified model

A $q\bar{q}$-pair is created (at rest)



We distinguish 3 effective pictures of what q and $\bar{q}$ quarks/hadrons undergo during QGP and thermalization phases by looking at the emissinon at freez-out hypersureface.

The q- and $\bar{q}$-hadrons with momenta inhertied from the corresponsing quarks (+ random perturbations due to hadronization and thermalization)

Simplified model

- Production of more than 1 $q\bar{q}$ pair within event is neglected:

$$\langle q\bar{q}\rangle < 1.$$

- Charm hadrons are emitted from the freeze-out hypersurface of a spherical fireball undergoing Hubble-like expansion:

$$v = \frac{r}{t}, \quad u^{\mu} = \frac{x^{\mu}}{\tau} = \frac{x^{\mu}}{\sqrt{t^2 - r^2}},$$

  where r is a distance from the center of the fireball.

- Freez-out hypersurface:

$$\tau = \tau_{fo} \text{ – QGP freeze-out time;}$$

$$r = r_{\max} \text{ – maximal radius of the fireball.}$$

- At the freeze-out, hadron momenta are sampled from the Boltzmann distribution:

$$\frac{d^3N}{dp d^3\Omega} \propto p^2 \exp\left(\frac{\sqrt{m^2 + p^2}}{T_{fo}}\right),$$

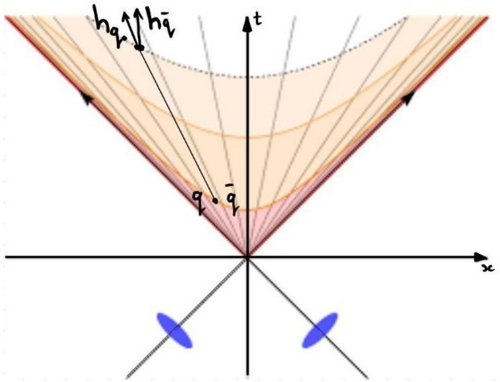
  where m is mass of a final state hadron, and T_{fo} is a kinetic freeze-out temperature.

- Finally, hadron momenta are boosted to the lab-frame.

I. *Local* emission

The q- and $\bar{q}$- hadrons are emited from the same fluid cell.

- The average of their momenta is set by drift velocity of the cell.
- The difference in momenta is due to independence of their momenta in the rest frame of the cell



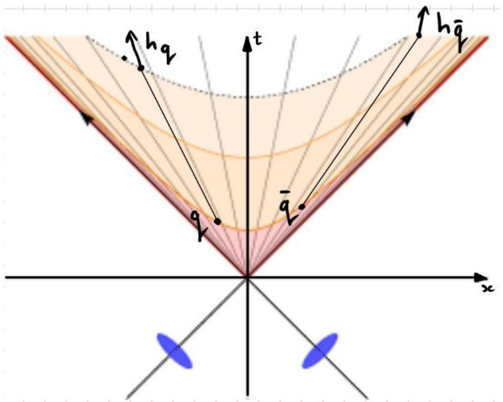
Simplified model

Three pictures of emission

II. *Independent* emission

The emission points are independent of each other.

- No correlation between momenta whatsoever.



Simplified model

Three pictures of emission

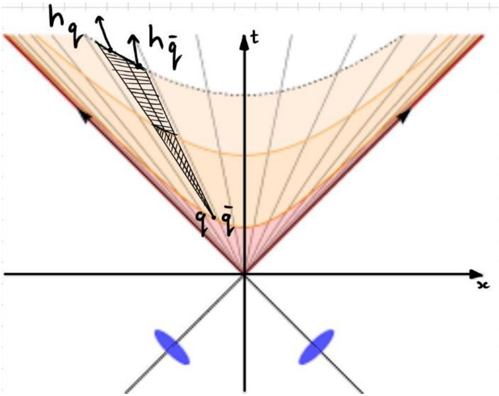
III. *Correlated* emission

We consider emission points to be correlated via a 3D Gaussian distribution with $\sigma_x = \sigma_y = \sigma_z = 2$ fm.

- Flow components of the momenta are different,
- but still correlated.

Thus this is an intermediate case:

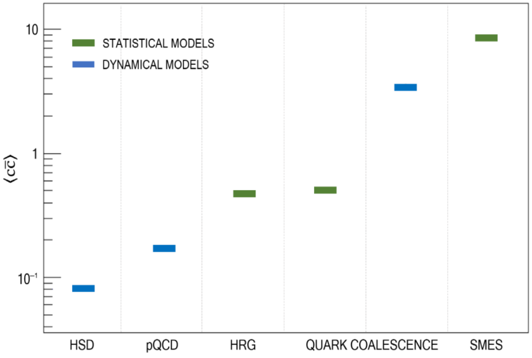
- $\sigma \to 0 \Rightarrow$ *local* emission
- $\sigma \to \inf \Rightarrow$ *independent* emission



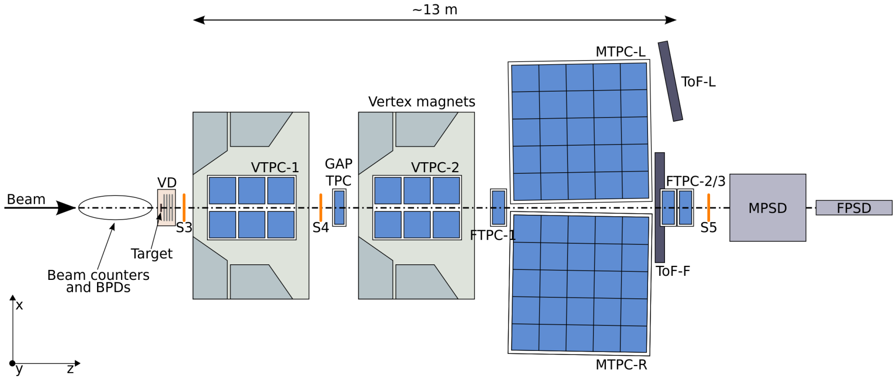
Fisibility of the measurement

Requirements

- We can focus on the lightest of the heavy quarks, c, and the lightest open charm hadron, namely D^0 meson.
- $\langle c\bar{c}\rangle < 1$ to suppress production of multiple $c\bar{c}$ pairs per event, which could wash out pair-wise correlations.
- Low energy is needed in order avoid trivial correlations due to momentum conservation.
- High acceptance of the detector is necessary because we need to reconstruct both hadrons (D^0 and $\bar{D}^0$) within the event.



Model predictions for $\langle c\bar{c}\rangle$ yield in Pb+Pb collisions at top SPS energy (150A GeV/c)

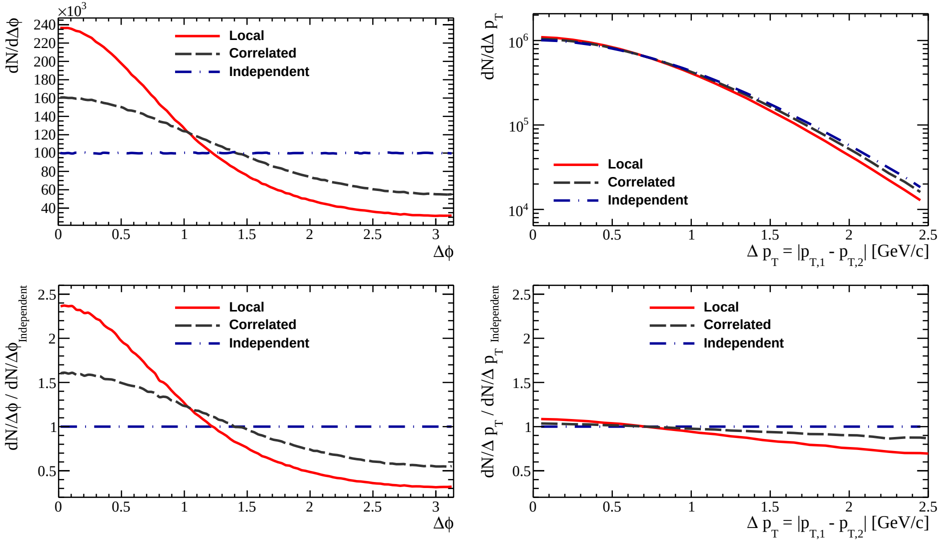


NA61/SHINE detector layout

Fisibility of the measurement

Results of modeling

Estimates for $D^0 - \bar{D}^0$ correlations from simulated 10^7 events in Pb+Pb @ $150A$ GeV/c



- $\tau_{fo} = 9$ fm/c
- $r_{max} = 6$ fm/c
- $m = m_{D^0} = 1.869$ GeV/c
- $T_{fo} = 150$ MeV

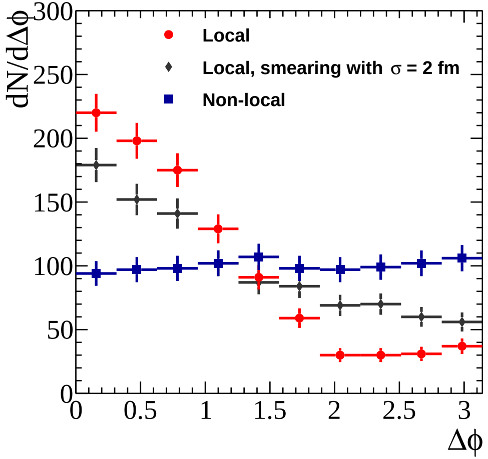
Fisibility of the measurement

Fisibility

Estimates for the duration of a data-taking period needed to collect 1000 $D^0\bar{D}^0$-pairs; and the ratio of the number of produced $c\bar{c}$ pairs to all $c\bar{c}$ combinations (NA61/SHINE, Pb+Pb @ 150A GeV/c):

	$\langle c\bar{c}\rangle = 0.1$	$\langle c\bar{c}\rangle = 0.2$	$\langle c\bar{c}\rangle = 0.5$	$\langle c\bar{c}\rangle = 1$
1 kHz	1000 days	500 days	200 days	100 days
10 kHz	100 days	50 days	20 days	10 days

N_{pair}/N_{comb}	91%	83%	66%	50%



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