

PHY397K - NUCLEAR PHYSICS - 2

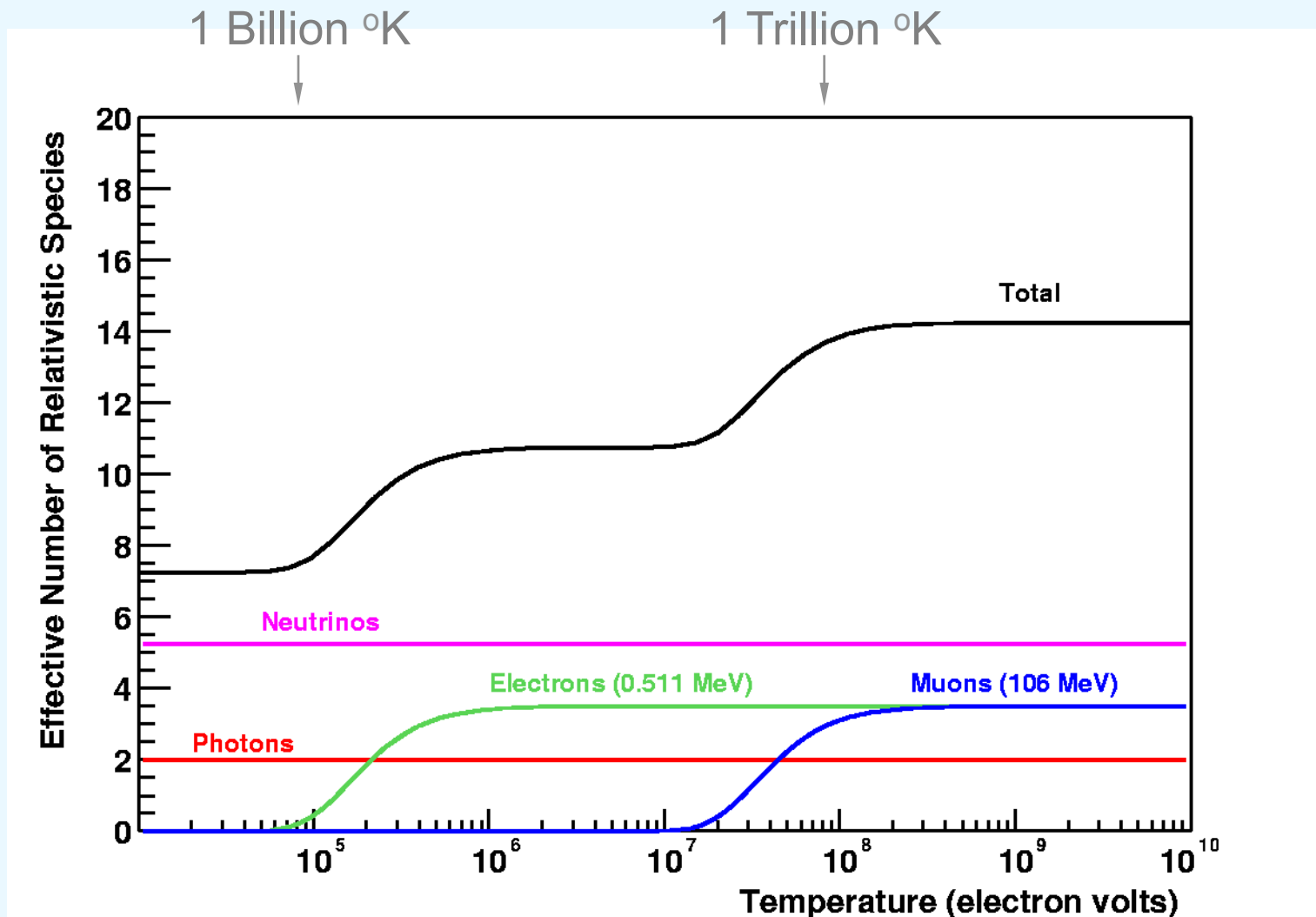
PHY397K - NUCLEAR PHYSICS
Spring 2015, Unique numbers: 57115
RLM 5.116, TTH 12:30 - 2:00 pm

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Elementary Particles Summary

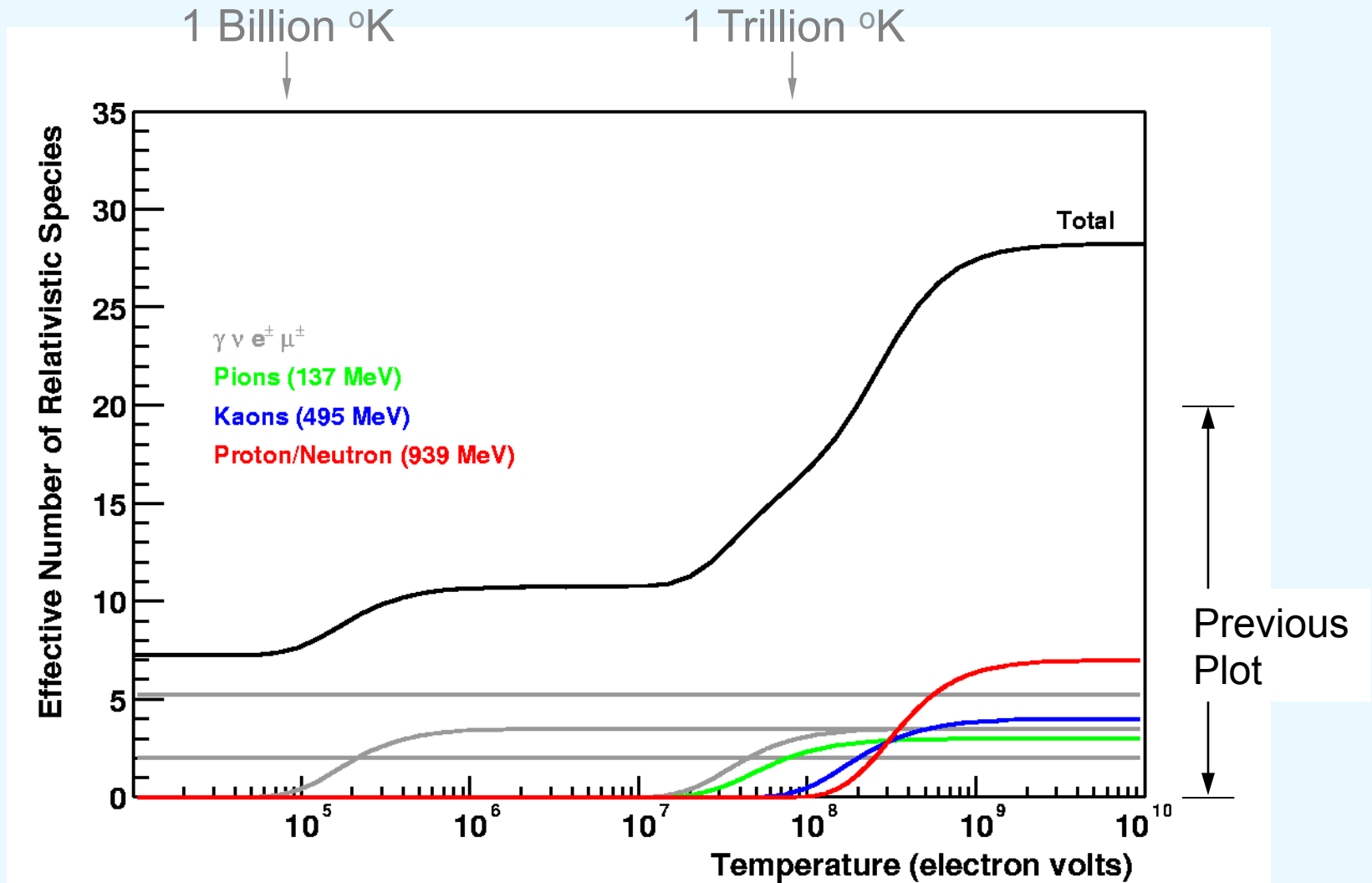
QUARK	CHARGE (e)	SPIN ($h/2\pi$)	MASS (MeV/c ²)
Up (u)	+2/3	1/2	2-8
Down (d)	-1/3	1/2	5-15
Strange (s)	-1/3	1/2	100-300
Charmed (c)	+2/3	1/2	1000-1600
Top (t)	+2/3	1/2	1.8x10 ⁵
Bottom (b)	-1/3	1/2	4100-4500
LEPTONS	CHARGE (e)	SPIN ($h/2\pi$)	MASS (MeV/c ²)
Electron (e ⁻)	-1	1/2	0.511
Muon (μ^-)	-1	1/2	106
Tau (τ^-)	-1	1/2	1784
Electron Neutrino (ν_e)	0	1/2	<7.3 eV
Muon Neutrino (ν_μ)	0	1/2	<270 keV
Tau Neutrino (ν_τ)	0	1/2	<35 MeV
GAUGE BOSONS (Field Particles)	ELECTRIC CHARGE	SPIN ($h/2\pi$)	MASS (GeV/c ²)
Graviton	0	2	0
W [±] , Z ⁰	±1, 0	1	80.41, 91.12
Photon (γ)	0	1	0
Gluon (g) – 8 varieties	0	1	0
Higgs Boson (H ⁰)???	0	1	40-1000???

Particle Production



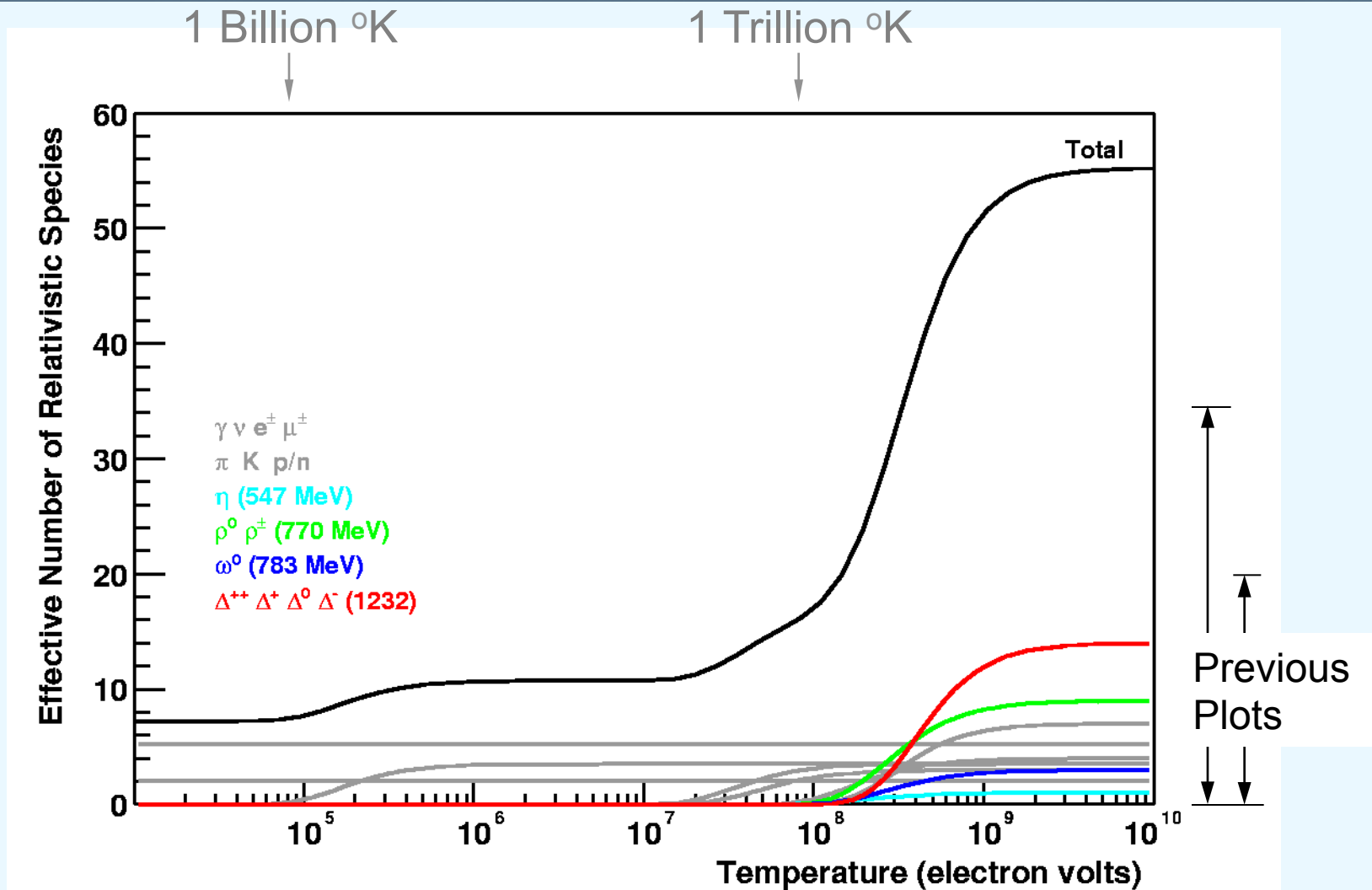
Start with light particles, no strong nuclear force

Particle Production



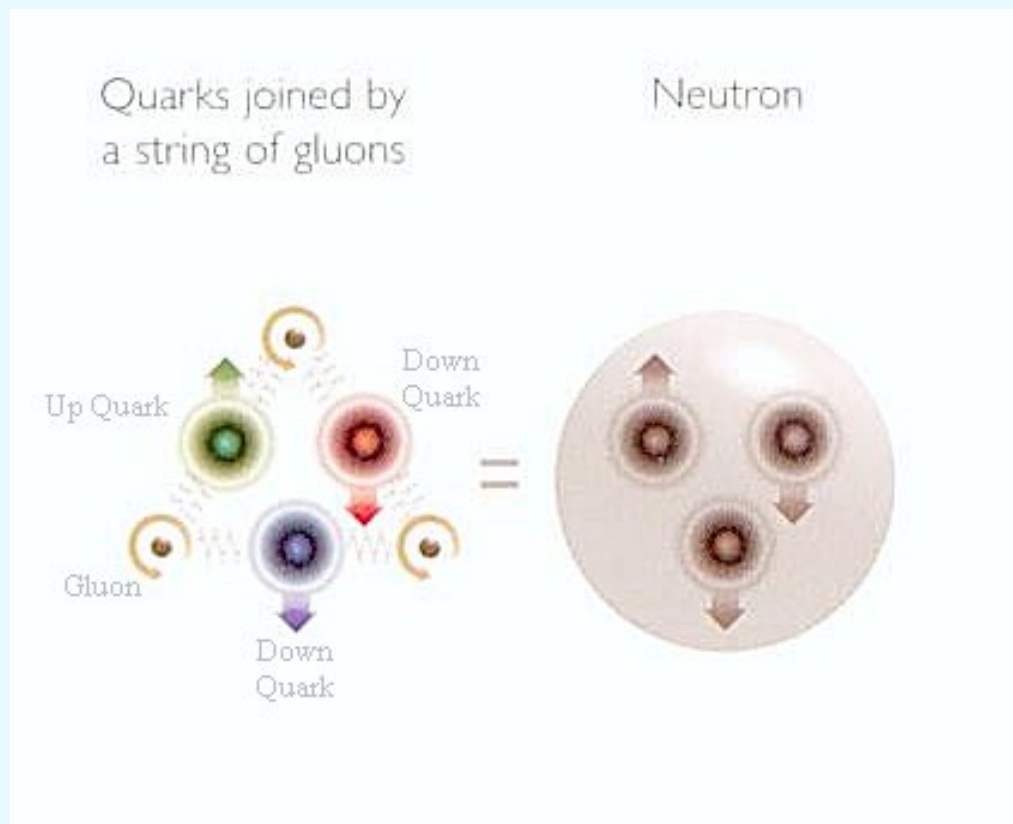
Now add *hadrons* = feel strong nuclear force

Particle Production



Keep adding more hadrons....

Hadrons and their Masses

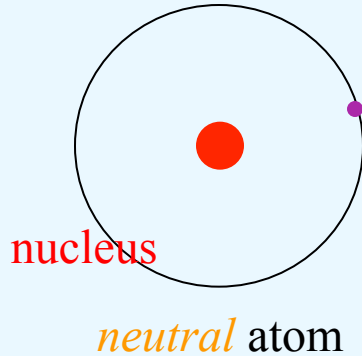


Theory:
Quantum
Chromo
Dynamics

The fundamental problem: how is baryonic mass generated
Based on quark interactions ($5+10+10 \neq 935 \text{ MeV}/c^2$) ?

Analogies and differences between QED and QCD

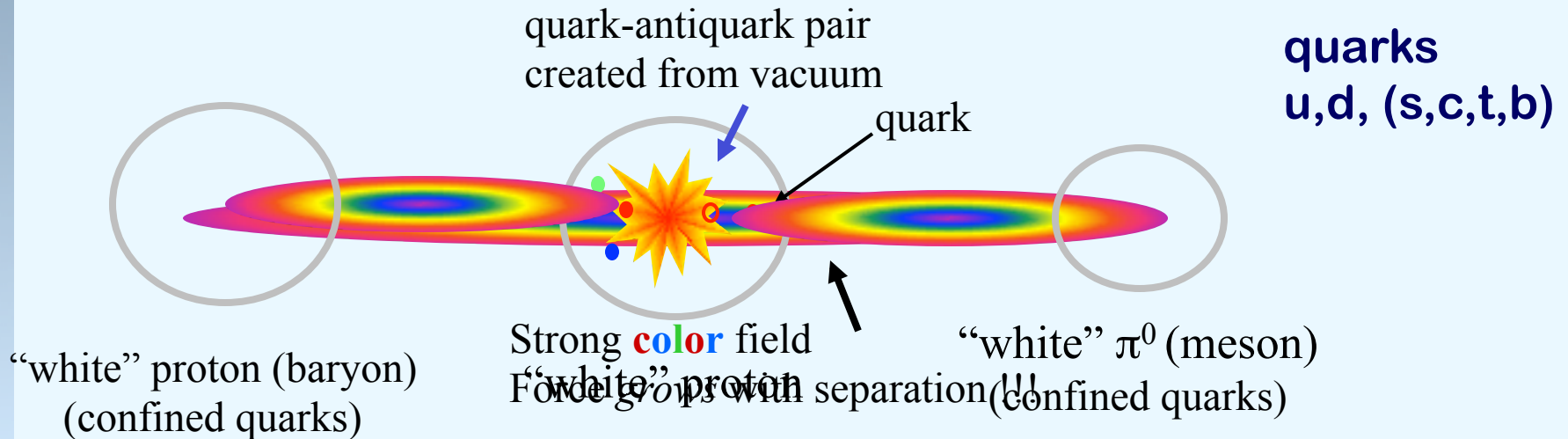
to study structure of an atom...



electron

...separate constituents

Confinement: fundamental & crucial (but *not* understood!) feature of strong force
 - colored objects (quarks) have ∞ energy in normal vacuum



High Energy and Heavy Ion Physics

High energy physics: Study of the constituents of matter and the nature of interactions between them. Study single processes

Accelerator: $e^+ + e^-$, $p+p$, anti- $p + p$, ...

Heavy ion physics: Study collective effects and medium properties of nuclear matter

Accelerator: $A+A$, reference data are $p+p$, $p+A$,...

The main features of Quantum Chromodynamics (QCD)

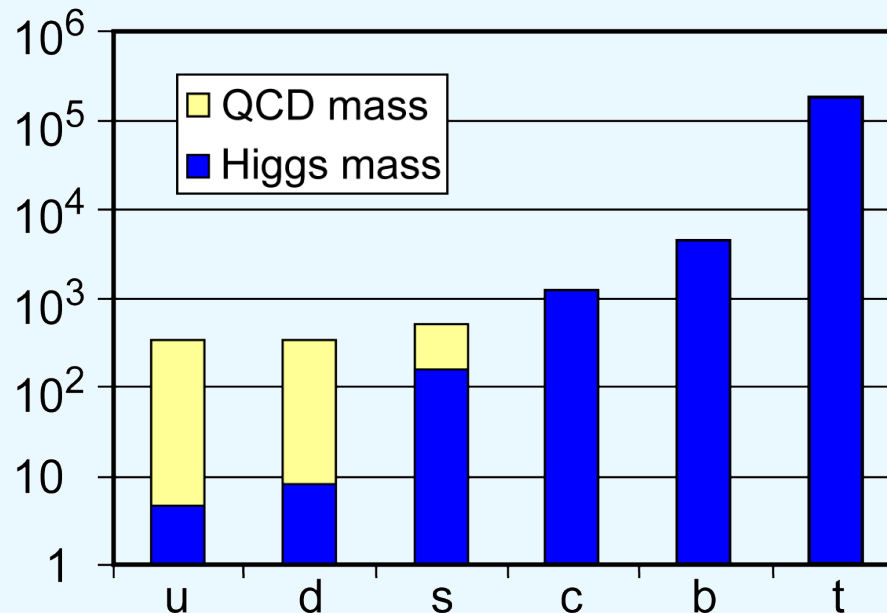
- **Confinement**
 - At large distances the effective coupling between quarks is large, resulting in confinement.
 - Free quarks are not observed in nature.
- **Asymptotic freedom**
 - At short distances the effective coupling between quarks decreases logarithmically.
 - Under such conditions quarks and gluons appear to be quasi-free.
- **(Hidden) chiral symmetry**
 - Connected with the quark masses
 - When confined quarks have a large dynamical mass – constituent mass
 - In the small coupling limit (some) quarks have small mass – current mass

Hadron Mass

In vacuum:

- asymptotically free quarks have current mass
- confined quarks have constituent mass
- baryonic mass is sum of valence quark constituent masses

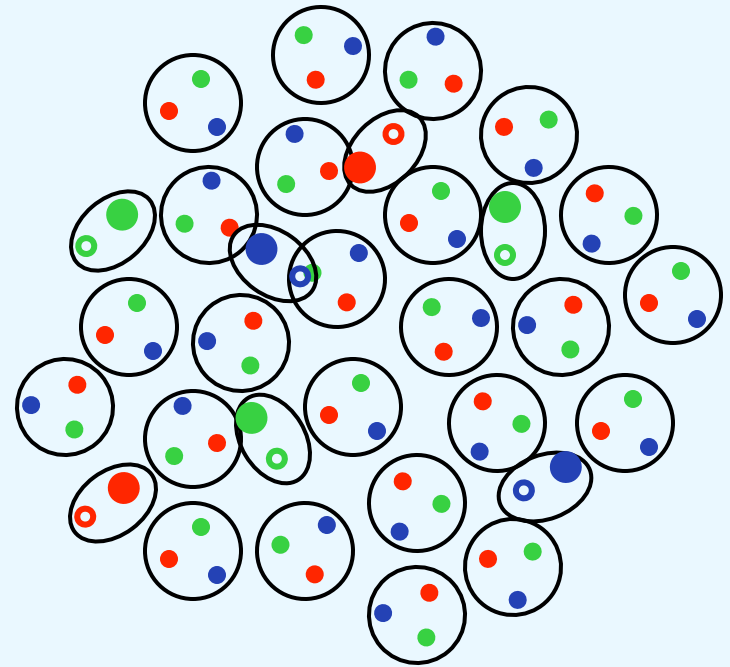
Masses can be computed as a function of the evolving coupling Strength or the 'level of asymptotic freedom', i.e. dynamic masses.



Generating a Deconfined State

Present understanding of
Quantum Chromodynamics (QCD)

- heating
 - compression
- *deconfined matter!*

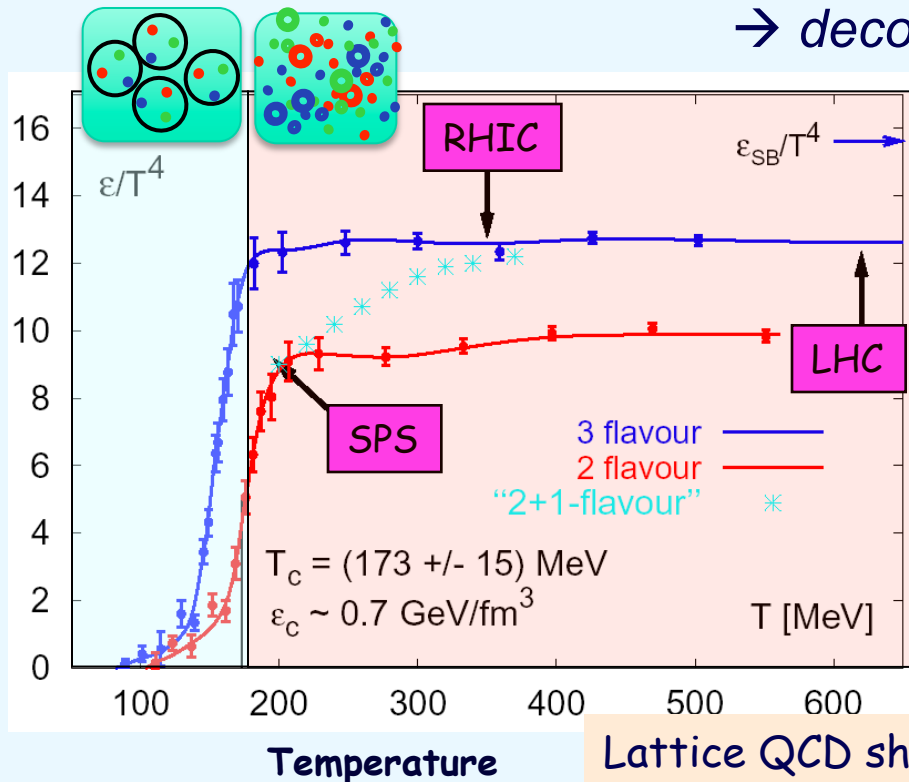


Quark-Gluon Plasma
(deconfined!)

Generating a deconfined state (QGP)

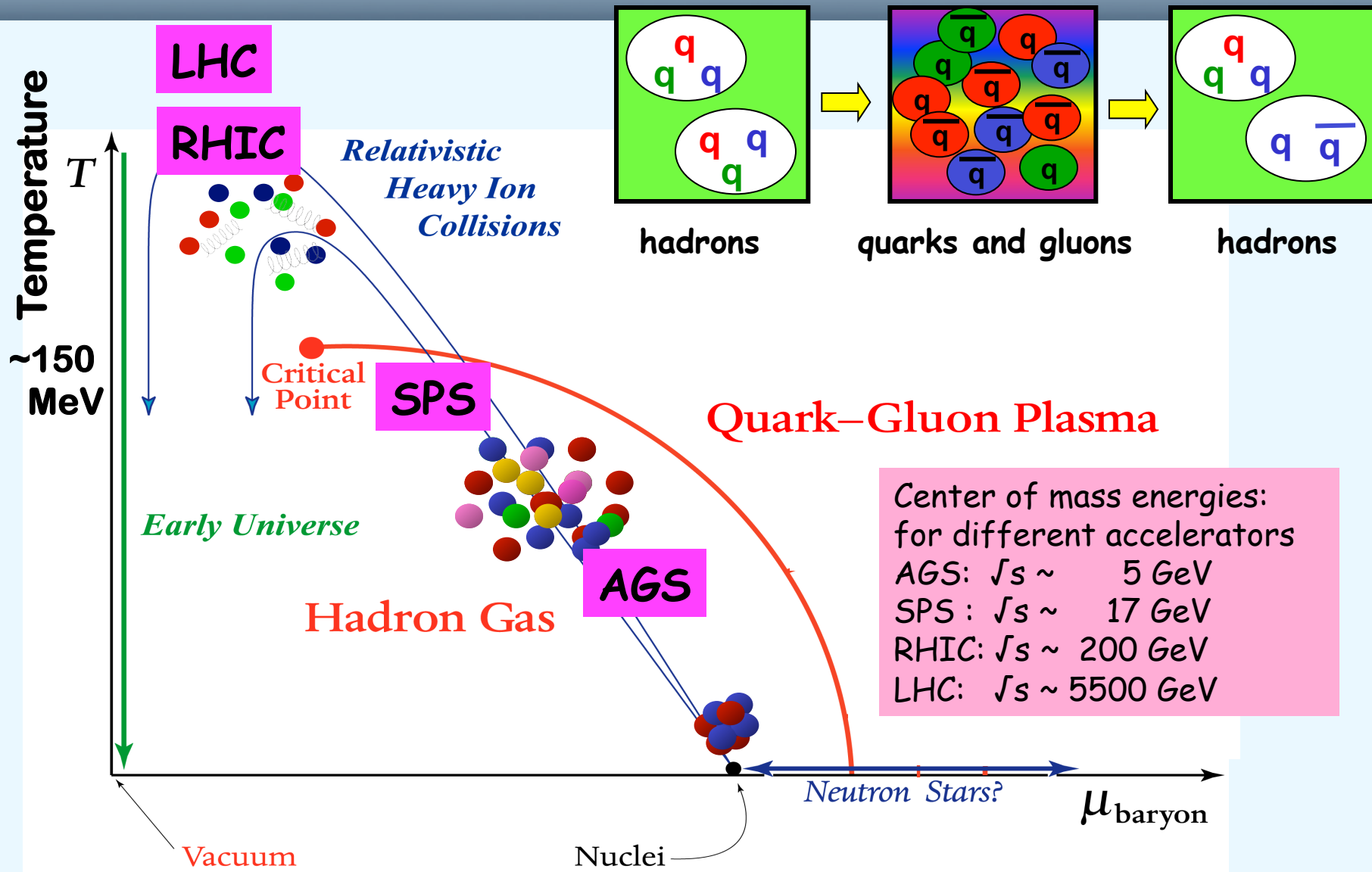
Present understanding of
Quantum Chromodynamics (QCD)

- heating + compression
- *deconfined matter !*

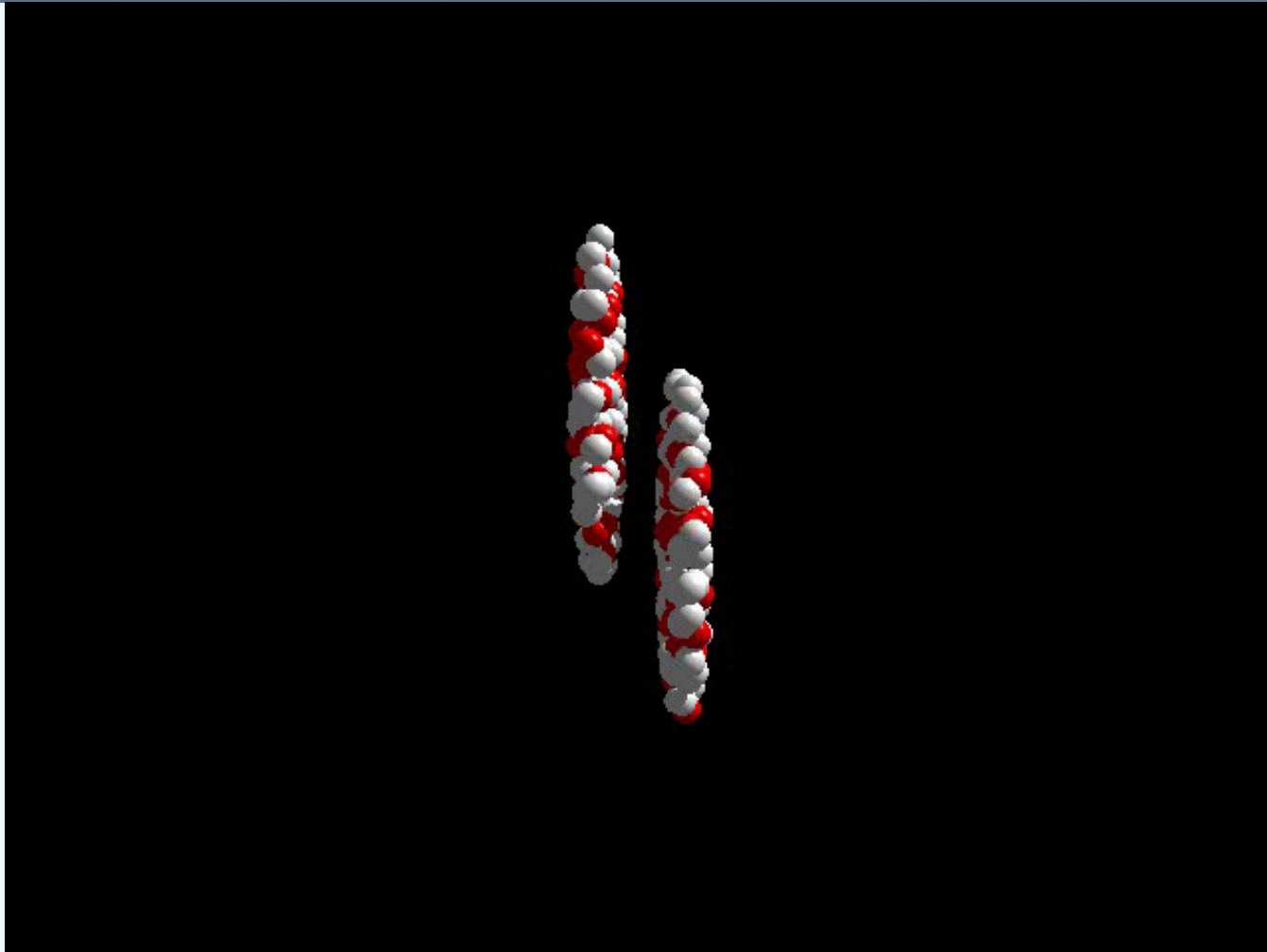


Lattice QCD shows a rapid increase in the entropy associated with the deconfinement of quarks and gluons.
→ Critical temperature (phase transition) $T_c = 173 \text{ MeV}$

Phase Diagram of Nuclear Matter

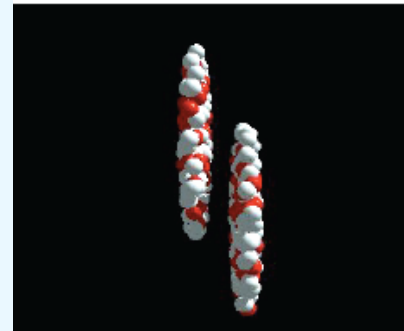
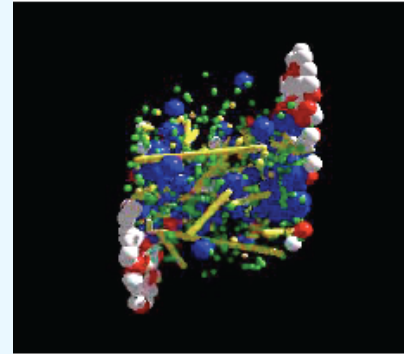
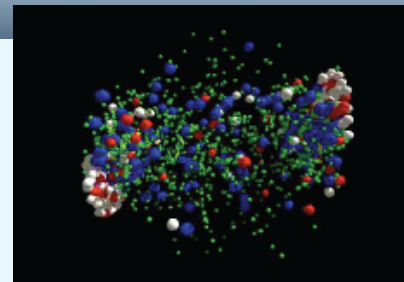
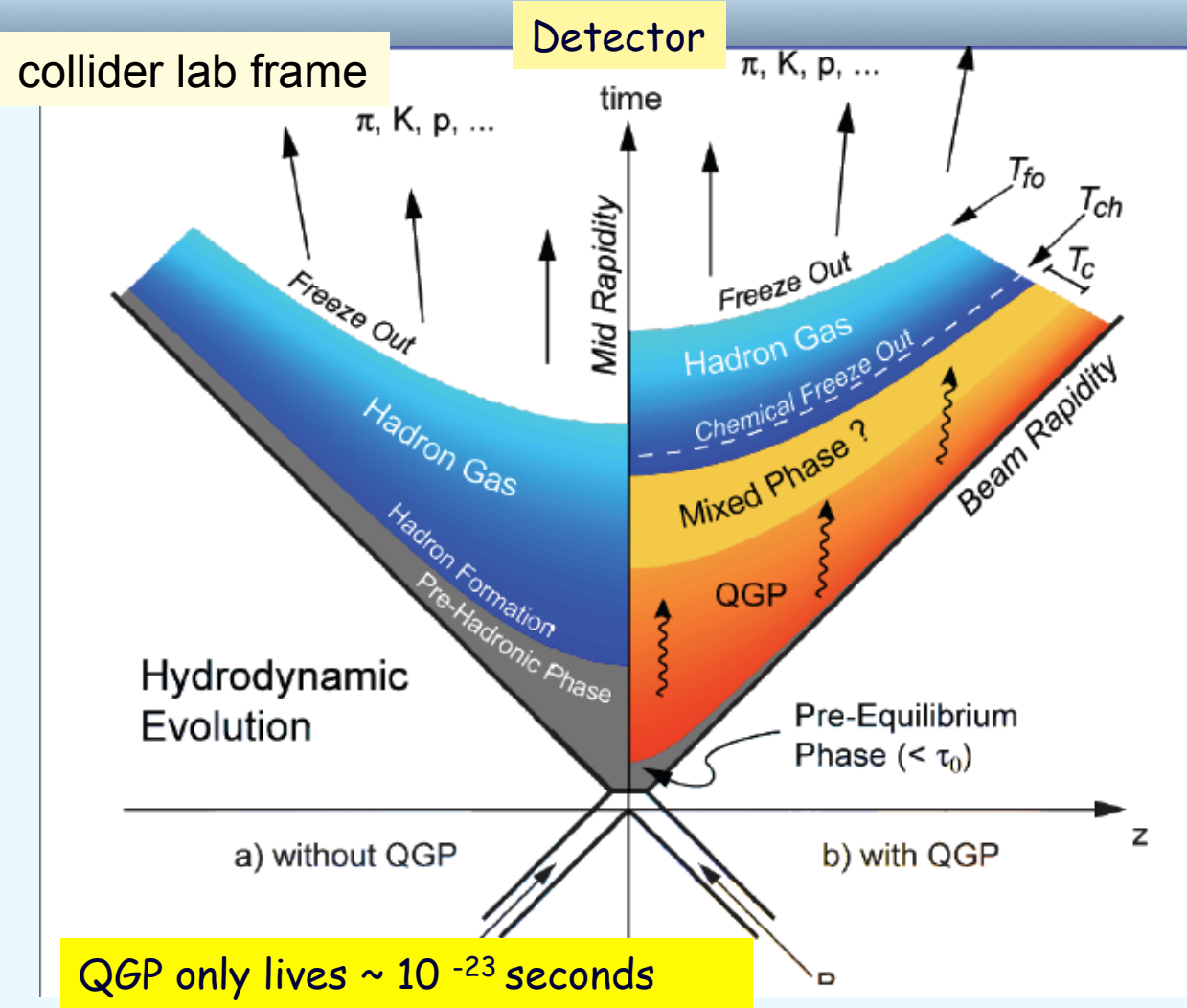


Study all phases of a heavy ion collision



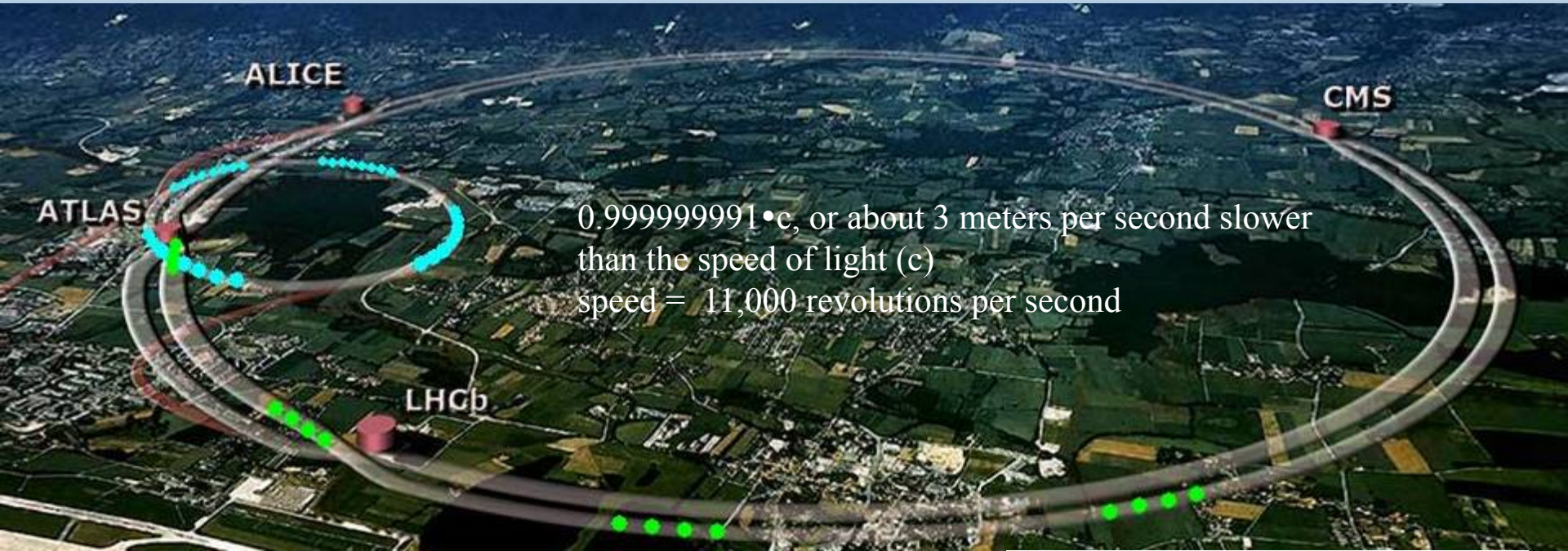
If the Quark Gluon Plasma was formed, it will only live for 10^{-23} s !!!!
Nuclei are so thin because of velocity = nearly speed of light

Phase transition in collisions (time vs space)



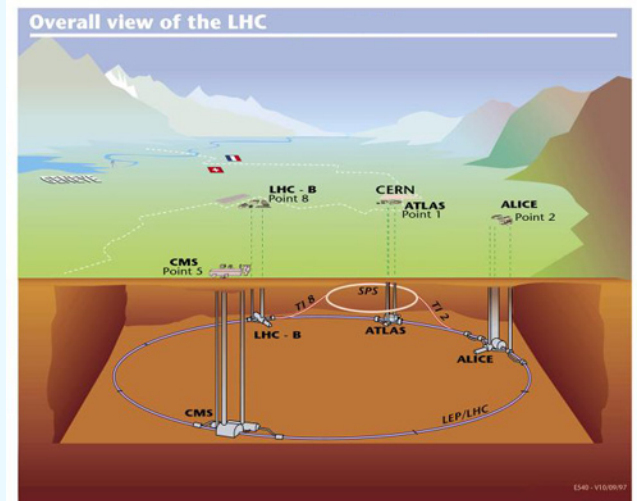
Chemical freeze-out ($T_{ch} \leq T_c$): inelastic scattering ceases
 Kinetic freeze-out ($T_{fo} \leq T_{ch}$): elastic scattering ceases

Large Hadron Collider (LHC)



$0.999999991 \cdot c$, or about 3 meters per second slower than the speed of light (c)
speed = 11,000 revolutions per second

- 27 km circumference,
- 50-175 m underground
- $p+p$ collisions: $\sqrt{s} = 0.9, 2.36, 2.76, 7, 14$ TeV
- $Pb+Pb$ collisions: $\sqrt{s}_{NN} = 2.76, 5.5$ TeV
 - 1 month per year (November 2010, 2011...)



ALICE detector

