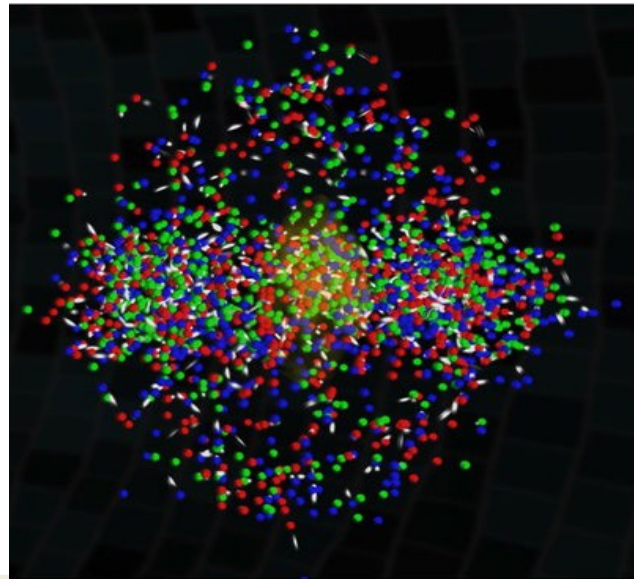


THE FIRST FEW MICROSECONDS

From the early universe to
the present day



Steven A. Murphy & Jens Oltmanns



Outline

- Motivation
- RHIC
- Results
- Nowadays



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1 - Motivation



“In the beginning there was nothing, which exploded.”

- Terry Pratchett

Recreating the situation in the first microseconds of the universe

Mixture of quarks, gluons, electrons, photons and other particles

Mixture at huge temperatures (10^{12}°C), density and pressure



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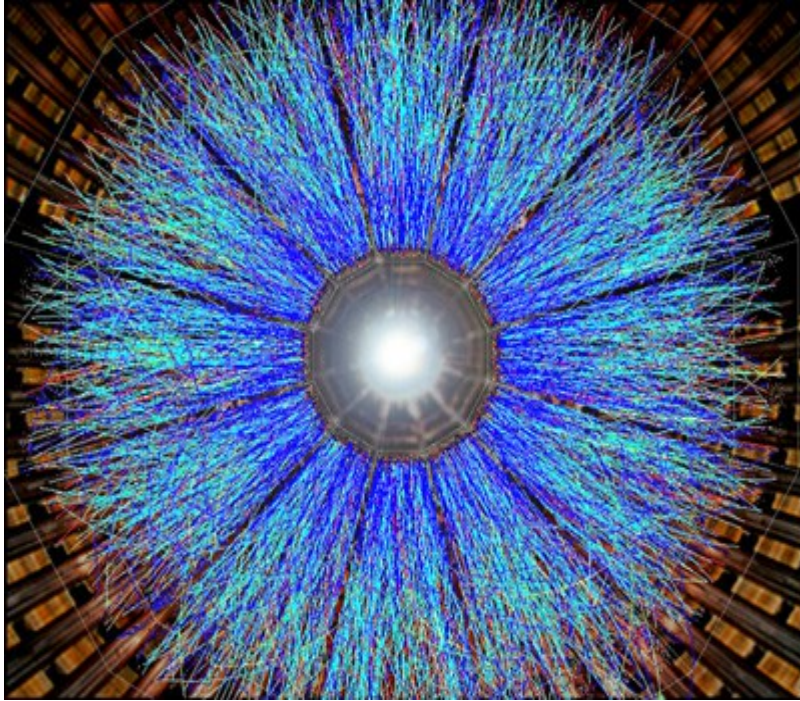


Chronology of the early universe

Time after the Big Bang	Phase	Temperature
0	Birth of the universe	
10^{-43}s	Quantum gravity era	10^{32}°C
10^{-35}s	Exponential expands era	10^{28}°C
10^{-11}s	Electroweak era	10^{15}°C
10^{-6}s	Quarks bound in hadrons	10^{12}°C
100s	Formation of nuclei	10^9°C
380000y	First neutral atoms	2700°C



Quark-Gluon Plasma



Quarks and gluons are not bound in hadrons, but building a quark-gluon plasma

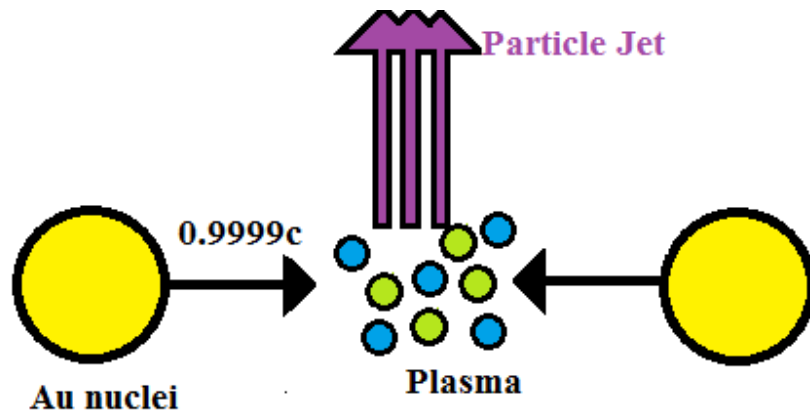
Quarks and gluons asymptotic free at short distances

Short distances are associated with high energies

High temperatures and high density result in a quark-gluon plasma



2 - Creating Quark-Gluon Plasma



Centre of Mass energy
from **7 - 200 GeV**

Generated from RHIC (Relativistic Heavy Ion Collider) Experiment - first collider experiment

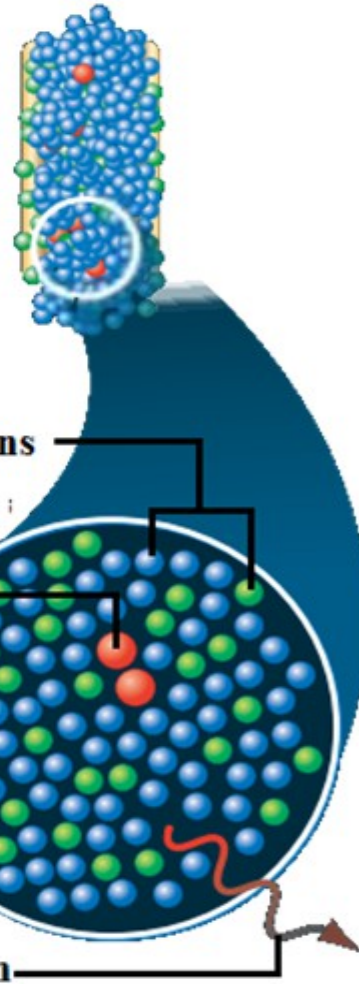
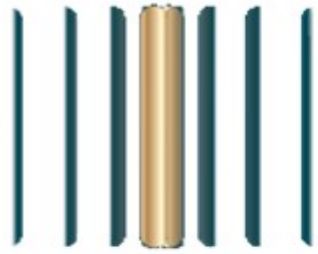
Accelerates heavy nuclei (such as gold) to 99.99% of the speed of light

Collision results in creation of "mini-bangs" - big bangs on a much smaller scale!

Probes the first 10 microseconds of the universe (the "confinement era")



Gold nuclei colliding
(flattened due to relativity)



Quarks/ gluons

Charm/ Bottom quarks

Photon

Particles from gold nuclei collide, producing high energy region of quarks and gluons



Plasma forms after 10-23s



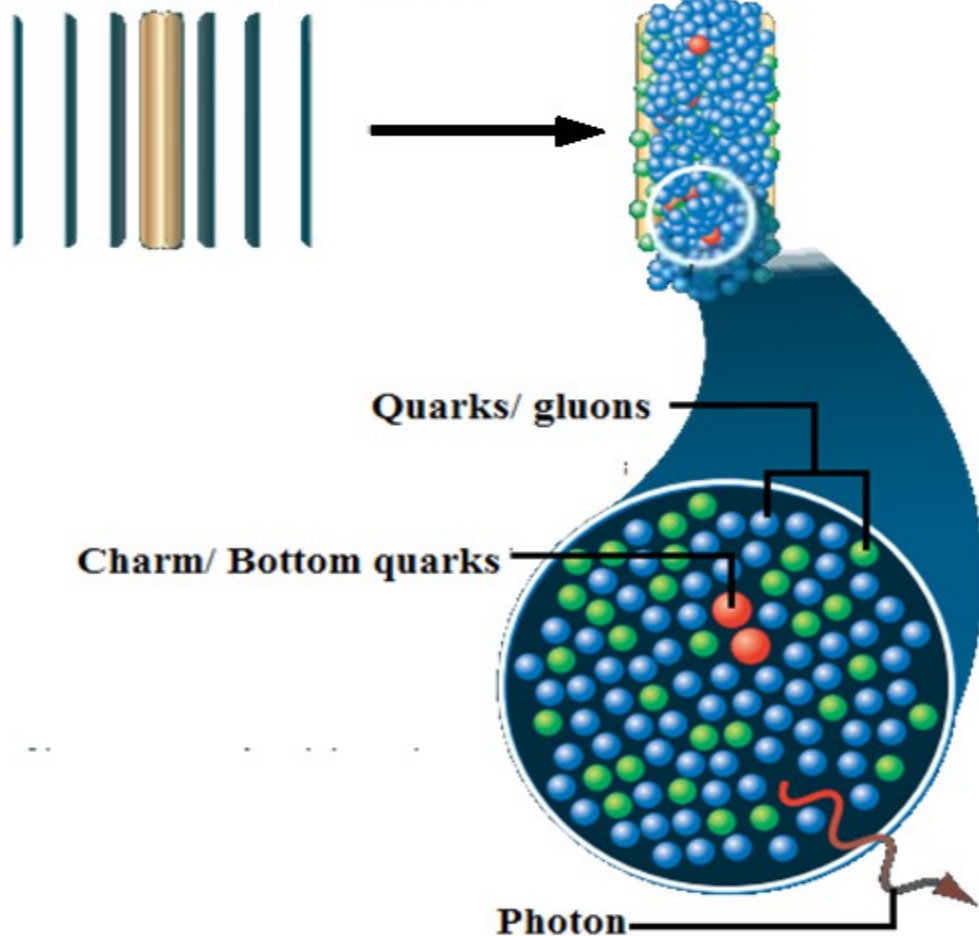
High density of free quarks and gluons that interact rapidly(!)



Can produce heavy quarks/ mesons e.g. J/ψ and $Y(4s)$, which can be detected



Gold nuclei colliding
(flattened due to relativity)



Medium expansion and collisions reduce energy



After 5×10^{-23} s, hadronisation occurs (also detected), so confinement occurs

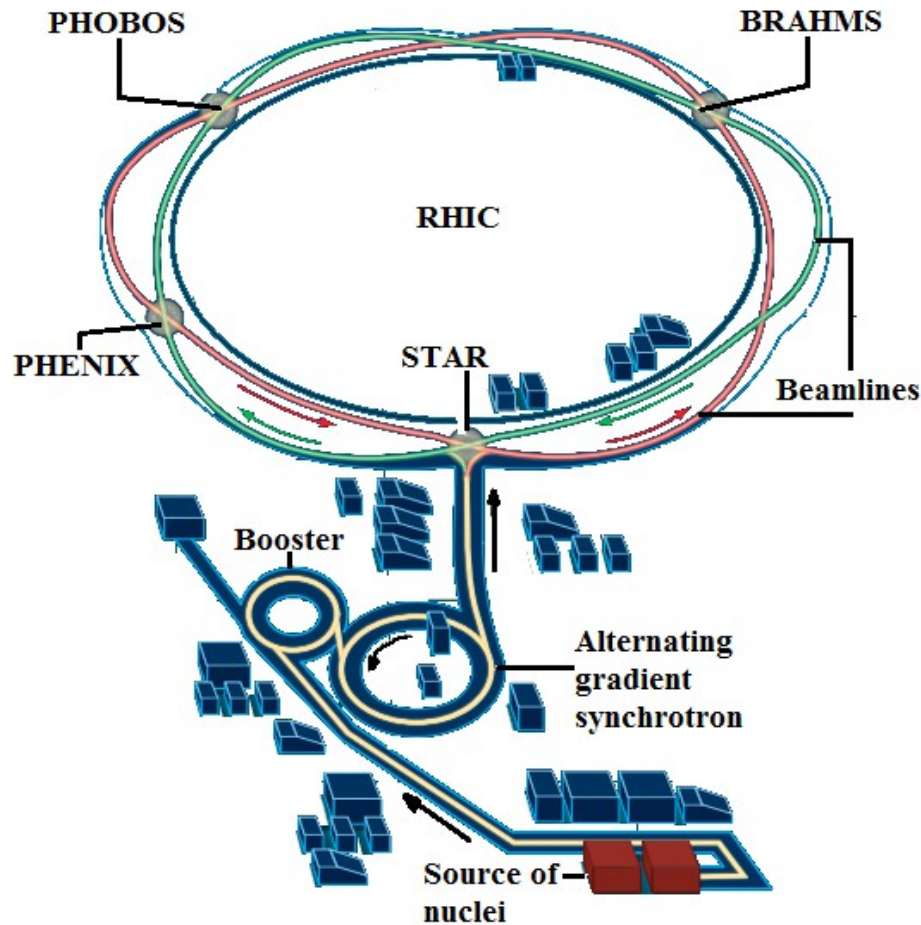


No more free quark-gluon region



How Does The Experiment Work?

2 crossing rings so the accelerated nuclei collide



STAR: Forms 3D picture of charged particles

PHENIX: Detects particles produced early in mini-bangs (B, D mesons)

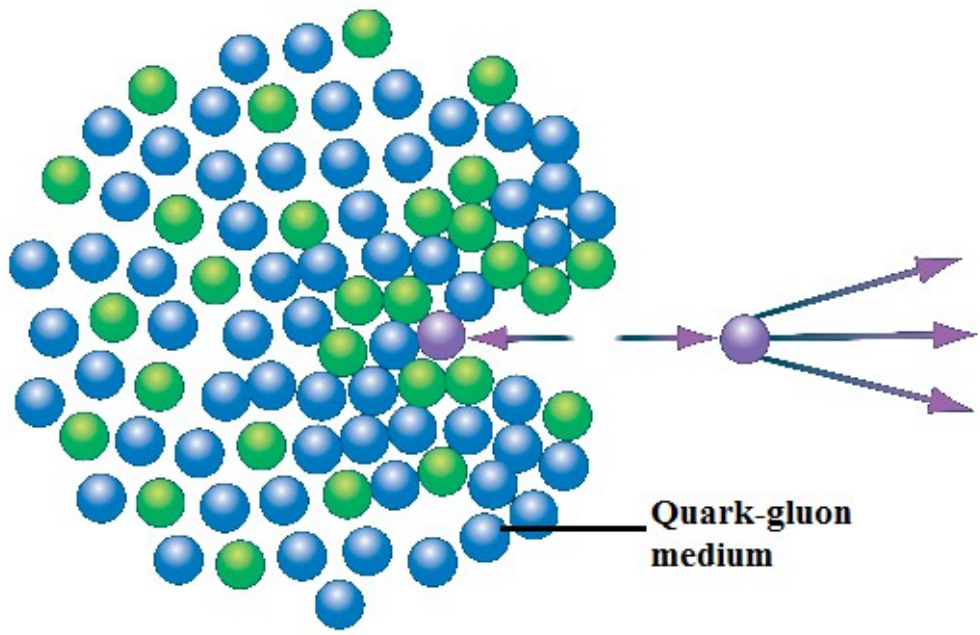
PHOBOS: Finds correlations of particles in a wide angular range

BRAHMS: Finds remnants of proton/ neutrons close to colliding nuclei



Quark-gluon medium is a LIQUID, not a plasma

Evidence 1: Jet quenching



Quark/ gluon from an interaction rebounds into quark-gluon medium



Particle is absorbed in medium



On average, only one jet seen, so closely packed region

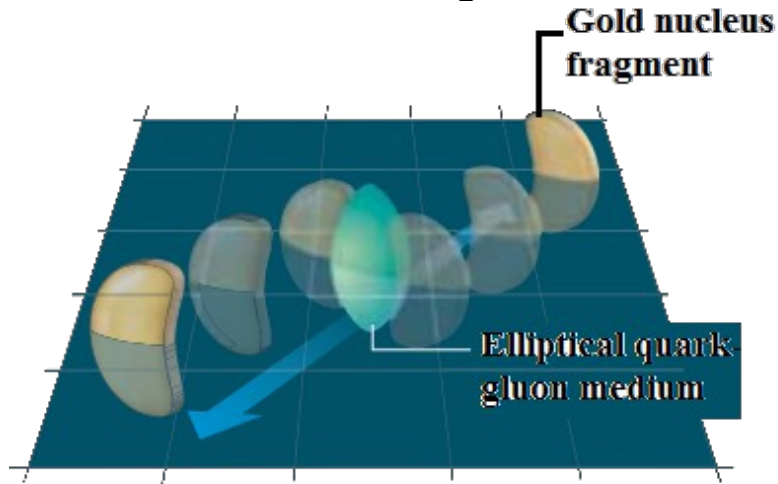


Quarks & gluons are closely packed!



Quark-gluon medium is a LIQUID, not a plasma

Evidence 2: Elliptic Flow



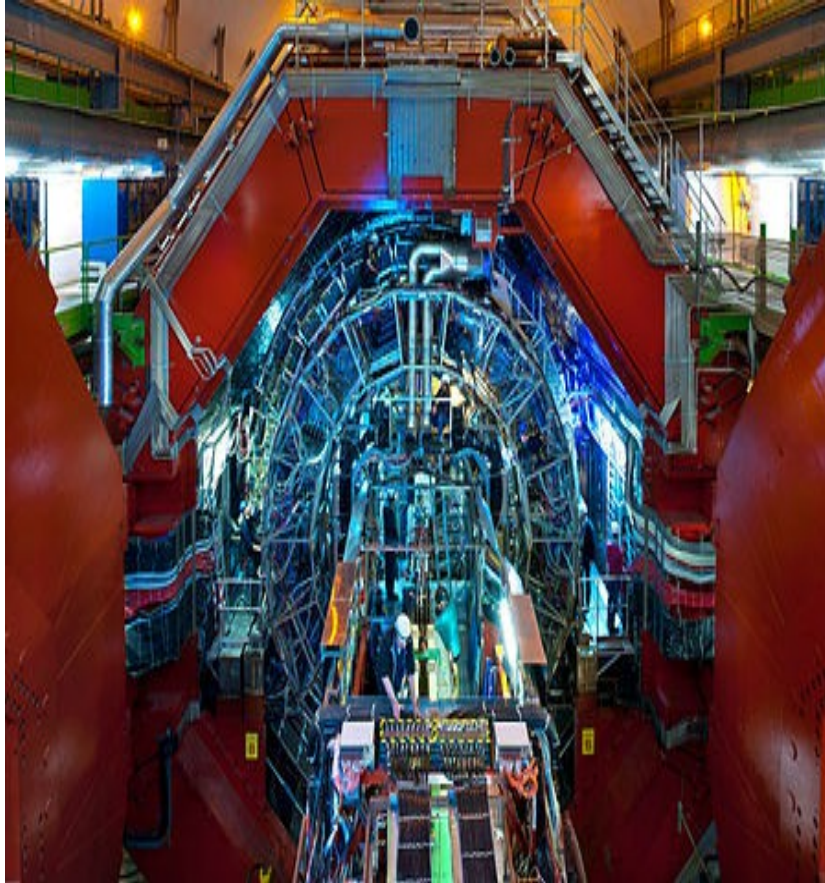
Off-centre collisions
produce elliptical
regions

Pressure gradients
imply more hadrons
ejected along
collision plane

Non-uniform emission
cannot be a gas!



4 - Nowadays



Still interesting: Lead collisions at LHC with 2.76 TeV per nucleon (575 TeV per ion)

ALICE detector specialized for ion collisions and quark-gluon plasma researches with good particle identifications at low energies

ATLAS and CMS also detecting lead collision data

Observations of the universe less than $1 \mu\text{s}$ after the Big Bang



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Thanks for your attention!



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