GOETHE
UNIVERSITÄT
FRANKFURT AM MAIN

Lecture

Introduction:

‘Physics of Strongly Interacting Matter‘

Lectures:
Thursday, 11:15-12:45

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http://theory.gsi.de/~ebratkov/LecturesWS2526/Lec_WS2526.html

Contents

In this course we will discuss the properties of strongly interacting matter which can be studied in relativistic heavy-ion collisions at existing (SPS, RHIC, LHC) and future (FAIR, NICA) facilities.

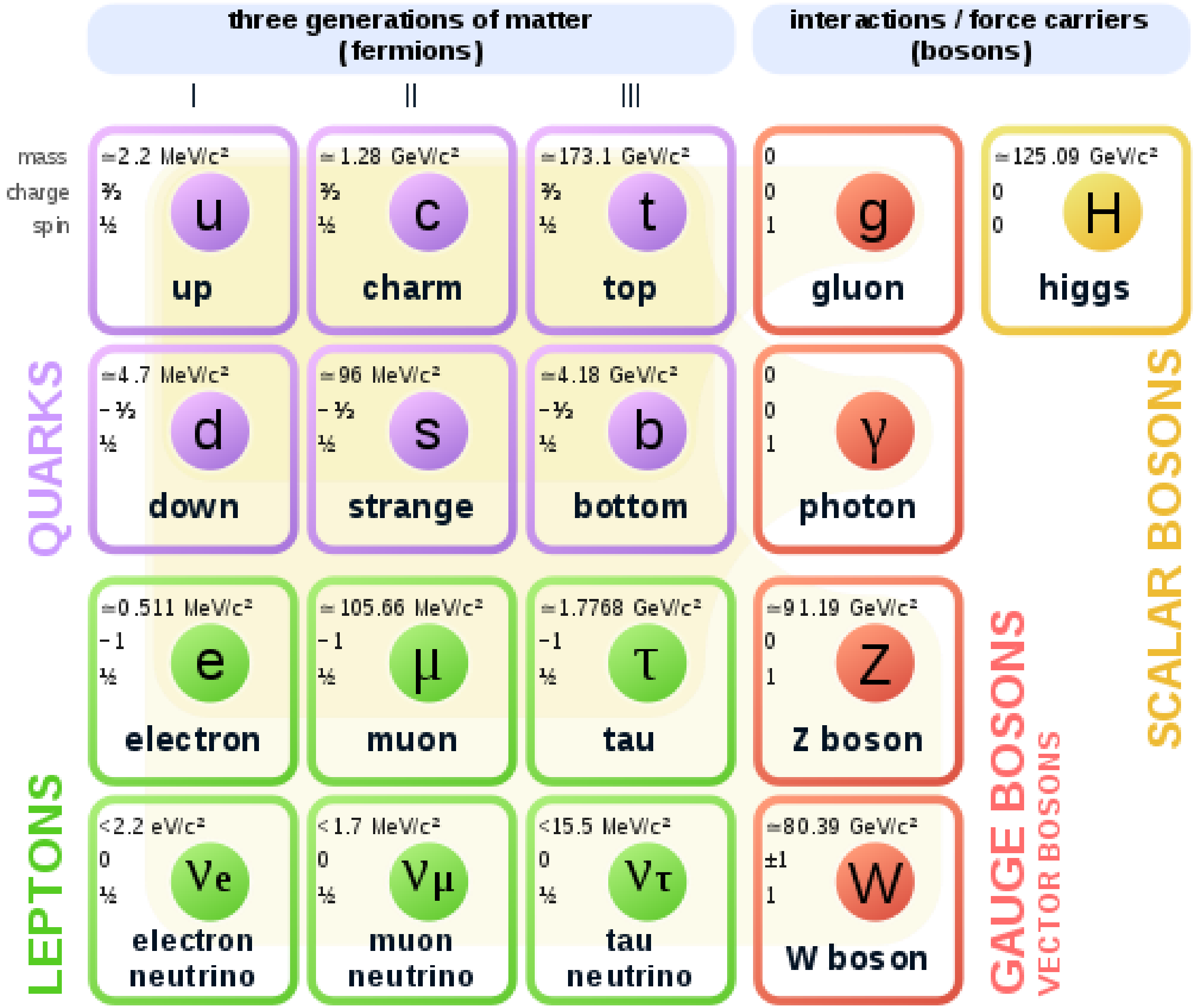
The list of topics includes:

- **basic building blocks of matter (nuclei, hadrons, partons);**
- **relativistic models of nuclear matter;**
- **Quantum Chromo Dynamics in short;**
- **QCD motivated models of hadrons:**
  liner σ-model, Numbu-Jona-Lasinio model, Bag model, string model
- **hadron resonance gas; quark-gluon plasma;**
- **chiral and deconfinement phase transitions;**
- **their observable signatures in heavy-ion collisions and compact stars.**

A List of the Metric Prefixes

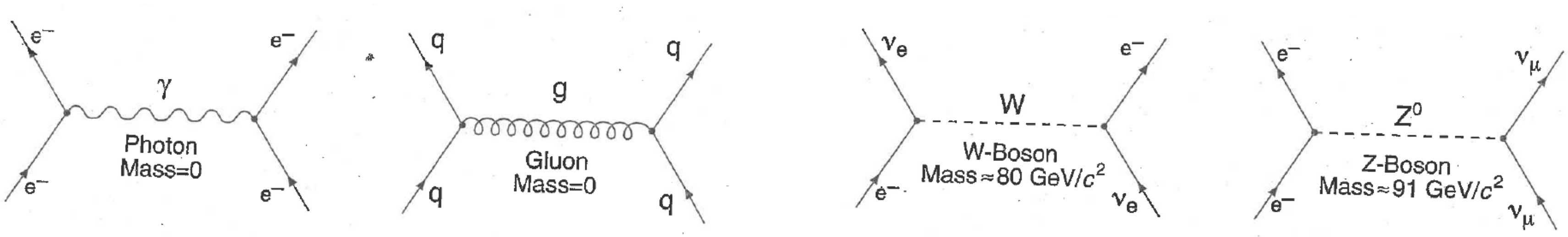
			Multiplier	
	Prefix	Symbol	Numerical	Exponential
	yotta	Y	1,000,000,000,000,000,000,000,000	10^{24}
	zetta	Z	1,000,000,000,000,000,000,000	10^{21}
	exa	E	1,000,000,000,000,000,000	10^{18}
	peta	P	1,000,000,000,000,000	10^{15}
	tera	T	1,000,000,000,000	10^{12}
1 GeV	giga	G	1,000,000,000	10^{9}
	mega	M	1,000,000	10^{6}
	kilo	k	1,000	10^{3}
	hecto	h	100	10^{2}
	deca	da	10	10^{1}
	no prefix means:		1	10^{0}
	deci	d	0.1	10^{-1}
	centi	c	0.01	10^{-2}
	milli	m	0.001	10^{-3}
	micro	μ	0.000001	10^{-6}
	nano	n	0.000000001	10^{-9}
	pico	p	0.000000000001	10^{-12}
1 fm	femto	f	0.000000000000001	10^{-15}
	atto	a	0.000000000000000001	10^{-18}
	zepto	z	0.000000000000000000001	10^{-21}
	yocto	y	0.000000000000000000000001	10^{-24}

Standard Model of Elementary Particles

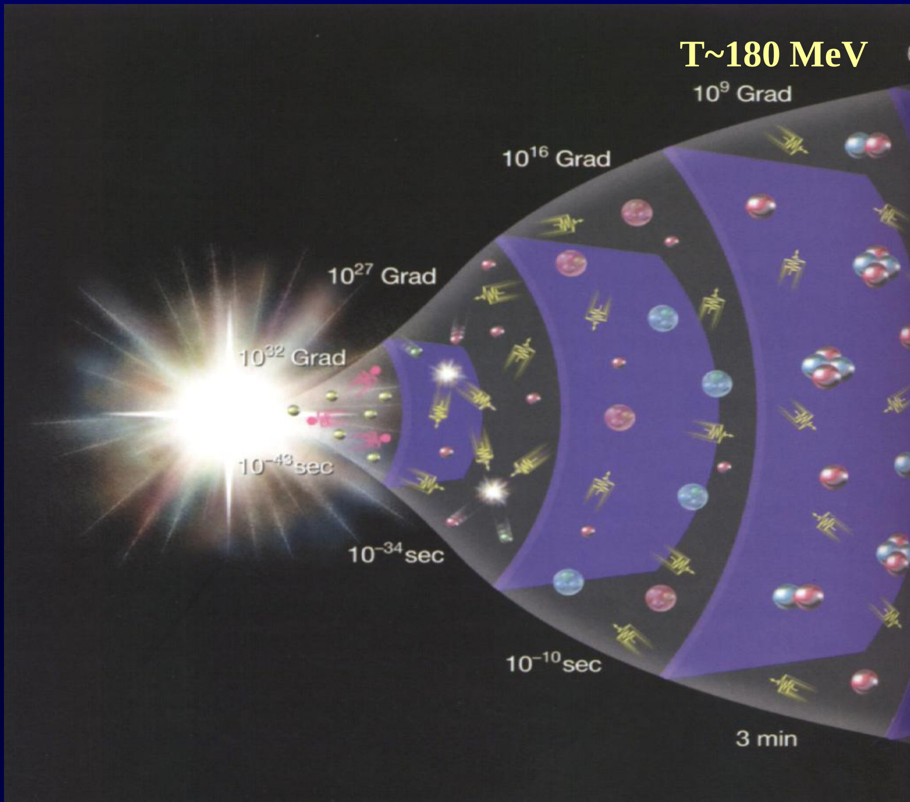


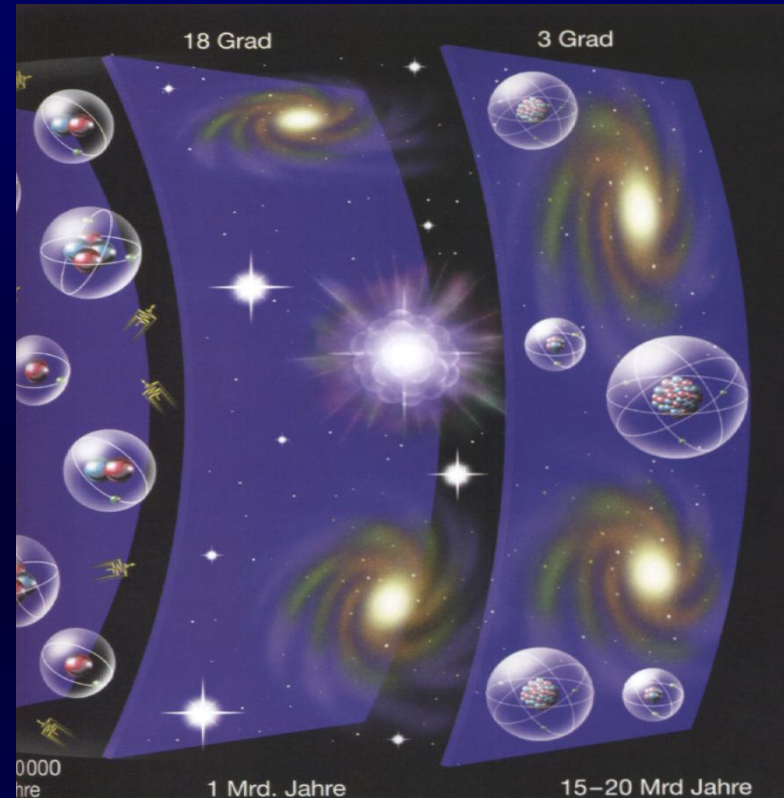
Fundamental interactions

Interaction	Current theory	Mediators	Relative strength[20]	Long-distance behavior (potential)	Range (m)[21]
Weak	Electroweak theory (EWT)	W and Z bosons	10^{33}	$\frac{1}{r}\, e^{-m_{\mathrm{W,Z}}\, r}$	10^{-18}
Strong	Quantum chromodynamics (QCD)	gluons	10^{38}	$\sim r$	10^{-15}
Gravitation	General relativity (GR)	gravitons (hypothetical)	1	$\frac{1}{r^2}$	∞
Electromagnetic	Quantum electrodynamics (QED)	photons	10^{36}	$\frac{1}{r^2}$	∞



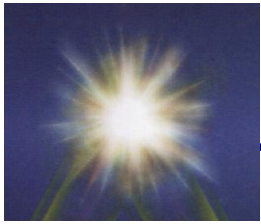
From Big Bang to Formation of the Universe





time	10^{-3}sec	3 min	300000 years	15 Mrd years
	quarks gluons photons	nucleons deuterons α–particles	atoms	our Universe

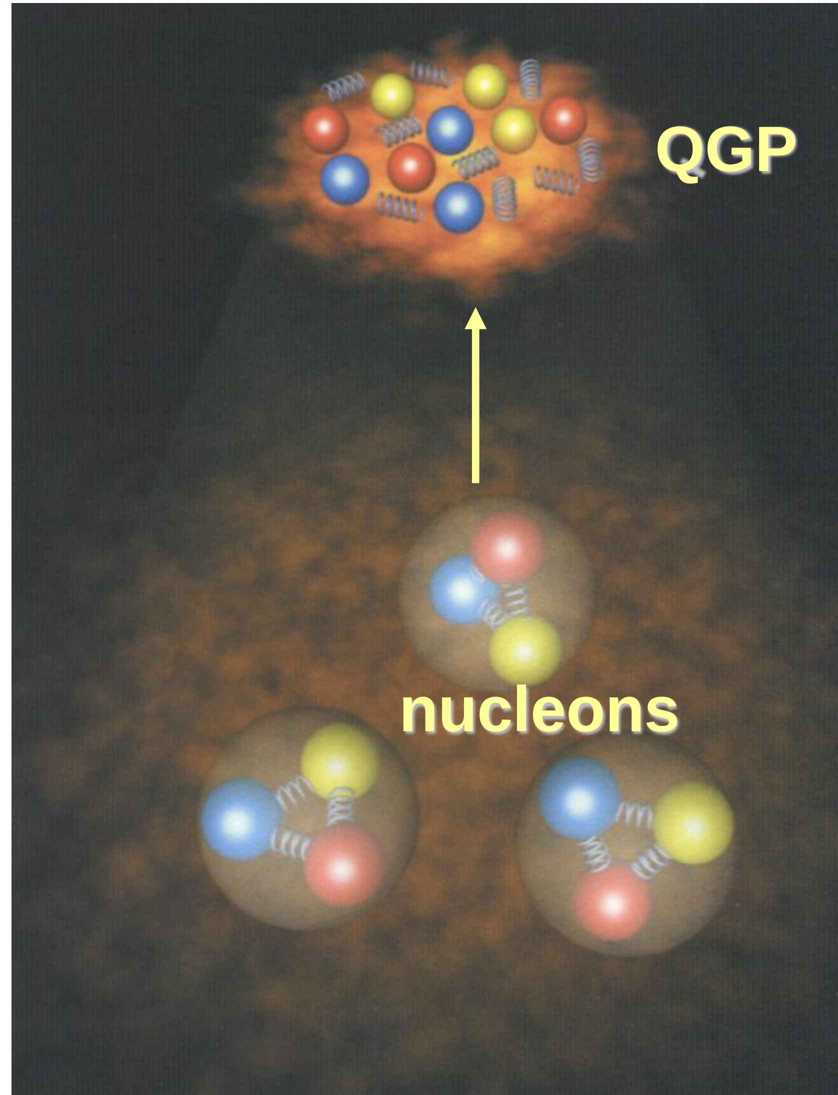
Can we go back in time ?



... back in time

‚Re-create‘ the **Big Bang conditions:**
matter at high temperature and pressure
such that
nucleons/mesons decouple to quarks and gluons --
Quark-Gluon-Plasma

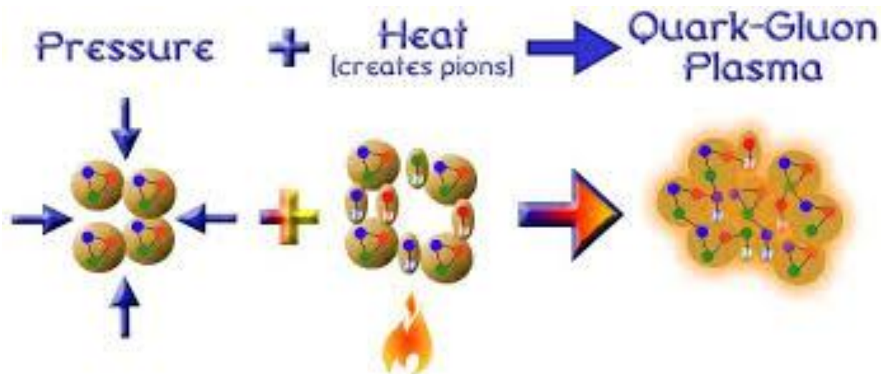
‚Little Bangs‘ in the Laboratory :
Heavy-ion collisions at ultrarelativistic energies

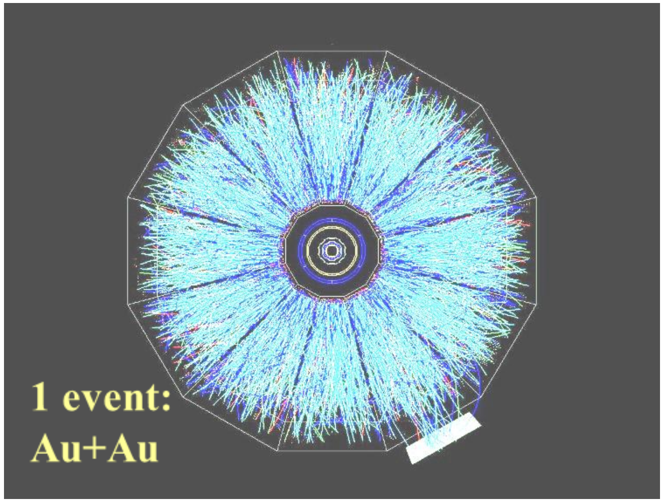


Heavy-ion collisions

❑ Heavy-ion collision experiment

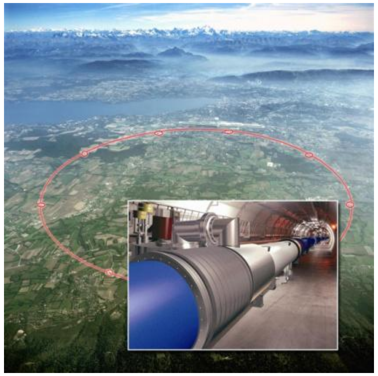
➔ ‚re-creation' of the Big Bang conditions in laboratory:
matter at high pressure and temperature



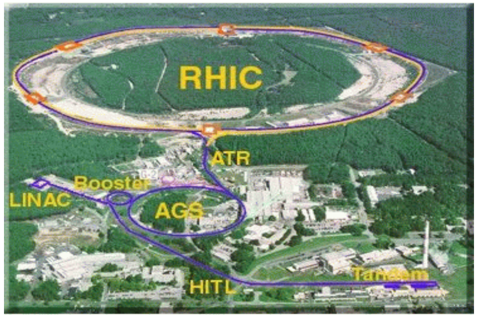


❑ Heavy-ion accelerators:

Large Hadron Collider - LHC (CERN):
Pb+Pb up to 574 A TeV

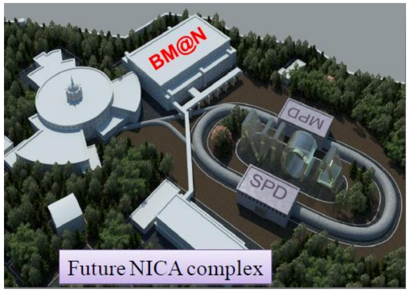


Relativistic-Heavy-Ion-Collider - RHIC (Brookhaven):
Au+Au up to 21.3 A TeV



Facility for Antiproton and Ion Research – FAIR (Darmstadt)
(Under construction)
Au+Au up to 10 (30) A GeV

Nuclotron-based Ion Collider fAcility – NICA (Dubna)
(Under construction)
Au+Au up to 70 A GeV

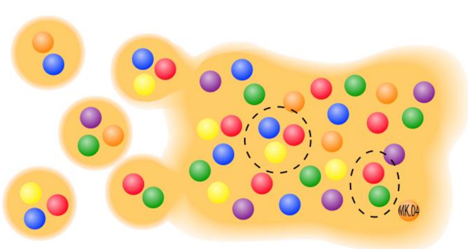


The QGP in Lattice QCD

Quantum Chromo Dynamics :

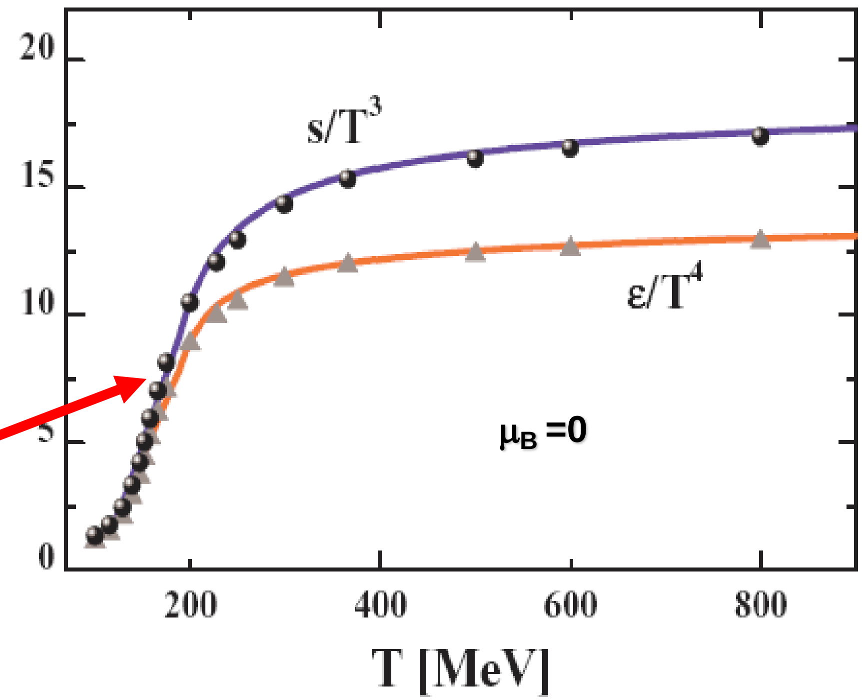
predicts strong increase of the energy density e at critical temperature T_C ~160 MeV

⇒ Possible phase transition from hadronic to partonic matter (quarks, gluons) at critical energy density ε_C ~0.5 GeV/fm^3



Lattice QCD:

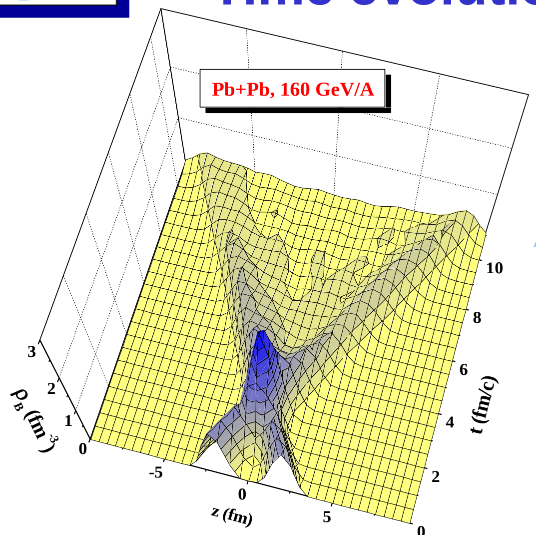
energy density versus temperature

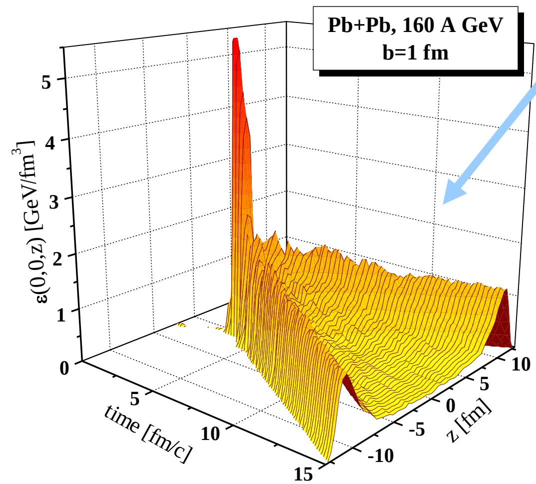


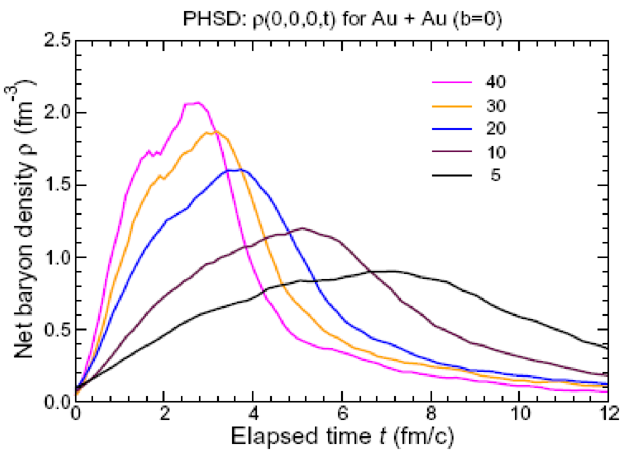
Critical conditions - ε_C ~0.5 GeV/fm^3 , T_C ~160 MeV - can be reached in heavy-ion experiments at bombarding energies > 5 GeV/A

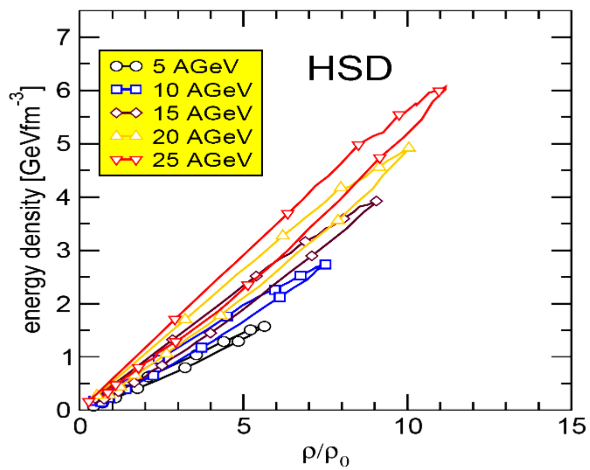
Dense and hot matter – average quantities

Time evolution of the baryon density and energy density





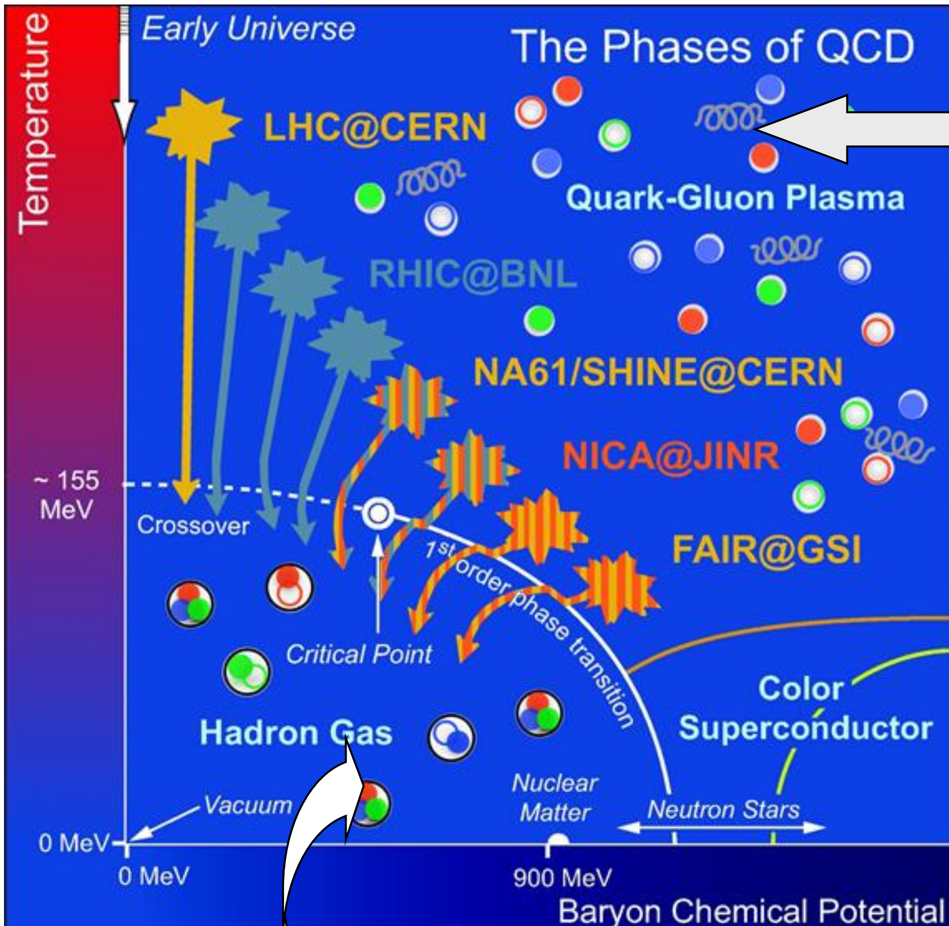




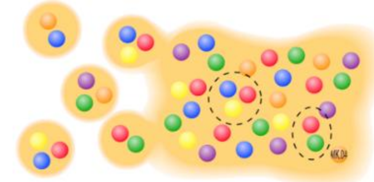
huge energy and baryon densities are reached ($\varepsilon > \varepsilon_{crit}$=0.5 GeV/fm^3) at FAIR/NICA energies (> 5 A GeV)

The ‚holy grail‘ of heavy-ion physics:

The phase diagram of QCD



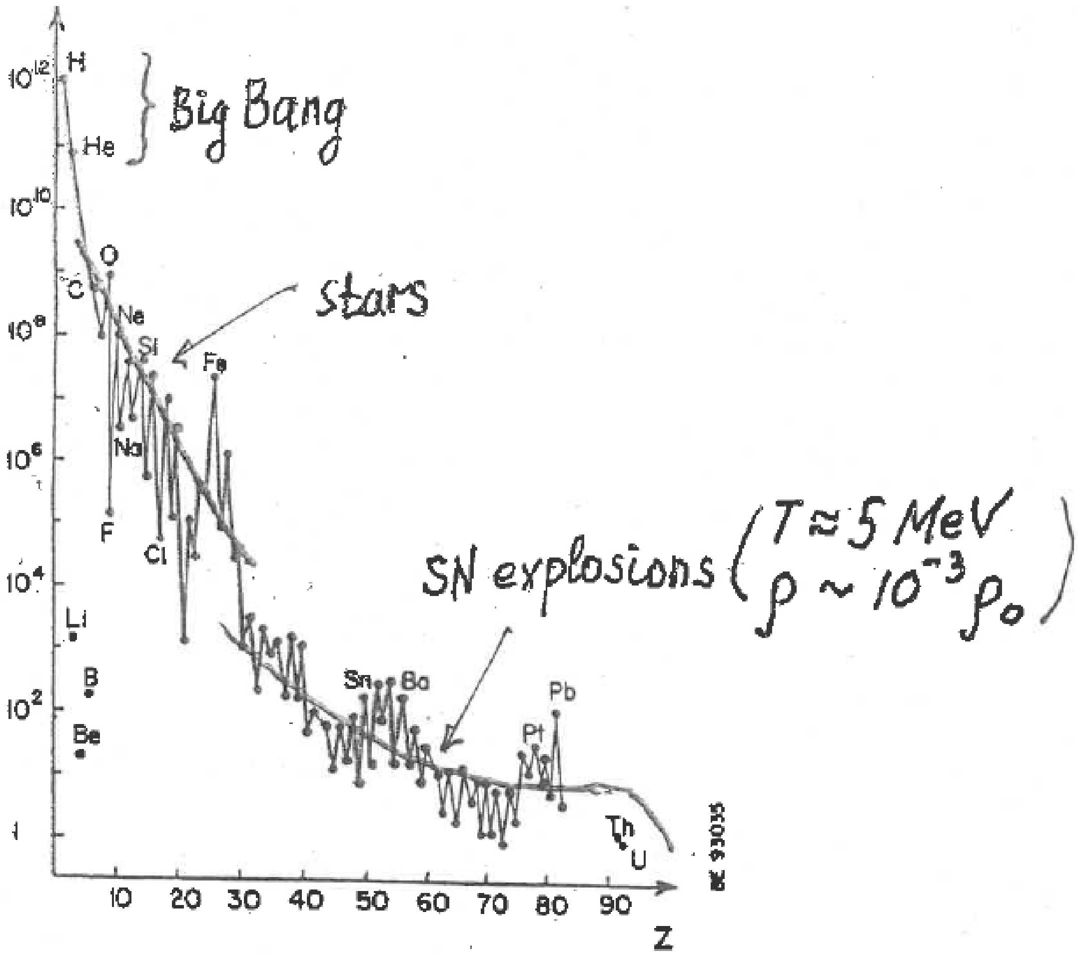
- Search for the critical point



- Study of the phase transition from hadronic to partonic matter – Quark-Gluon-Plasma
- Search for signatures of chiral symmetry restoration
- Search for the critical point
- Study of the in-medium properties of hadrons at high baryon density and temperature

Creation of chemical elements in the Universe

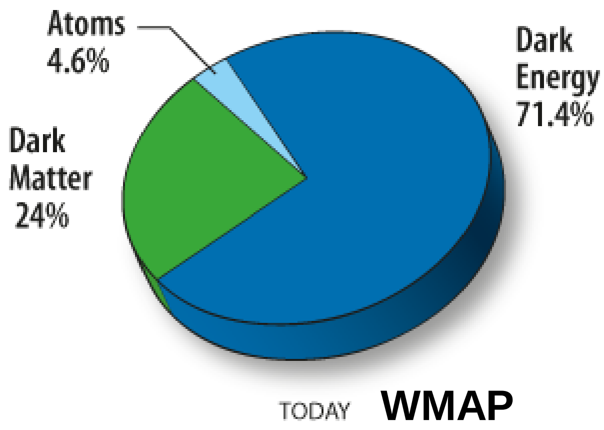
- result of long evolution!



75% of matter is in hydrogen , almost all the rest is Helium. Heavy elements are produced in stars.

Structure of Universe

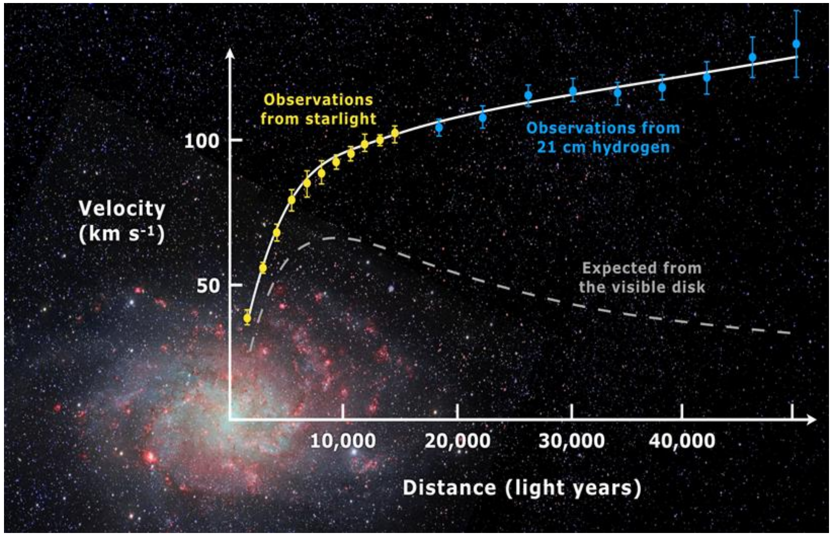
- Dark matter (DM) ~24%
- DM detected by astrophysical observations based on gravitational effects:



WMAP

1933: F. Zwicky: observation of galaxy clusters

1970: V. Rubin: rotation anomalies in galaxies



Hubble: gravitational lensing