3.10.14

Causality Constraints in Statistical Hadron Production

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QCD Hadronization and the Statistical Model

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Two Questions:

- **Why is strangeness suppressed for hadron production in elementary collisions?**
- **Why is strangeness not suppressed for hadron production in nuclear collisions?**

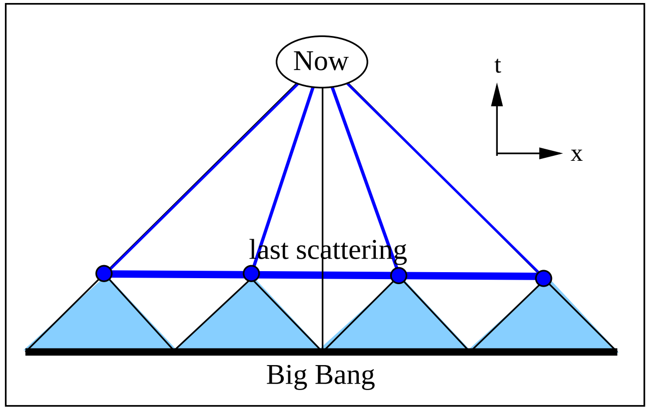
One Answer:

- **Causality constraints restrict production to separate small spatial regions, and within a given region**
  - **there is one pair of strange quarks (elementary collisions)**
  - **there are many pairs of strange quarks (nuclear collisions)**

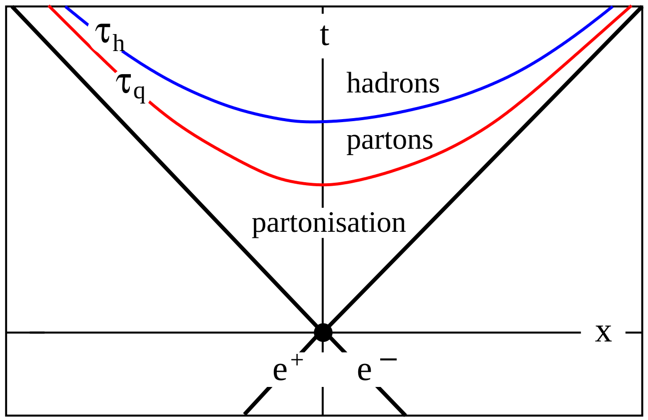
Joint work with Paolo Castorina

Recall horizon problem of cosmology:

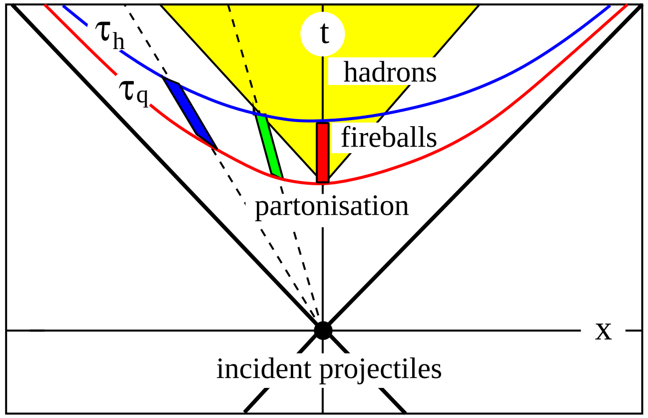
cosmic background radiation
is today 2.72548 ± 0.00057 °K
up to fourth decimal
throughout observable universe
why? It comes from
causally disconnected regions



∃ horizon problem also
in high energy hadroproduction;
inside-outside cascade
locally after time τ_q:
partonisation (equilibrium QGP)
locally after time τ_h:
hadronisation



bubble of partonic medium of proper time τ
with $\tau_q < \tau < \tau_h$: fireball;
fireballs at different spatial
rapidities η



$$t = \tau \cosh \eta, \quad x = \tau \sinh \eta,$$

with transition lines

$$t^2 - x^2 = \tau^2$$

red fireball ($\eta = 0$) - causality region yellow
green fireball ($\eta = \eta_d$) - one common x-t point with red
blue fireball ($\eta > \eta_d$) - outside causality region of red

for $\eta > \eta_d$, with $\tanh \eta_d = (\tau_h^2 - \tau_q^2)/(\tau_h^2 + \tau_q^2)$

forward and backward fireballs are out of communication
with central fireball

examples:

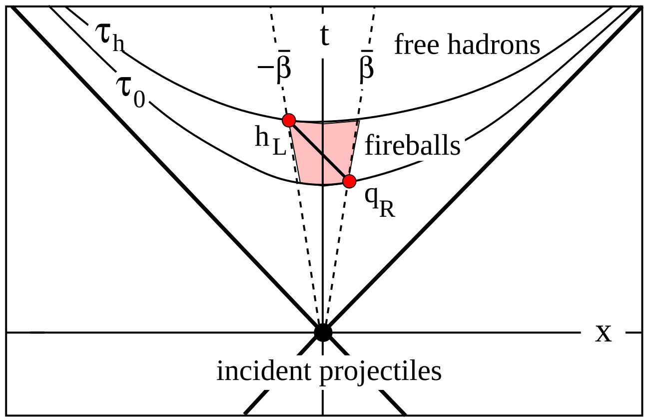
$\tau_q = 1$ fm, $\tau_h = 2$ fm $\to \eta_d = 0.7$

$\tau_q = 1$ fm, $\tau_h = 7$ fm $\to \eta_d = 2$

at RHIC and LHC, hadronisation occurs through causally disjoint fireballs

so far, have neglected spatial size:
what is the size of a fireball?
define through causal connectivity

require: the most separate points can still communicate



spatial diameter d of fireball in cms at hadronisation time

$$d = \sqrt{\frac{\tau_h}{\tau_q}(\tau_h - \tau_q)}$$

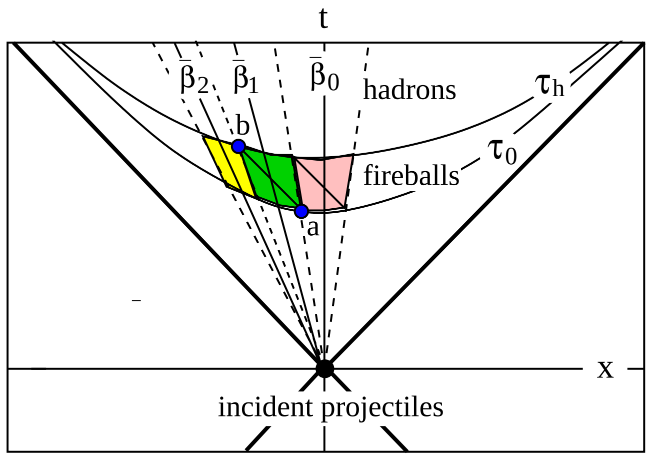
examples for different hadronisation times:

τ_h [fm]	β	η	$r = d/2$ [fm]
2	0.33	0.35	0.7
3	0.50	0.55	1.7
4	0.60	0.69	3.0
5	0.67	0.81	4.5

denote average cms velocity of of central fireball by $\bar{\beta}_0 = 0$
can then partition production region into successive causally disjoint fireballs, of velocities

$$\bar{\beta}_n = \frac{\tau_h^{2n} - \tau_q^{2n}}{\tau_h^{2n} + \tau_q^{2n}}$$

$$n = 0, 1, 2, \ldots$$



statistical hadronisation:

- massive colorless clusters distributed over rapidities, each decays statistically
- mass and charge distributions of clusters again statistically

$\Rightarrow$ equivalent global cluster

- $V = \Sigma V_i$, $Q = \Sigma Q_i$; large enough for thermodynamics

$$\langle n_j \rangle^{\text{primary}} = \frac{V T m_j^2}{2\pi^2} \gamma_s^{n_j} \mathrm{K}_2 \left(\frac{m_j}{T} \right)$$

with $\gamma_s \sim 0.5 - 0.7$ to account for strangeness suppression in elementary collisions

Causality constraints $\Rightarrow$ equivalent global cluster not allowed in elementary collisions

$\sim$ one pair of strange particles/causality cluster, strangeness must be conserved locally

Local strangeness suppression [Hamieh, Redlich, Tounsi 2000]

- **canonical strangeness conservation**

$$\frac{Z_{\text{can}}(T, V, S)}{Z_{\text{gcan}}(T, V, \langle S \rangle)} < 1$$

- **local strangeness conservation in a strangeness correlation volume $V_c \ll V$**

$\Rightarrow$ **3 parameters: T, V, V_c**

accounts for data, with V_c in place of γ_s

Here: V_c = volume of causal correlation cluster
data analysis: $d_c \sim 2$ fm $\rightarrow \tau_h \sim 2 - 3$ fm

- **causality constraints provide basis for local strangeness conservation**

Nuclear collisions:

space-time overlap of many causally connected clusters at each $\bar{\beta}_i$ provides equivalent global cluster containing many $s\bar{s}$ pairs

moreover, superposition increases parton density & hence τ_h: larger correlation volume

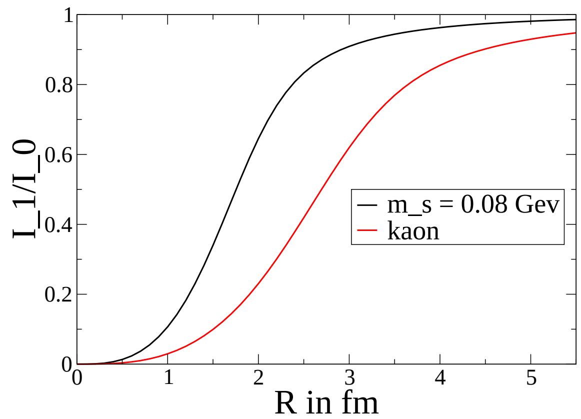
for RHIC & LHC, $\sim$ no strangeness suppression

So far: strangeness correlation on hadronic level, at τ_h.

what about $\phi(s\bar{s})$?

possible solution:
local strangeness correlation
on quark level, prior to hadronisation

suppression factor for $m_s = 80$ MeV



Conclusions

- **Onset of thermalisation implies the existence of causally disconnected space-time formation regions**
- **For rare species (strangeness), this requires local conservation in elementary collisions, rules out equivalent global cluster**
- **In nuclear collisions, superposition of causally connected clusters (at the same space-time location) allows global clusters, removes strangeness suppression**
- **open horizon problem remains: CGC $\sim$ false vacuum,**
  glasma $\sim$ inflation?