Why Heavy Ion Collisions ?

Dr.Sc. Mais Suleymanov

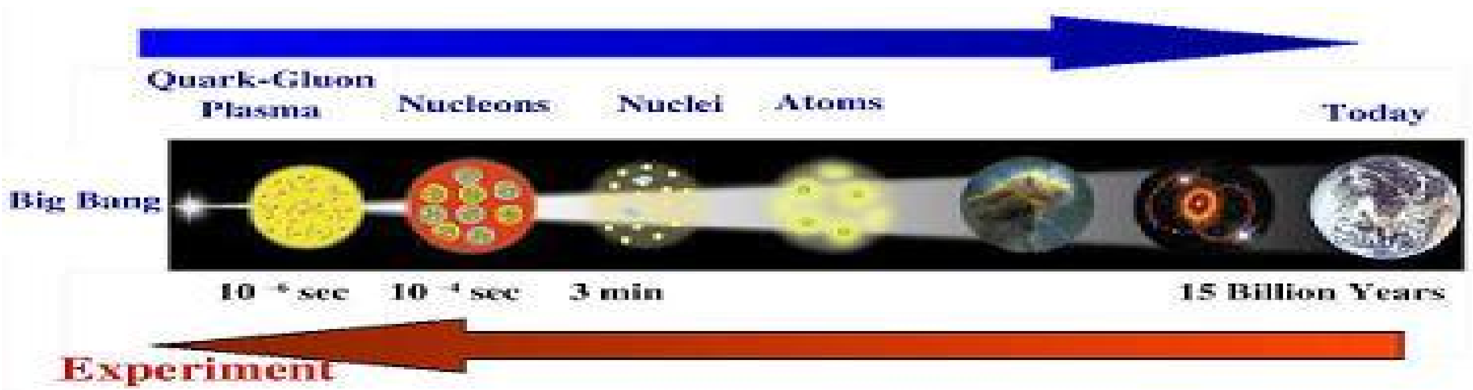
Department of Physics CIIT Islamabad

First School on LHC Physics: ALICE week
NCP Islamabad, 12-30 October,2009

- ***Over the last 25 years a lot of efforts have been made to search for new phases of strongly interacting matter under extreme conditions of high temperature and/or baryon density, as predicted by QCD.***

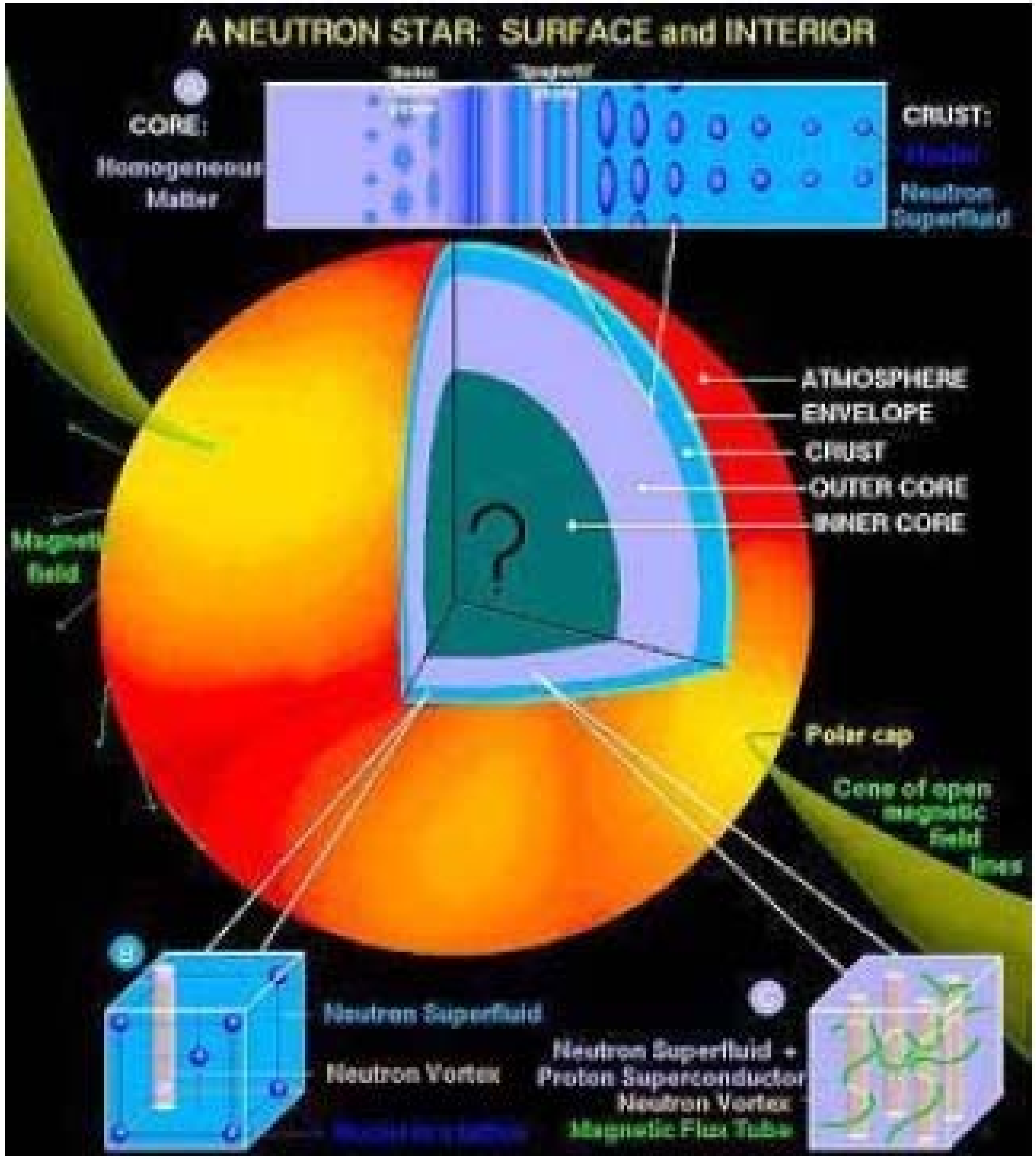
- ***These Phases are relevant for understanding the evolution of the early Universe after Big Bang, the formation of neutron stars.***

S. Weinberg, *The first three minutes* Basic Books (1977)



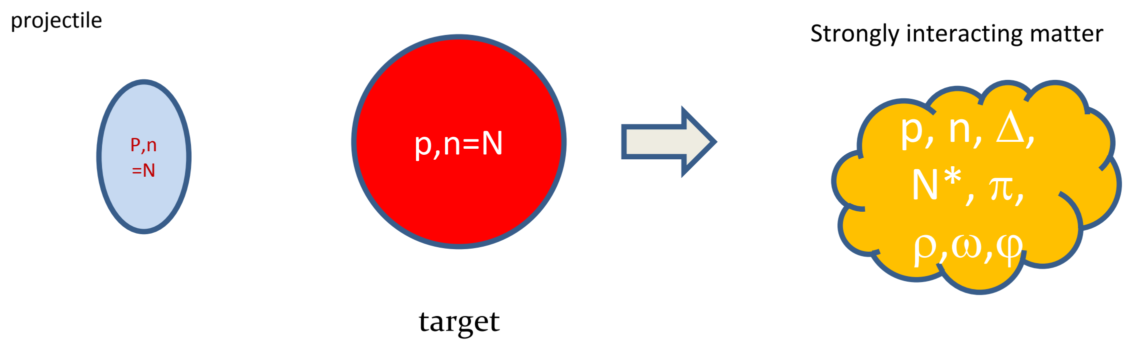
Sizes ~15-20 km

m ~ 1.5 m_{sun}



Definitions:

Strongly Interacting Matter : some bounding system of protons, neutrons, baryon resonances (Δ and N^*), π-mesons, and meson resonances (ρ,ω,φ) with life time ~ 10^{-22} sec. It could appear during the interaction of relativistic and ultrarelativistic particles (or nuclei) with nuclei (or particles).



Relativistic Energies : when the energy of projectile

$$E_p > m_N \sim 1 \text{ GeV} = 10^9 \text{ eV}$$

Academician Baldin A.M.

Definitions:

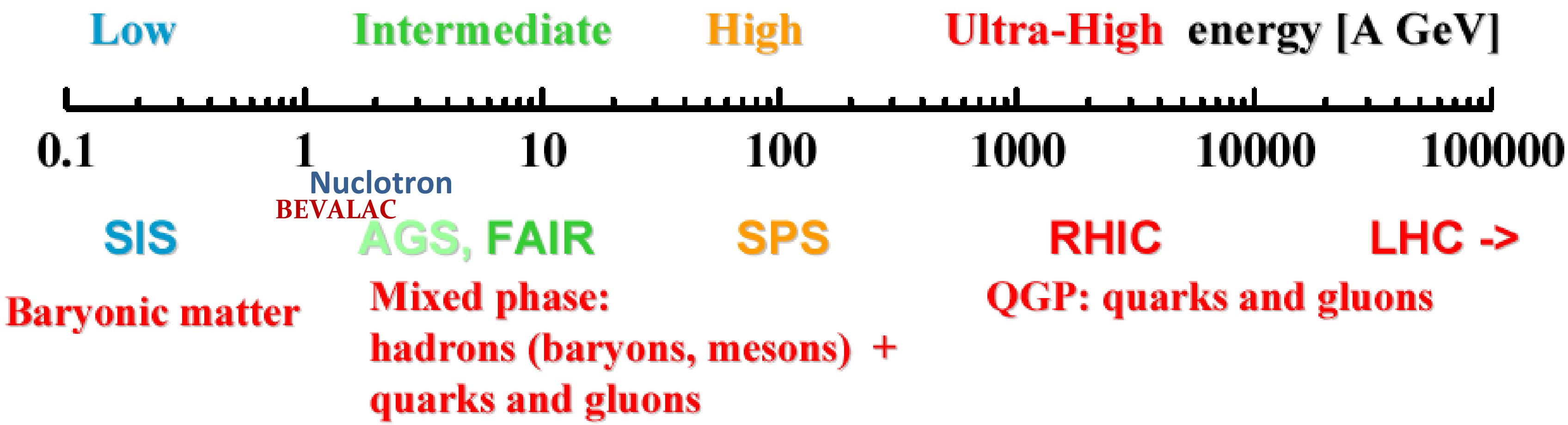
Ultra-Relativistic Energies : when the energy of projectile

$$E_p >> m_{target} \;\; > 5\text{-}10 \text{ GeV} = 5\text{-}10 \; 10^9 \text{ eV}$$

Sources of Relativistic and Ultrarelativistic particles and nuclei

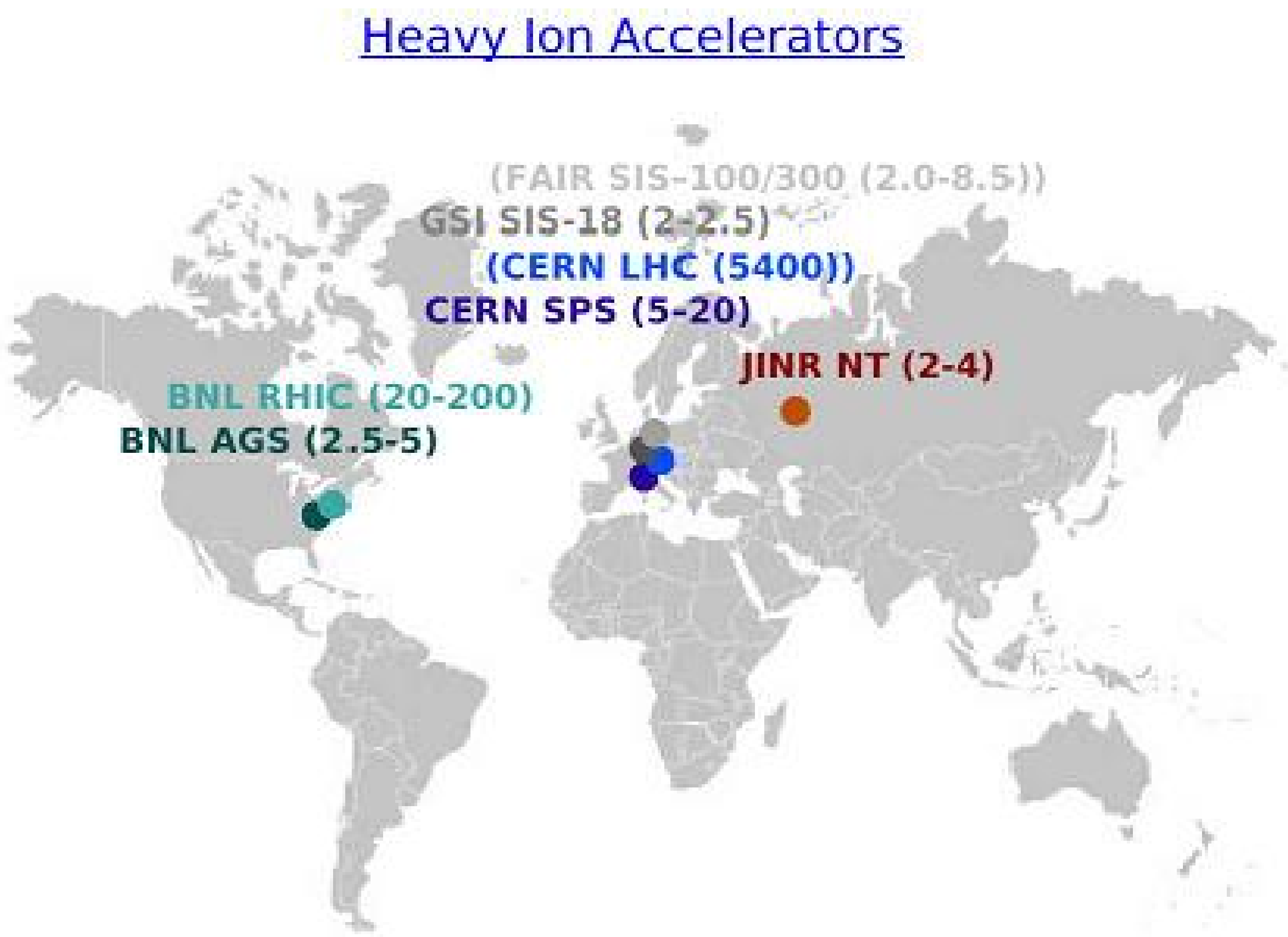
- Cosmic rays : unlimited energy; small intensity

- Accelerators : limited energy; high intensity


Low
Intermediate
High
Ultra-High
energy [A GeV]
0.1
1
10
100
1000
10000
100000
Nuclotron
BEVALAC
SIS
AGS, FAIR
SPS
RHIC
LHC ->
Baryonic matter
Mixed phase:
hadrons (baryons, mesons) +
quarks and gluons
QGP: quarks and gluons

Accelerators and Colliders of Relativistic and Ultrarelativistic particles and nuclei

Name	Location	Beam	Energy
Synchrophasotron	JINR Russia	Light nuclei	4.2 A GeV
BEVALAC	BERCLY USA	Au	2 A GeV
SIS	GSI Germany	Au	1-2 A GeV
AGS	BNL USA	Au	11 A GeV
SPS	CERN Geneva	Pb-Pb	17.3 AGeV
NUCLOTRON	JINR, Russia	Au	5 -9 AGeV
SIS	GSI Germany	Au	10– 30 AGeV
RHIC	BNL USA	Au-Au	200 AGeV
LHC	CERN Geneva	Pb-Pb	5200 AGeV


Heavy Ion Accelerators
(FAIR SIS-100/300 (2.0-8.5))
GSI SIS-18 (2-2.5)
(CERN LHC (5400))
CERN SPS (5-20)
JINR NT (2-4)
BNL RHIC (20-200)
BNL AGS (2.5-5)

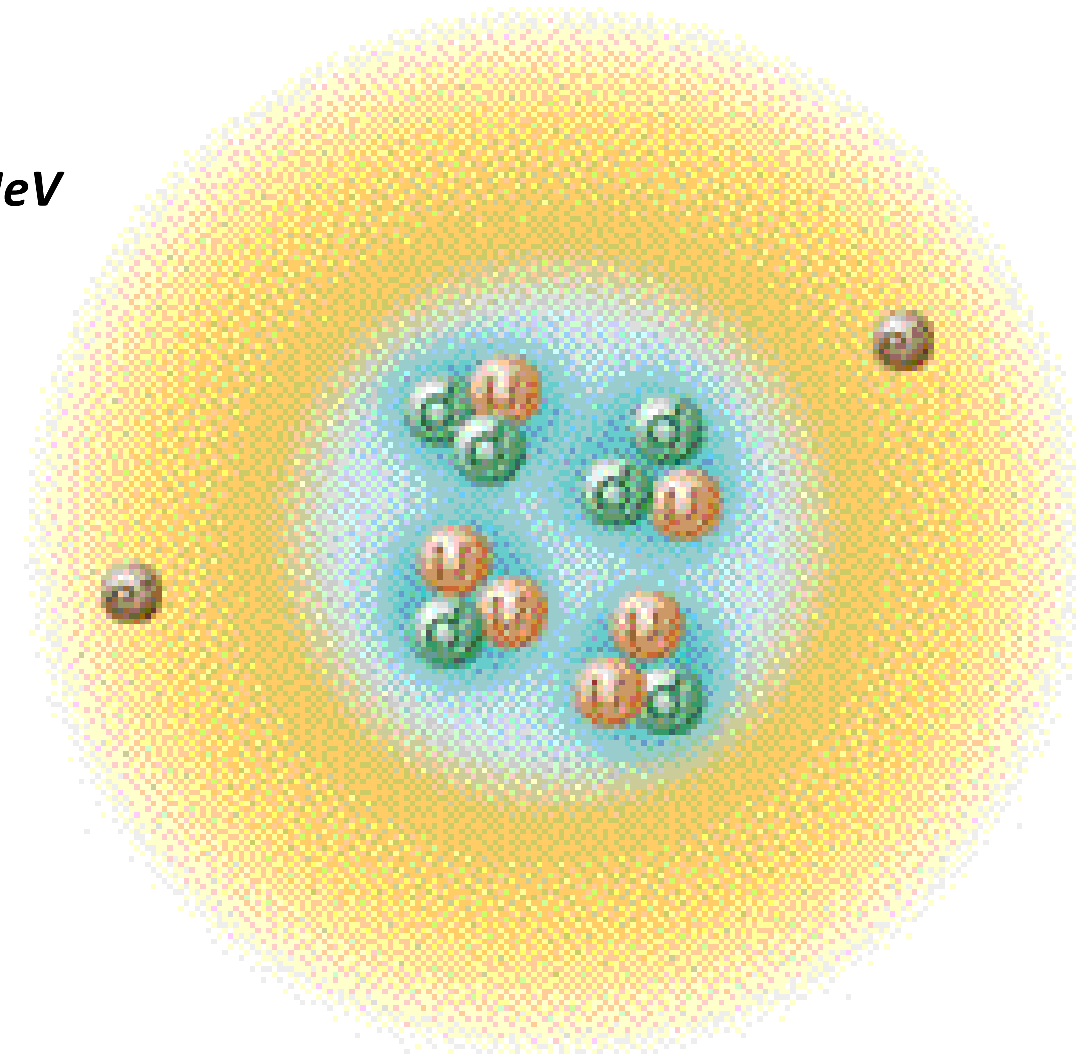

SIS
BEVALAC
NUCLOTRON
Synchrophasotron
SPS
RHIC

$$\rho = \frac{m_N A}{\frac{4}{3}\pi R^3} = \frac{3 m_N A}{4\pi r_0^3 A} \leq 180 \text{ million ton /sm}^3$$

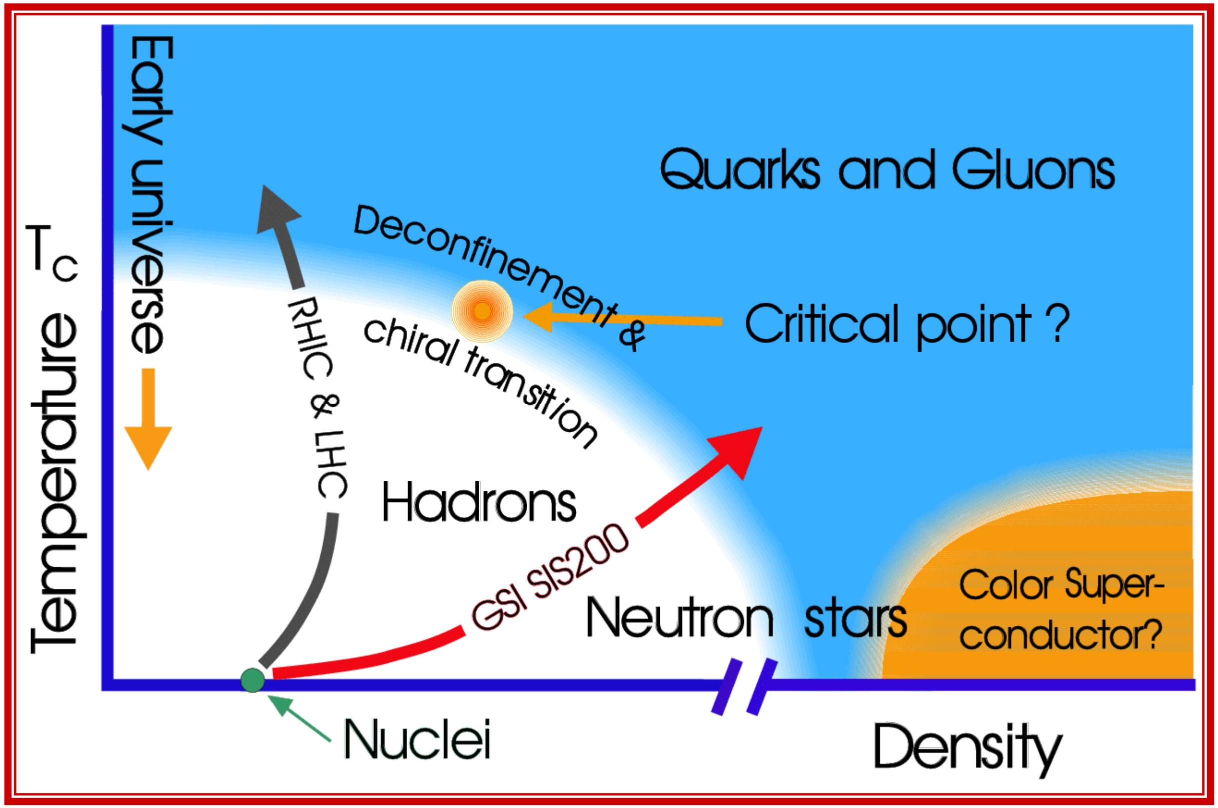
Nuclear Physics

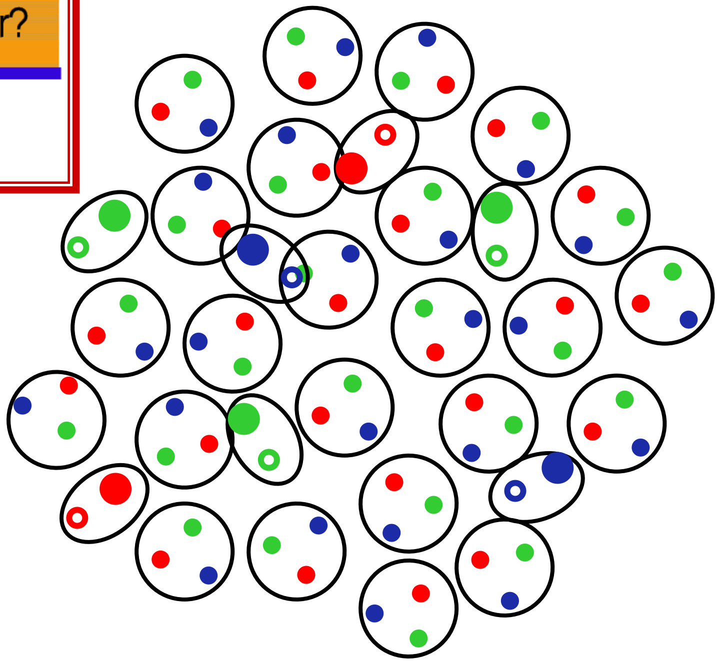
T* $\leq$ *30 MeV

ε $\leq$ 2-3 A MeV



Nuclear Matter under normal conditions


Quarks and Gluons
Deconfinement &
chiral transition
Critical point ?
Early universe
Temperature
T_C
RHIC & LHC
Hadrons
GSI SIS200
Neutron stars
Color Super-
conductor?
Nuclei
Density



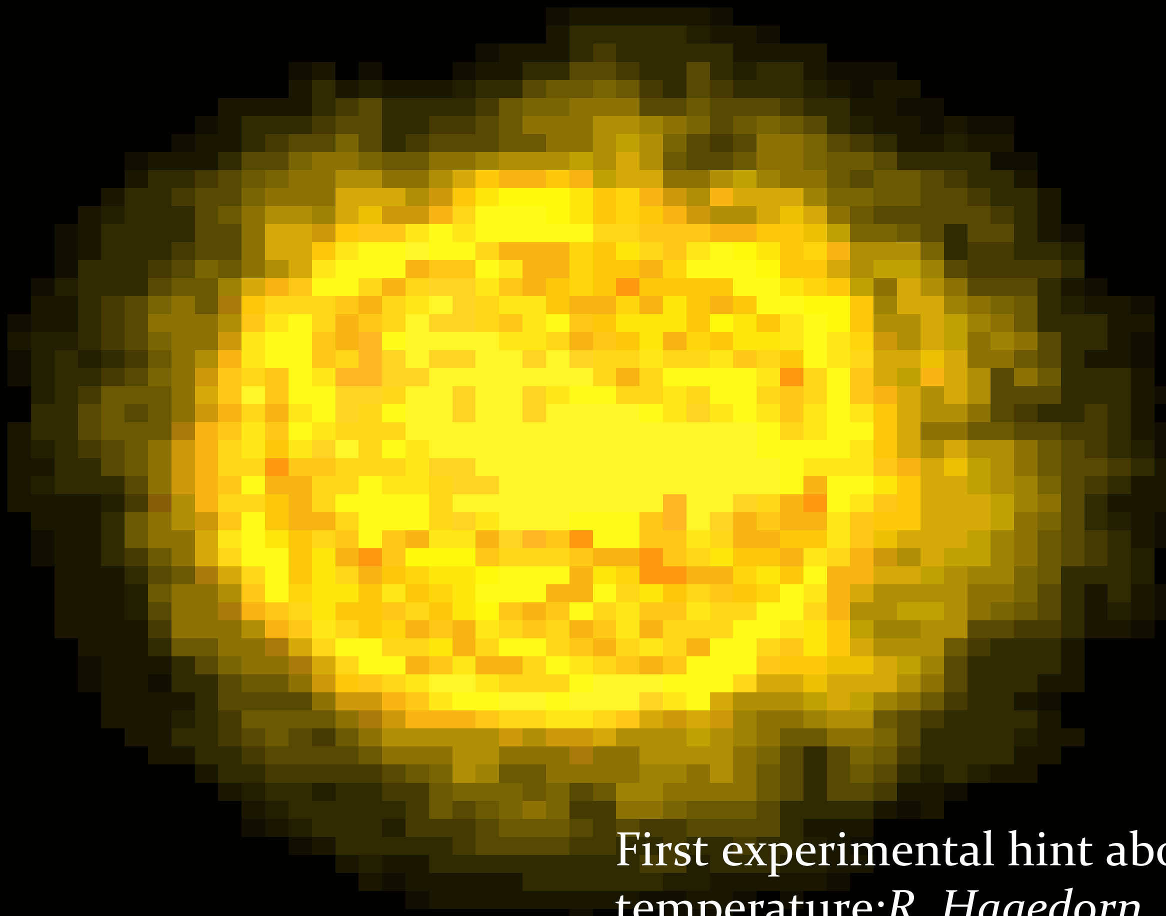
First experimental hint about critical temperature

R. Hagedorn, Suppl. Nuovo. Cimento **3** 1965, 3, p. 147.

.

$T_c \approx 200$ MeV Critical temperature

$\rho_c \geq 7\text{-}10 \ \rho$



First experimental hint about critical temperature:*R. Hagedorn*, Suppl. Nuovo. Cimento **3** 1965, 3, p. 147.

$T_c \geq 5 \ T$

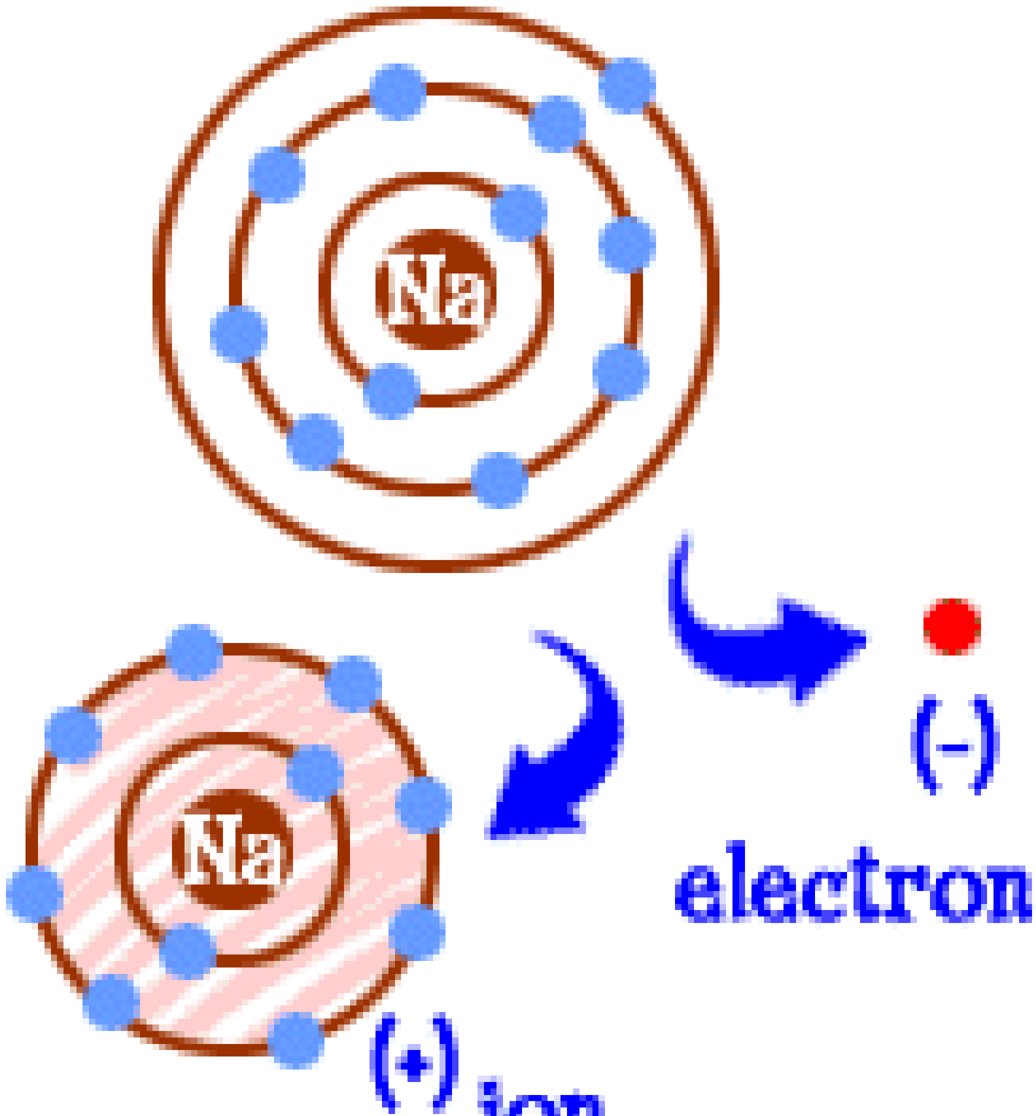
Heavy ion collisions are of great importance since they open a way to reproduce necessary extreme conditions in the Earth laboratory.

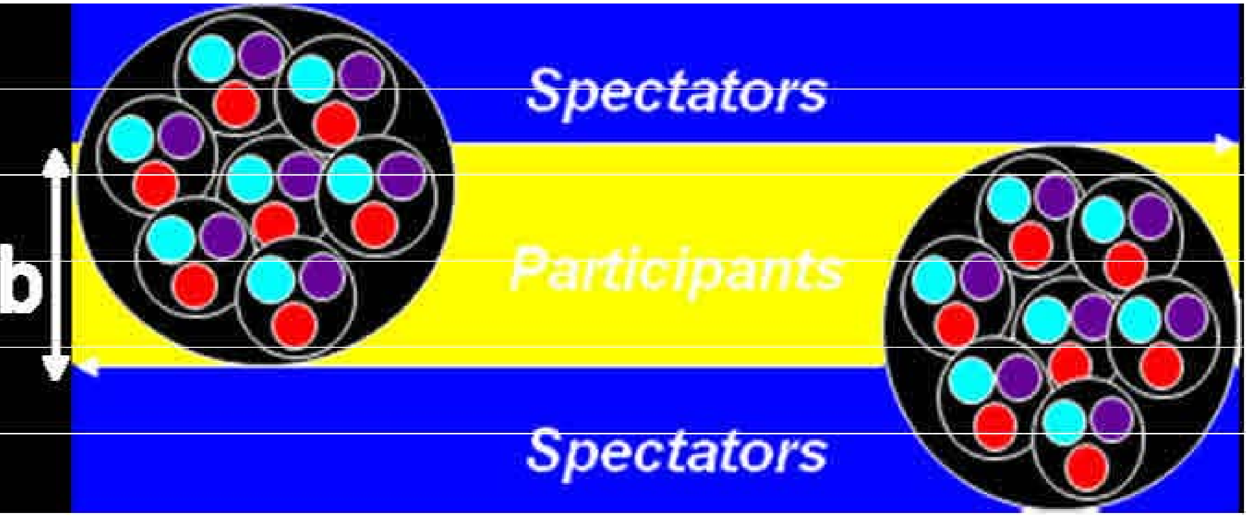
After the first experiments at the Dubna Synchrophasotron, heavy-ion physics successfully developed at Bevalac (Berkley), AGS (Brookhaven),SPS (CERN) , SIS (GSI) and RHIC (Brookhaven).

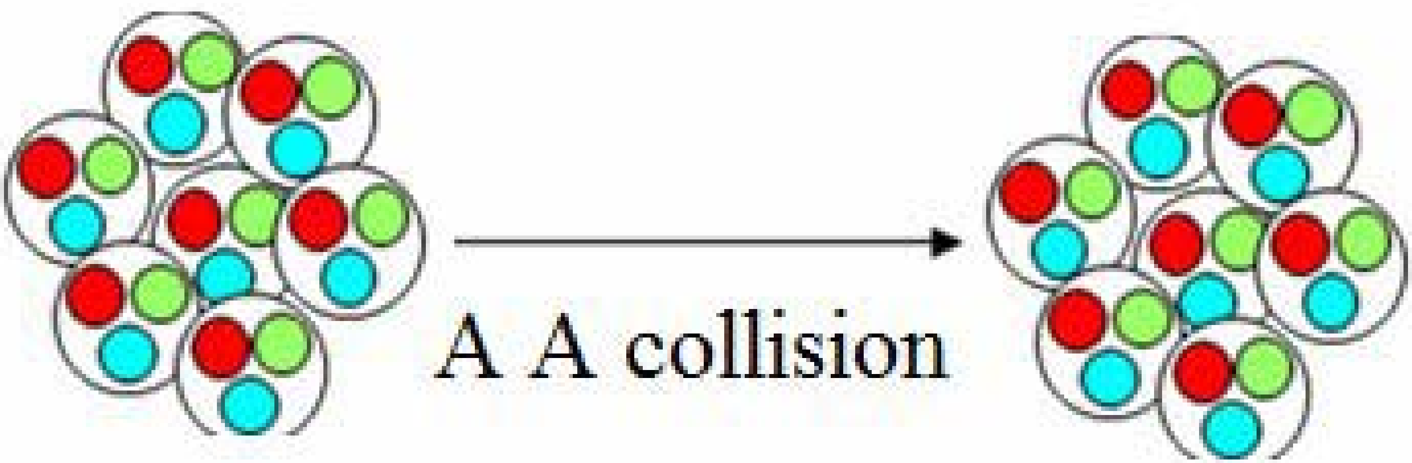
Many hopes are related to the Large Hadron Collider (LHC,CERN) which will start to work in the TeV energy range.

IONS

- IONS are atoms or groups of atoms with a positive or negative charge.
- Taking away an electron from an atom gives a CATION with a positive charge
- Adding an electron to an atom gives an ANION with a negative charge.

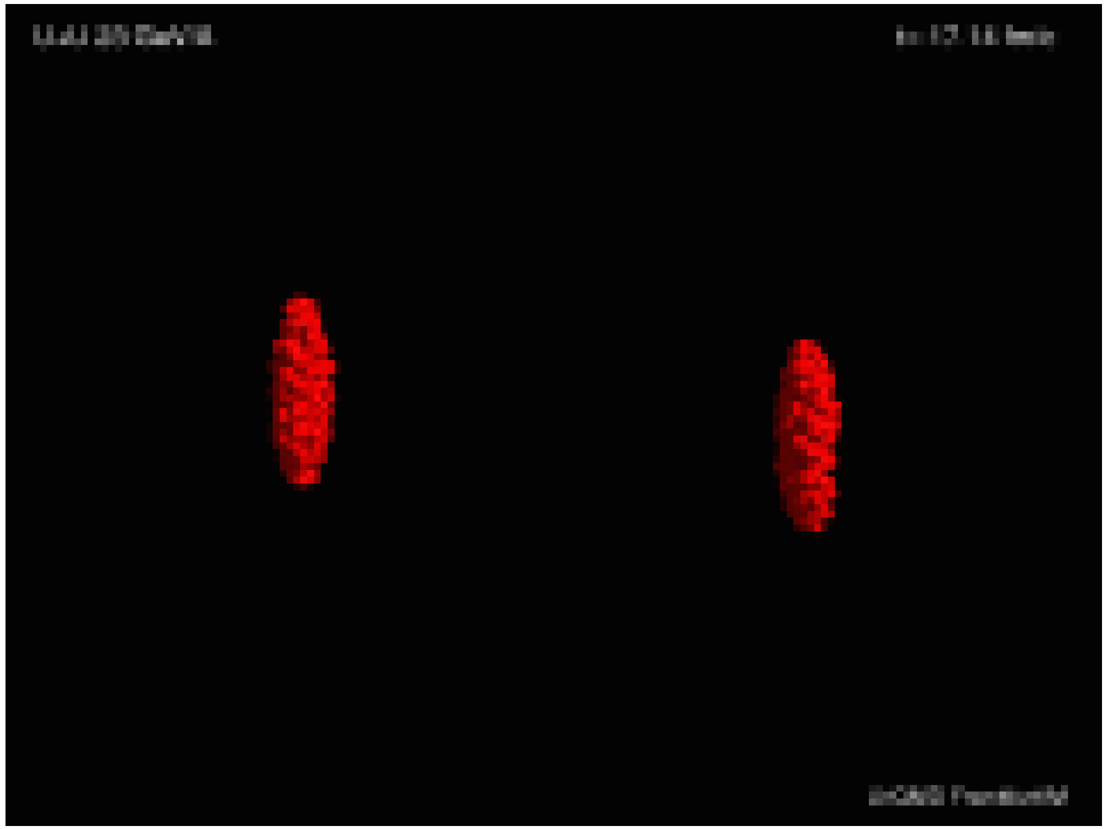

Na
Na
(-)
electron
(+)
ion


Spectators
b
Participants
Spectators


A A collision

Where could be QGP formed ?

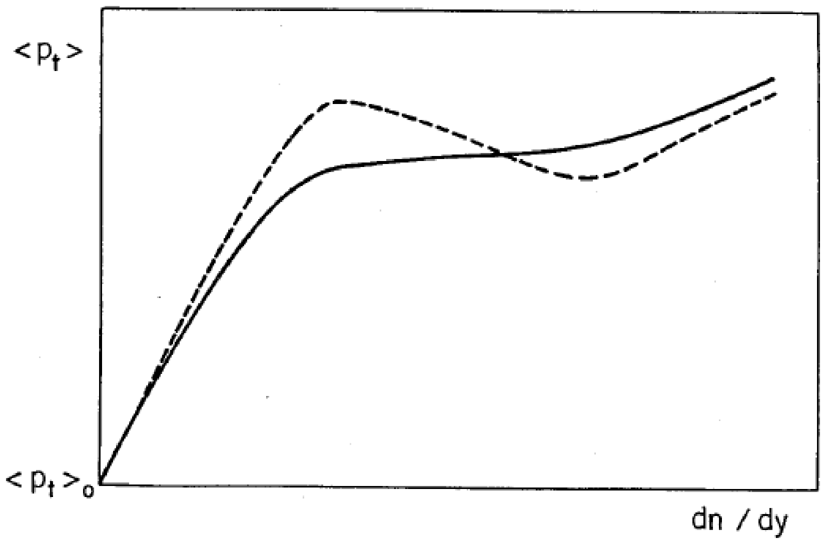
Central collisions of ultrarelativistic heavy ions



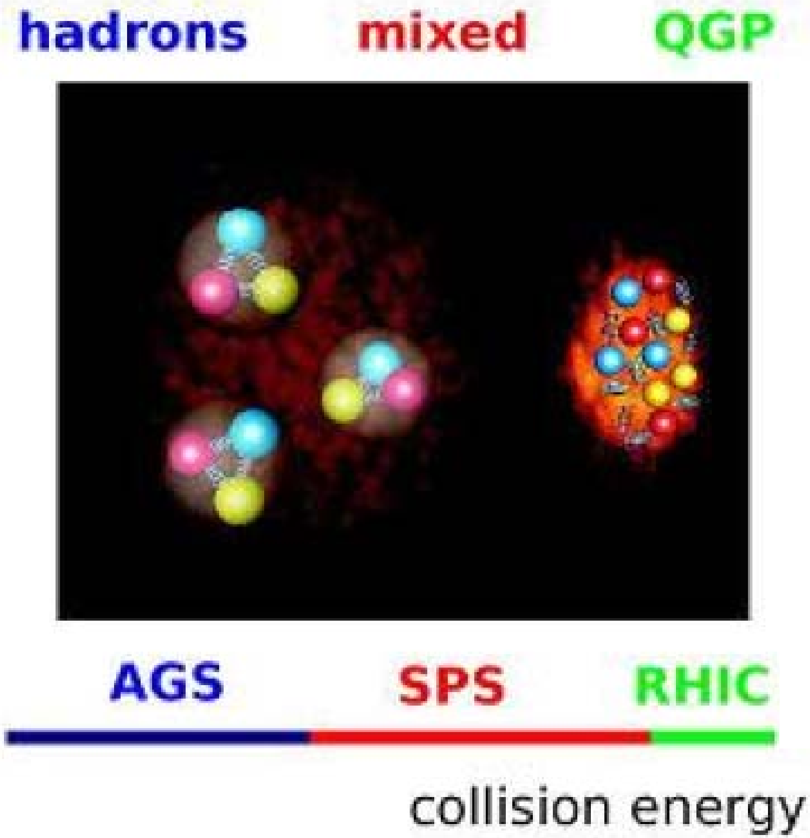
$$b \to 0$$

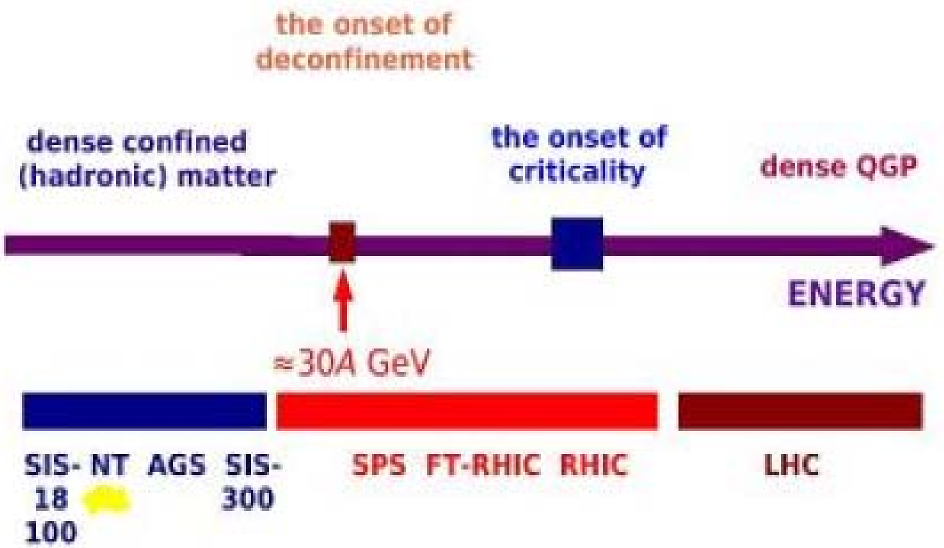
Studying of the centrality dependence of the characteristics of hadron-nuclear and nuclear-nuclear interactions is an important experimental way for obtaining information on phases of strongly interacting matter formed during the collision evolution.

L. Wan Hove may be first man who tried to use the centrality to get the information on the new phases of matter [L.Wan Hove.Ref.TH.3391-CERN, 1982, CERN] using the data coming from the ISR CERN experiments on pp-interactions.

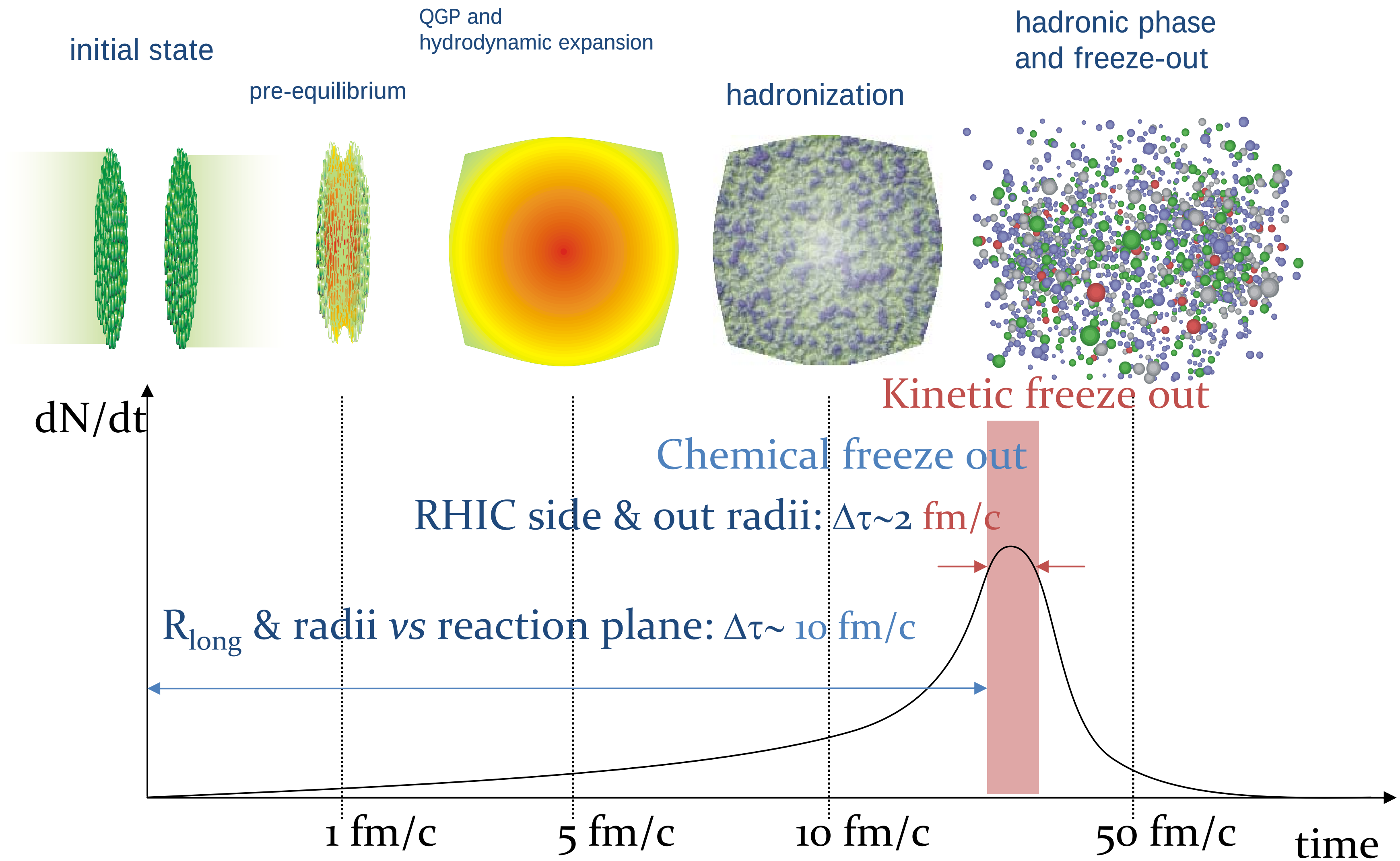


L. Wan Hove may be first man who tried to use the centrality to get the information on the new phases of matter [L.Wan Hove.Ref.TH.3391-CERN, 1982, CERN] using the data coming from the ISR CERN experiments on pp-interactions. Wan Hove tried to explain the fact as a signal on deconfinement in hot medium and formation of the Quark Gluon Plasma (QGP). But some after time it was understood that in pp interaction it is very difficult to reach the necessary conditions for QGP formation.


hadrons
mixed
QGP
AGS
SPS
RHIC
collision energy


the onset of
deconfinement
dense confined
(hadronic) matter
the onset of
criticality
dense QGP
ENERGY
≈30A GeV
SIS- NT AGS SIS-
18
100
300
SPS FT-RHIC RHIC
LHC

Expected evolution of HI collision vs RHIC data



Effect of Nuclear Transparency

Light Nuclei Production

Experimental methods for determination of Transparency effect.

$$R = \frac{n_1}{n_2}$$

(here e.g., n_1 and n_2 could be heavy flavor particles yields with fixed values of p_T and η) as a function of centrality, the masses and energy it is possible to get necessary information on the properties of the nuclear matter. In such definition of R, appearance of transparency could be identified using the condition $R \to 1$. Using some statistical and percolation models and experimental data on the behaviour of the nuclear modification factors it is possible to get information on the appearance of the anomalous nuclear transparency as a signal of formation of the percolation cluster.

Light Nuclei Production

One of the ways to identify Quark-Gluon-Plasma could be to study the centrality dependence of the light nuclei production in heavy ion collisions. Observation of the regime change on the behavior of those distributions as a function of the centrality could be some signal of the appearance of the freeze out state. In this state light nuclei could be formed as a result of nuclear coalescence.

The coalescence parameter B_2 characterizes the probability that two nucleon with similar momentum form abound state.

$$B_2 = \frac{(E_d \frac{d^3 N_d}{dp_d^3})}{(E_p \frac{d^3 N_p}{dp_p^3})^2} \propto \frac{1}{V} \qquad (1)$$

here and are the deuteron, proton density in momentum space respectively, E_d and E_p the deuteron and proton energies respectively V is the volume of source size at freeze out.

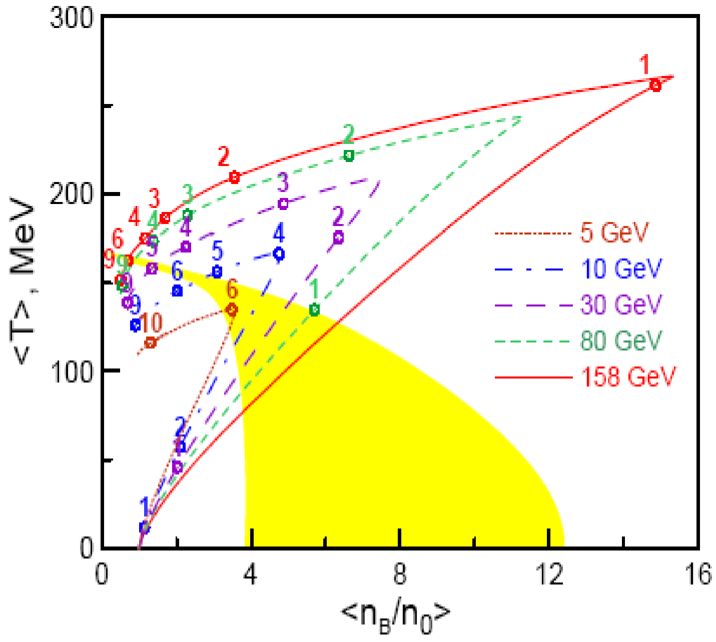


Figure Dynamical trajectories for central $Au + Au$ collisions in $T - n_B$ (left panel) for various bombarding energies calculated within the relativistic 3-fluid hydrodynamics [ ]. Numbers near the trajectories are the evolution time moment. Phase boundaries are estimated in a two-phase bag model.

Thank you