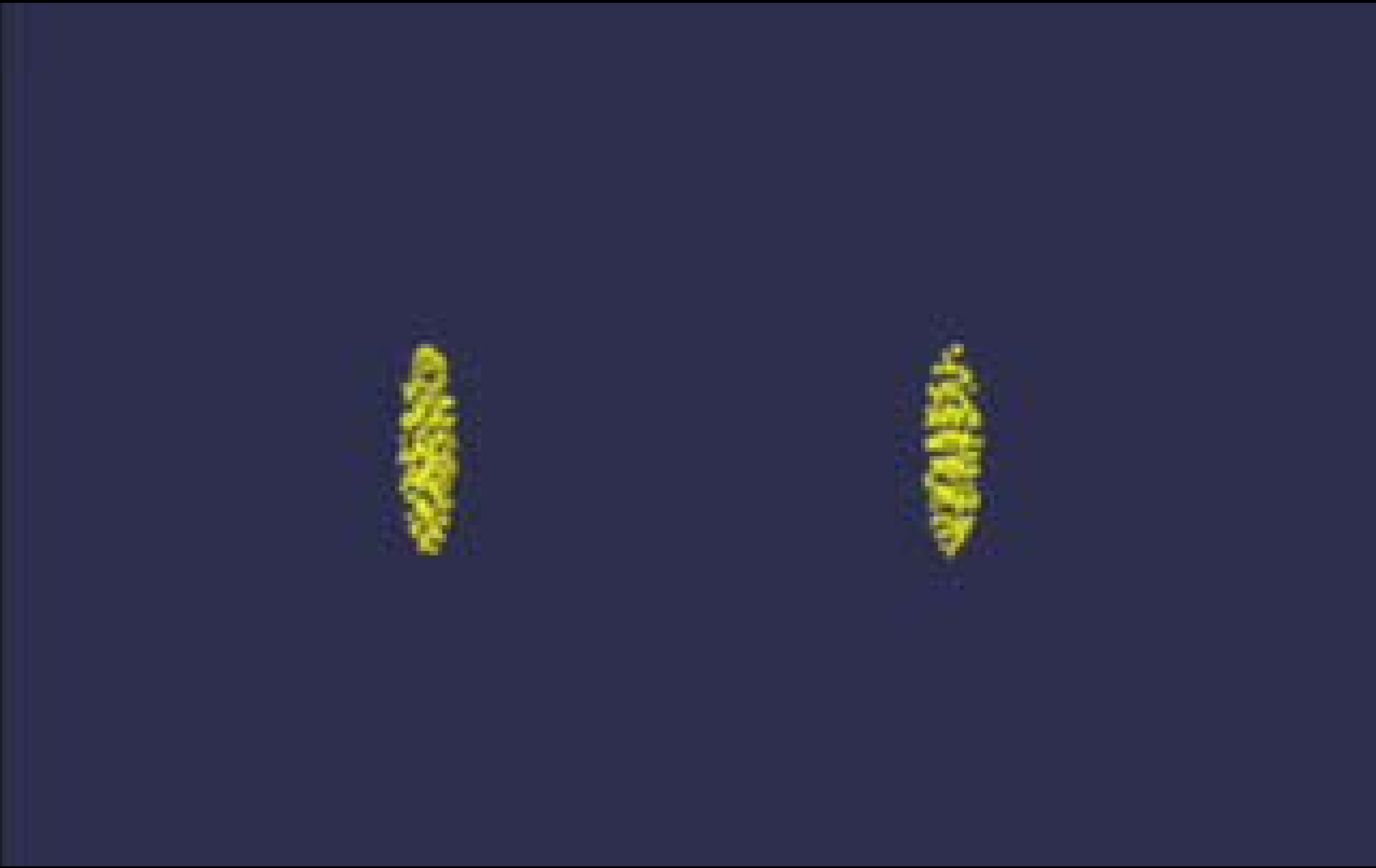
200 GeV Au+Au Collisions, RHIC at BNL

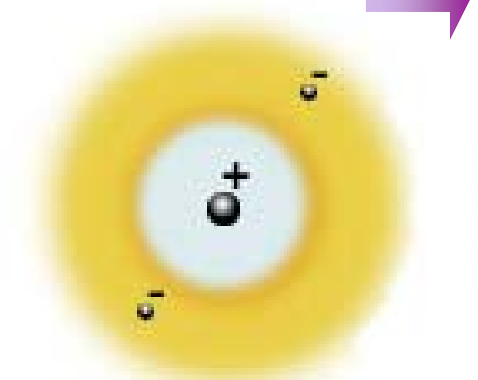


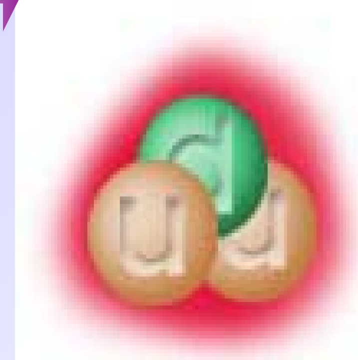
Animation by Jeffery Mitchell

Elephants in a Liquid

A Closer Look at the Nucleus

Atom → **Nucleus** → **Proton**





Atom: positive nucleus and negatively charged electron cloud

Ion = Atom stripped of electrons

Nucleus: nucleons = protons and neutrons

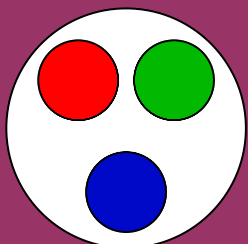
Nucleon: partons = quarks and gluons

- arises from fundamental strong force
  - acts on color charge of **quarks**

Interactions described by theory of Quantum-Chromo-Dynamics (QCD)

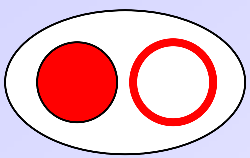
Particles

hadrons



baryons

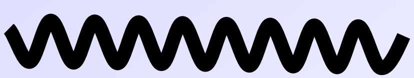
protons,
neutrons



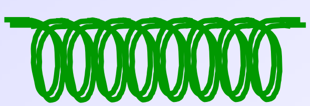
mesons

pions,
kaons

**Bound states,
no free quarks
observed**



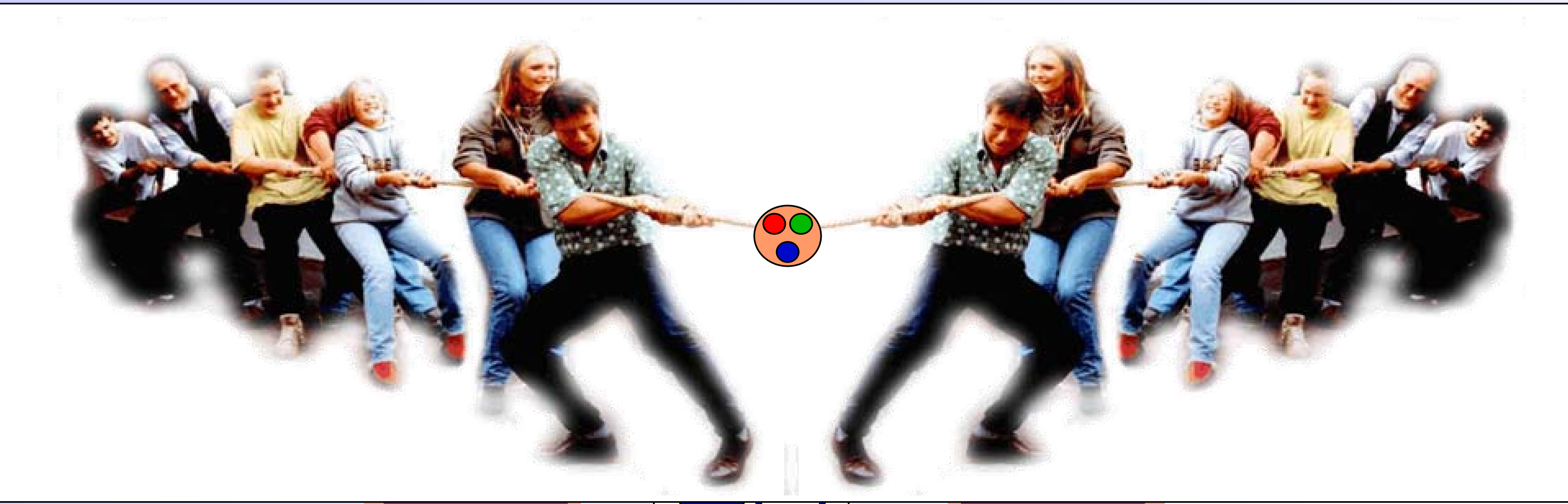
photons

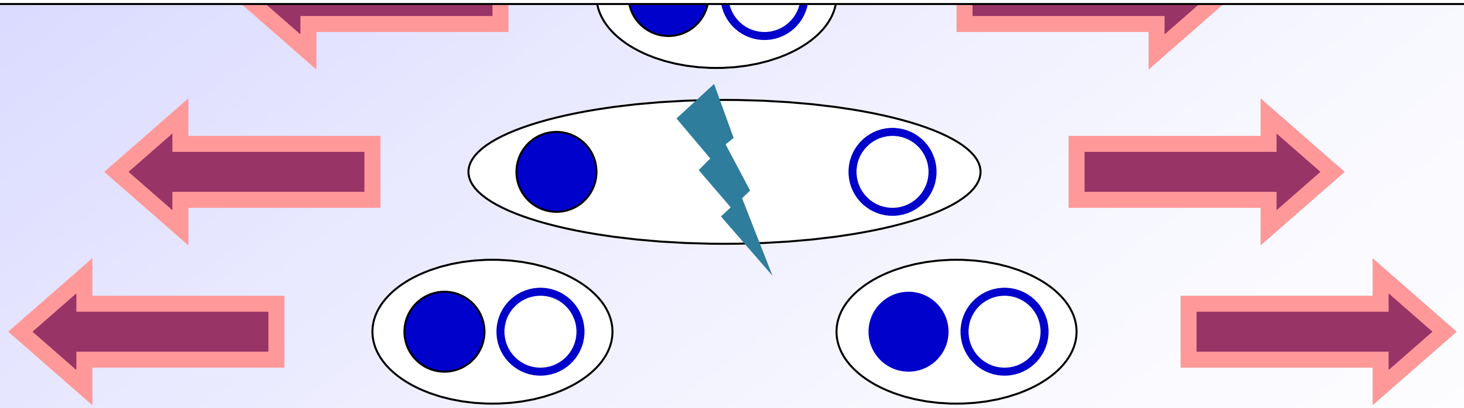


gluons

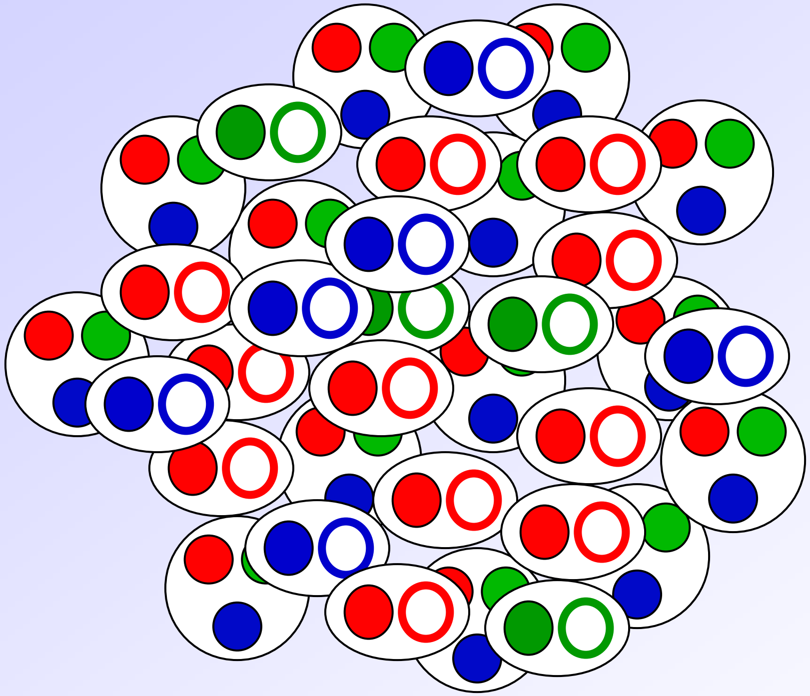
Confinement – Quarks are not “free”

The Strong Nuclear Force





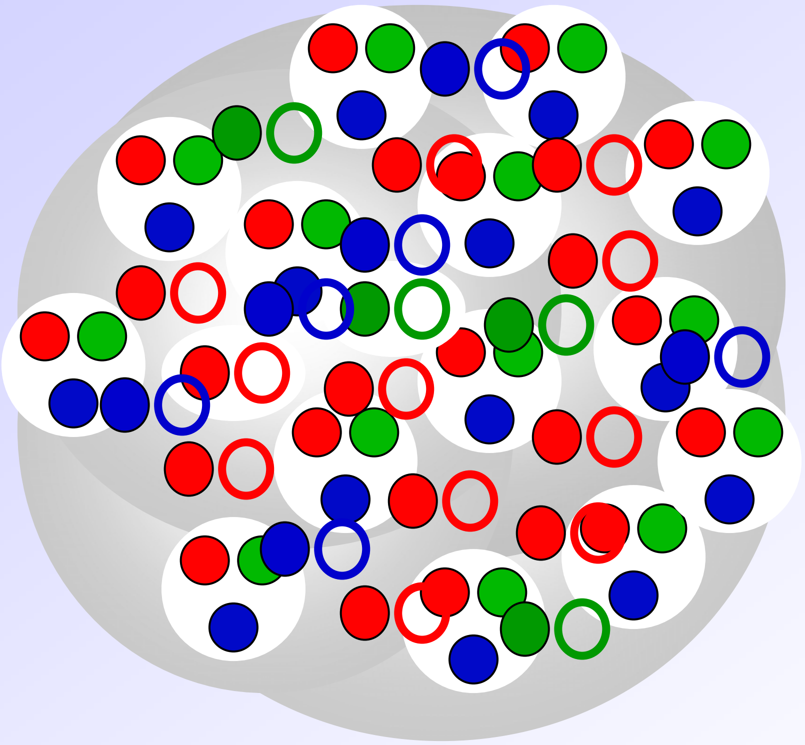
Deconfinement



Au+Au = 197 + 197 nucleons

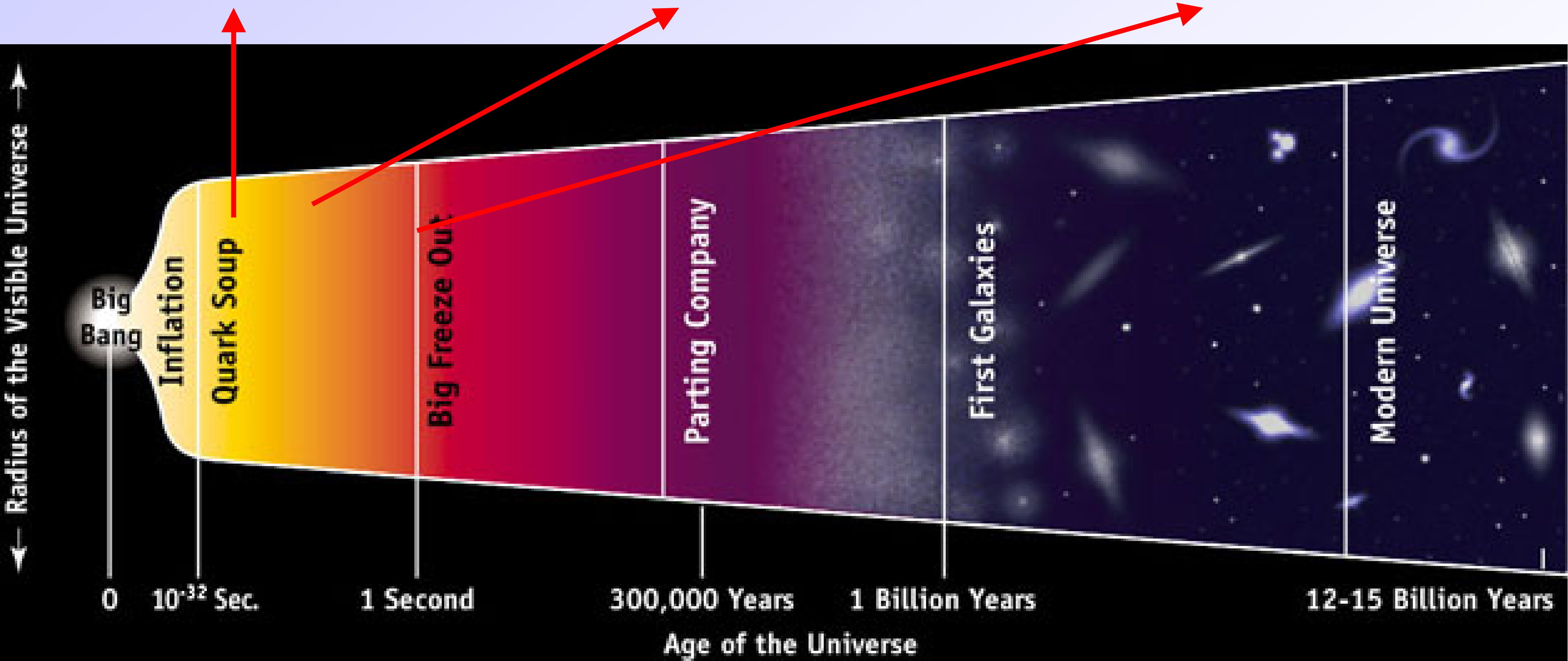
Collide at High Energy → Add pions

Deconfinement



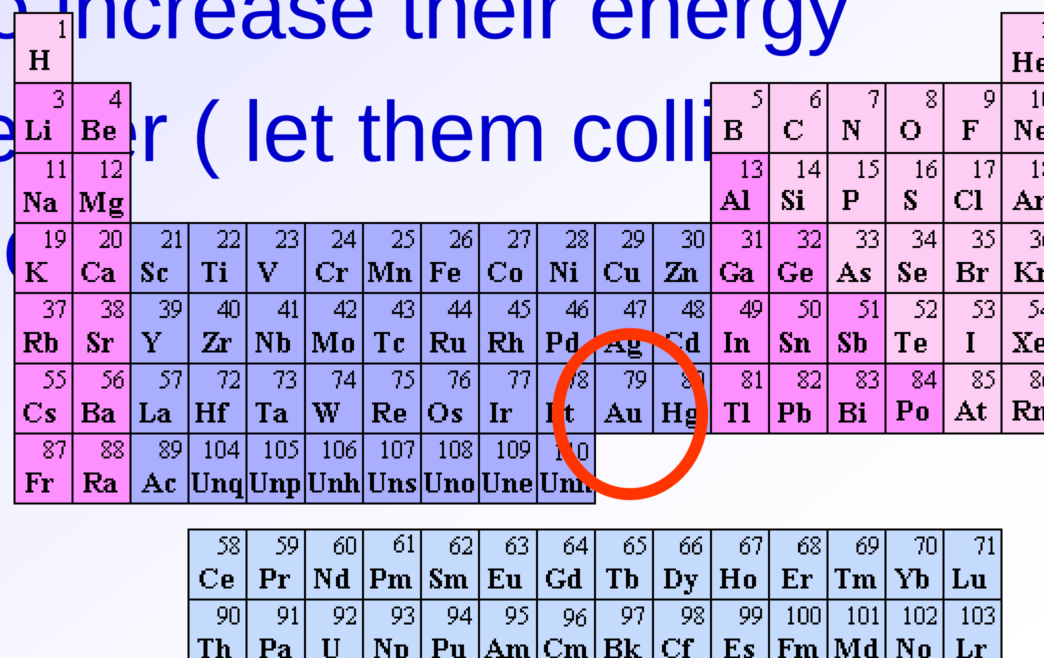
Quark Gluon Plasma

The Early Universe



Try to create QGP in Lab

- Take heavy ions
  - Au (at RHIC)
  - big atoms, many protons, gluons and quarks
- Accelerate ions to increase their energy
- Smash them toge r (let them colli
- Hope to create Q



RHIC Physics Program - Why collide Heavy Ions?

- RHIC was proposed in 1983
- One of the main emphases is study of properties of matter under extreme conditions
  - large energy densities
  - high temperatures

To achieve these conditions we collide heavy nuclei at very high energies

Why?

- To help us understand the basic building blocks of matter and their interactions
- To help us understand the early composition of our universe and its formation

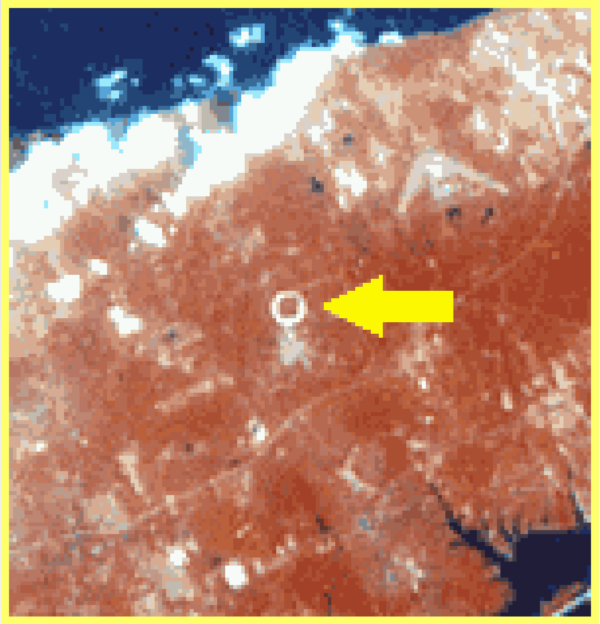
Relativistic Heavy Ion Collider

RHIC

Relativistic → Einstein's relativity $E=mc^2$, near light speed

Heavy Ion → Elements like gold,without electrons

Collider → Two ion beams hit head-on



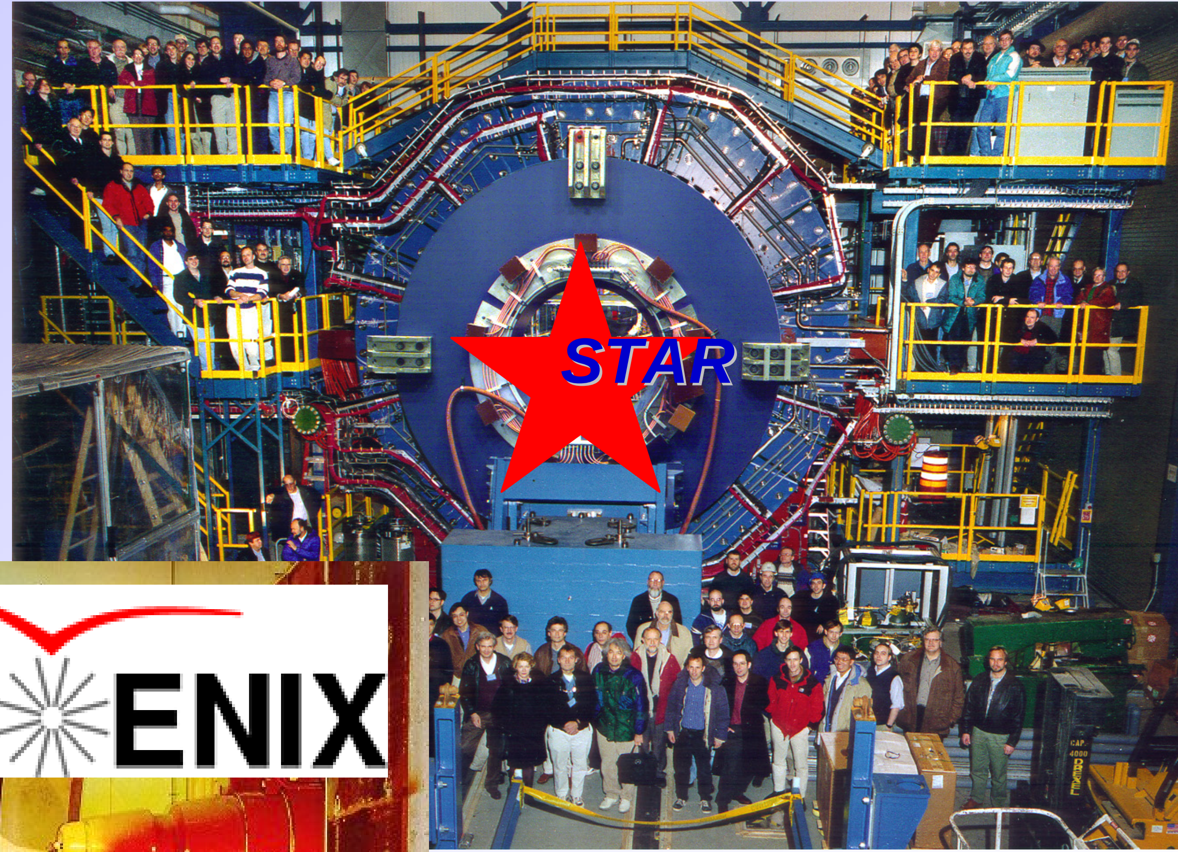
as seen by the Landsat-4 satellite…

RHIC from Space


A Virtual Tour of RHIC
2004
BROOKHAVEN
NATIONAL LABORATORY
Animation by
Jeffery Mitchell

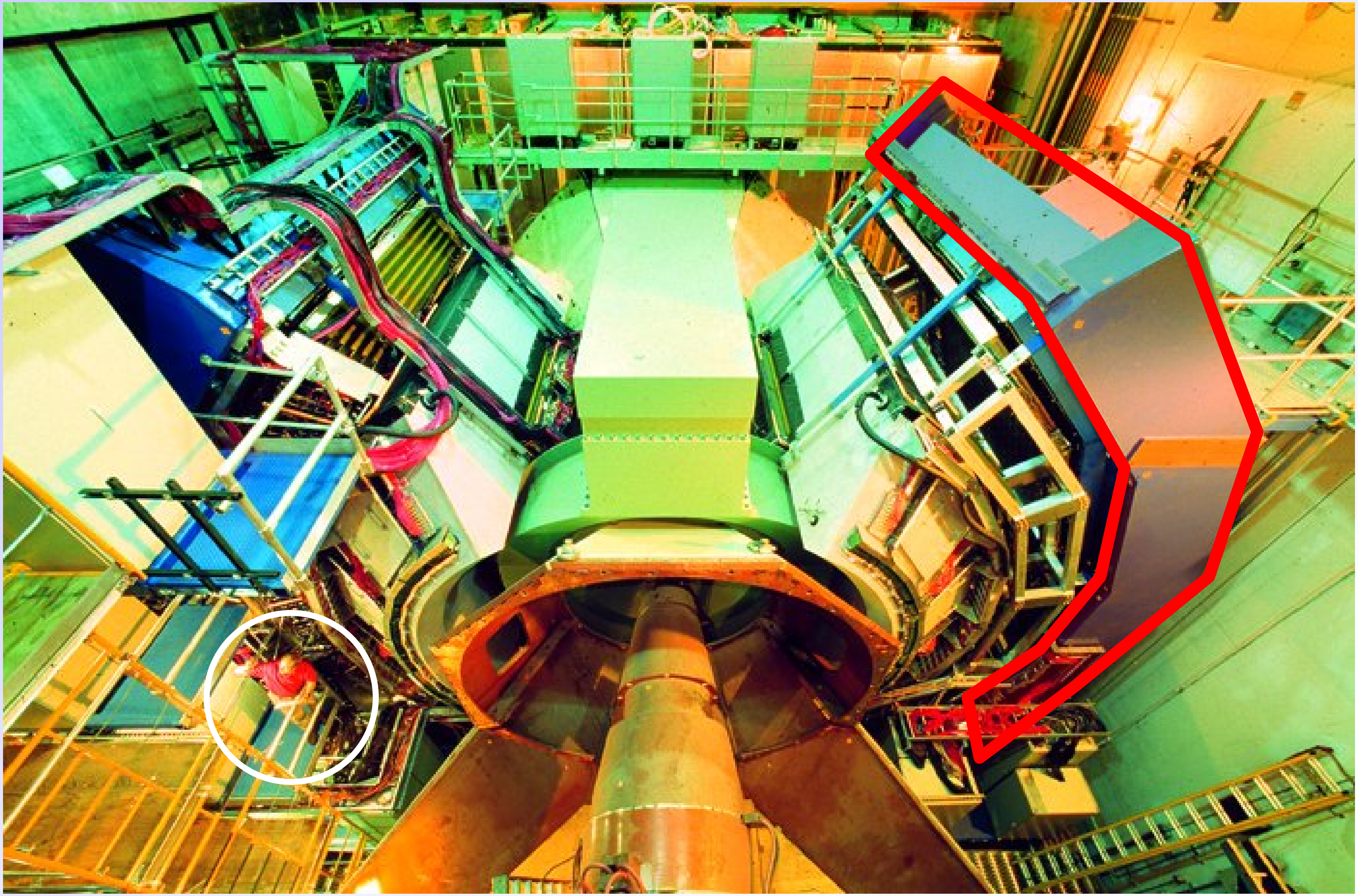
Inside the RHIC Ring

- Underground tunnel
- Super-conducting magnets cooled by liquid helium (@ 4.5 K)
- 1740 Magnets
- 2.4 Mile circumference

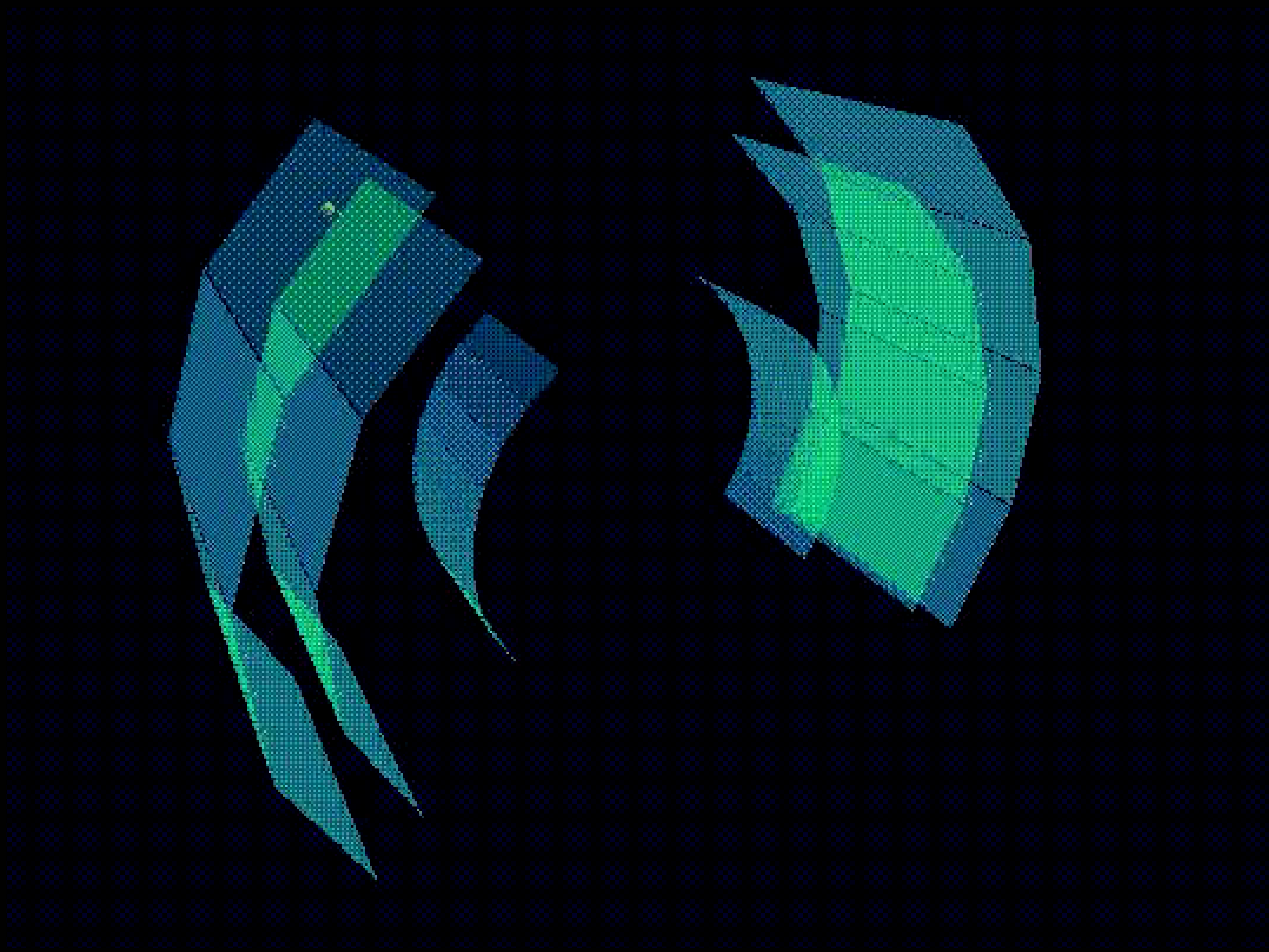


Each collaboration about 400 physicists and engineers

PHENIX

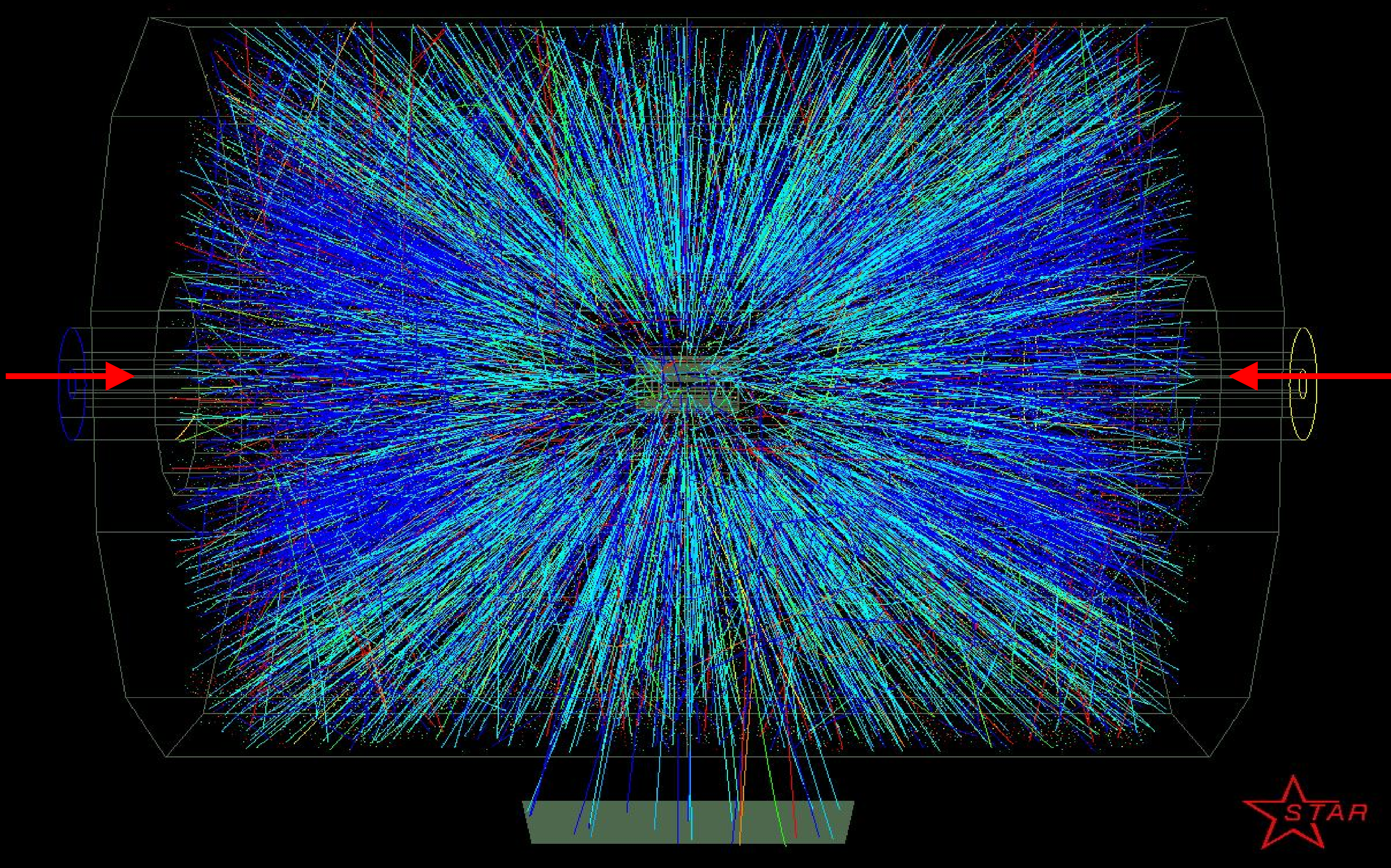


200 GeV Au+Au Collisions in the PHENIX detector



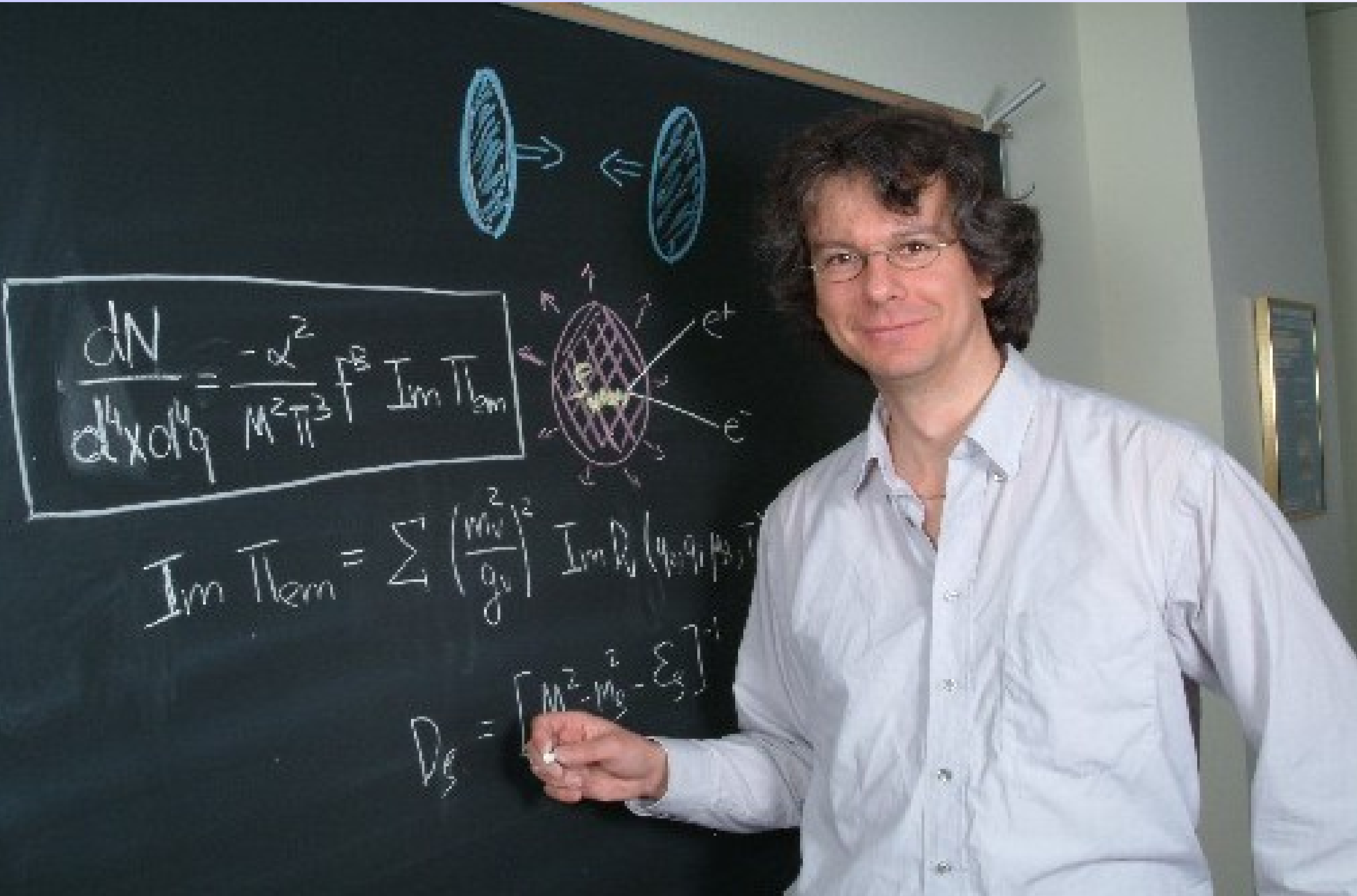
Animation by Jeffery Mitchell

Example of Au+Au collisions in collider (STAR event display)

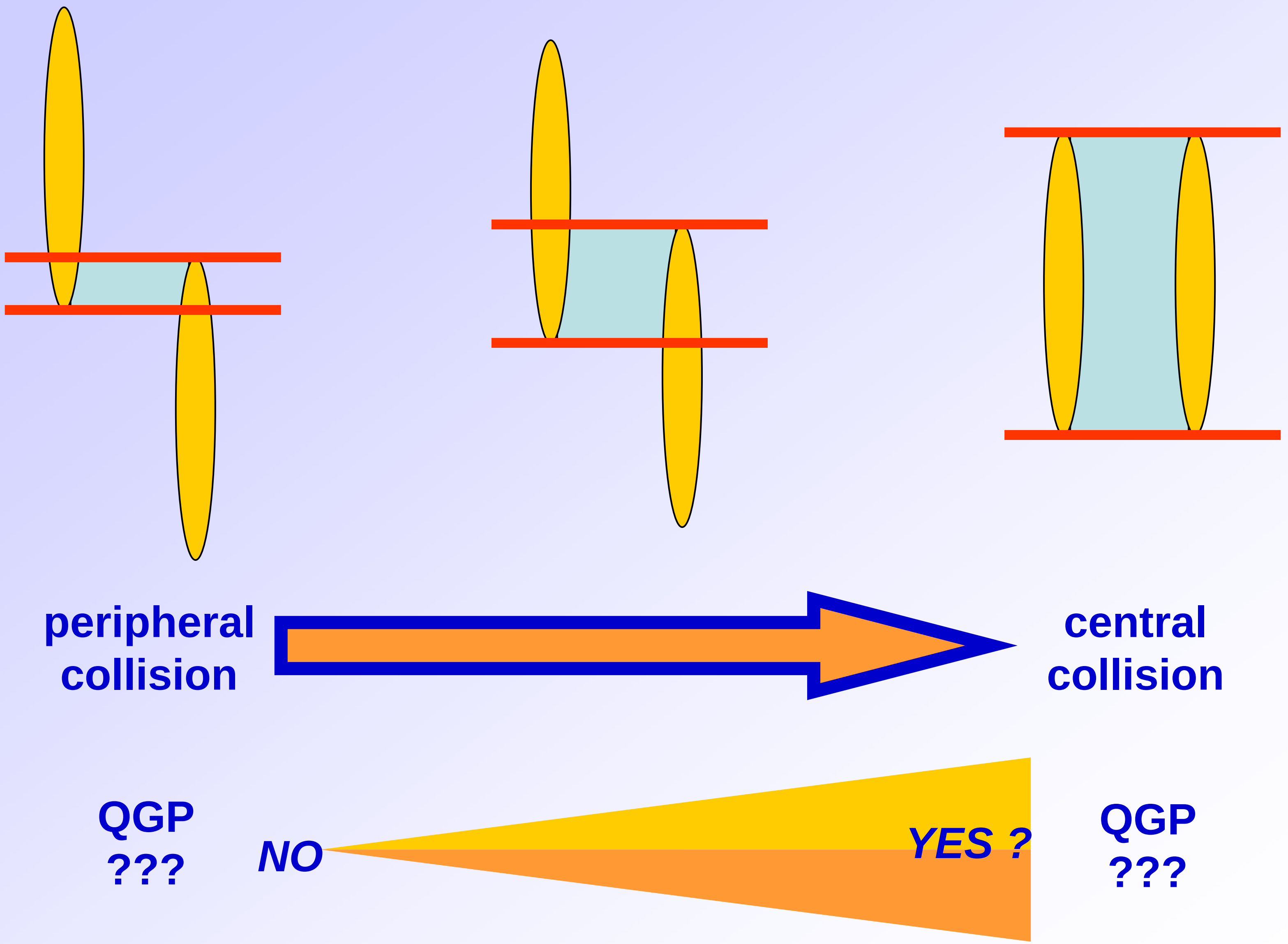


Experimentalist at work ….

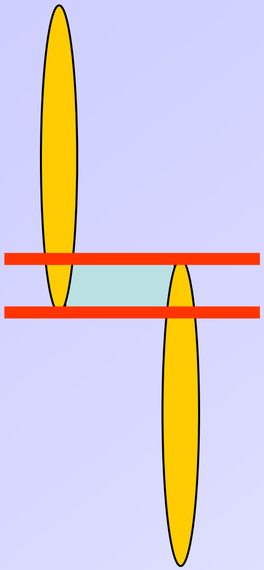
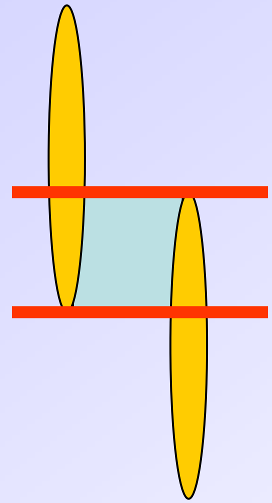
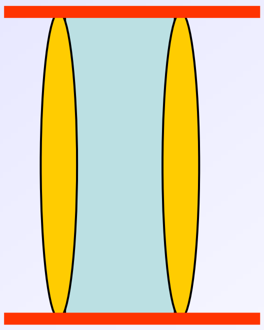
…. as opposed to a theorist working

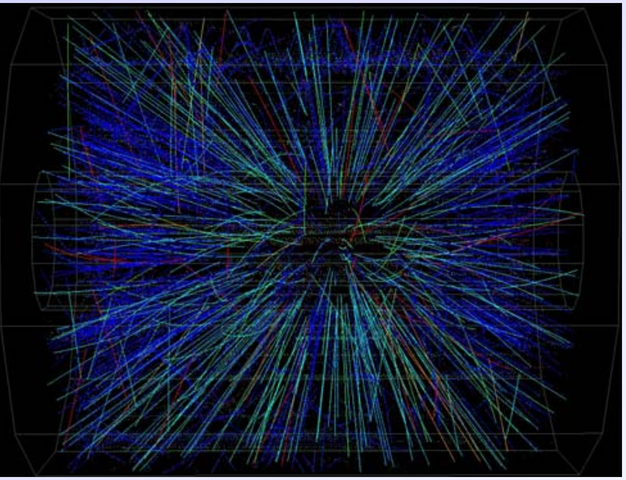
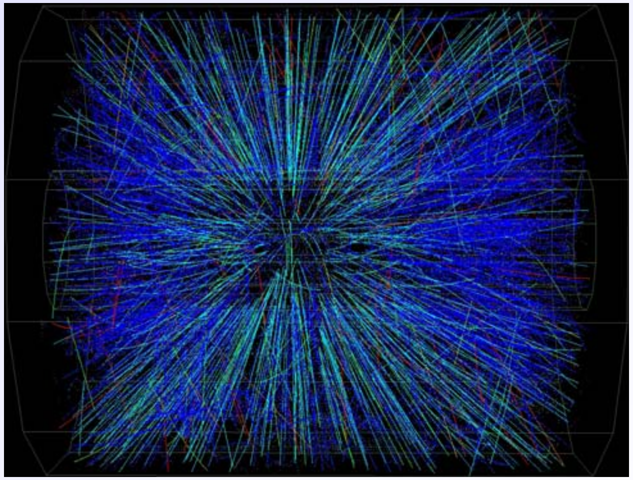
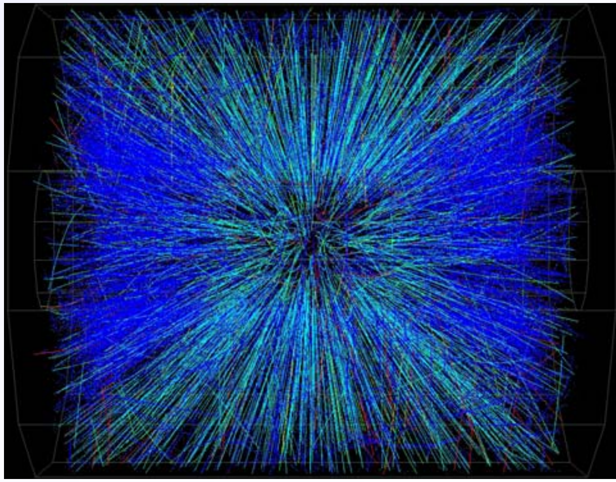


Not all collisions look the same

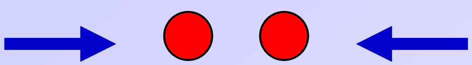


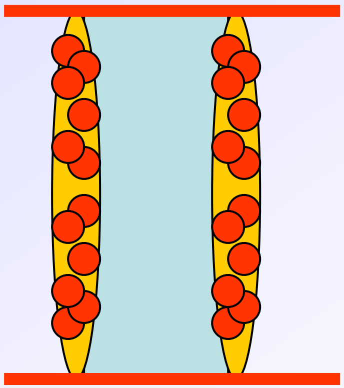
Not all collisions look the same

Not all collisions look the same





Just More ?

Just x 1000 ?

Number of particles

Number of events

central collision

QGP ???

1=

Proton-prot

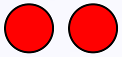
collision

QG

???

Number of particles

Number of events

X  ***- Collision***

The New York Times

At One Trillion Degrees, Even Gold Turns Into the Sloshiest Liquid

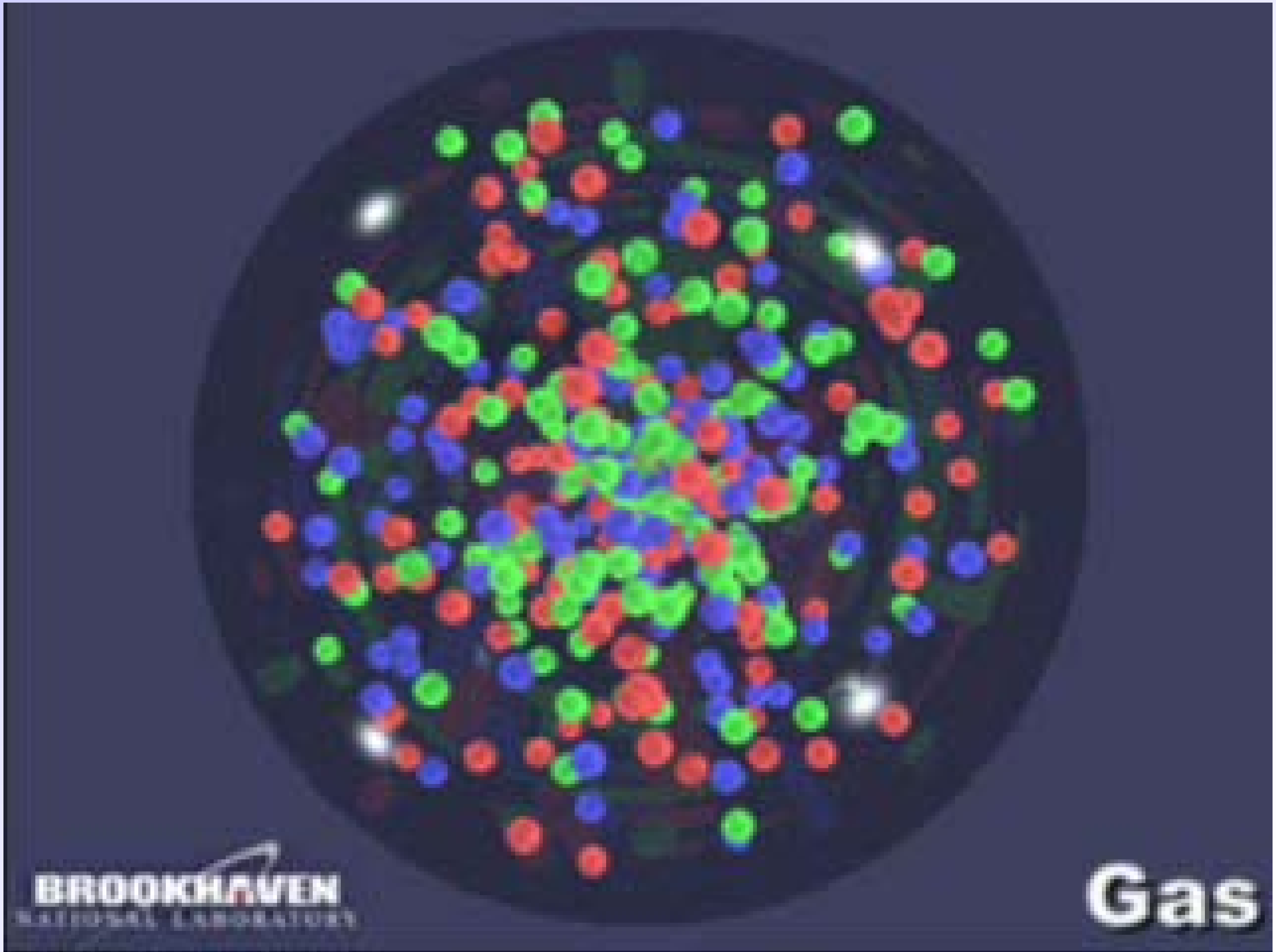
Source: New York Times
Published: 4/19/2005
Written by: Chang, Kenneth

The New York Times ON THE WEB

Scientists Report Hottest, Densest Matter Ever Observed

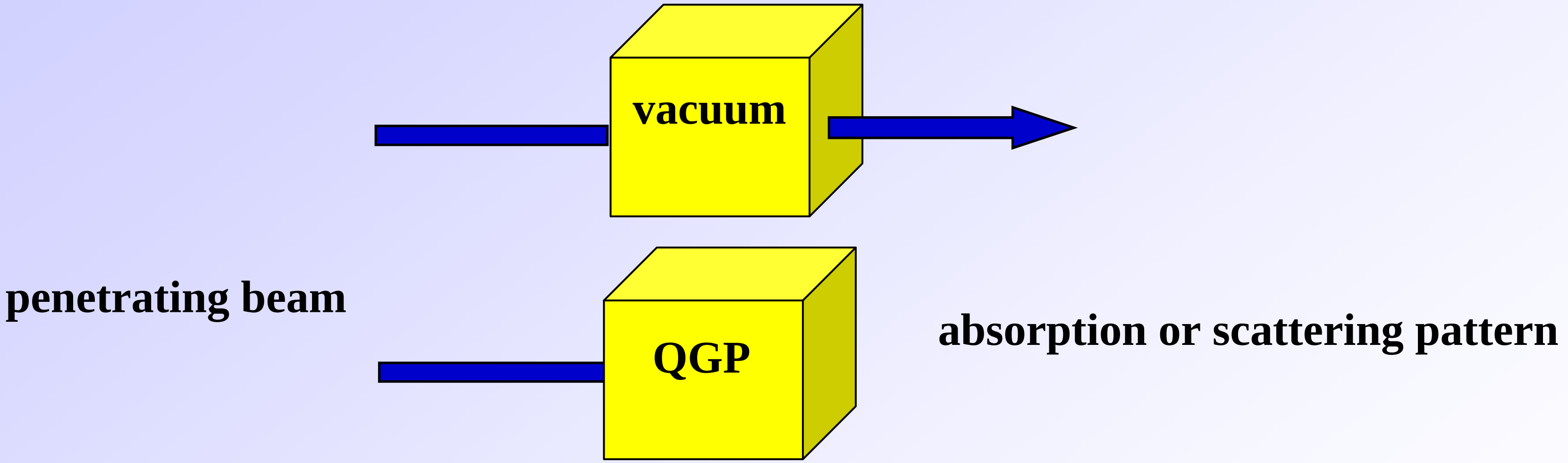
It is about a trillion degrees hot and flows like water.
Actually, it flows much better than water.
Scientists at the Brookhaven National Laboratory on Long Island announced yesterday that experiments at its Relativistic Heavy Ion Collider - RHIC, for short, and pronounced "rick" - had produced a state of matter that is unexpectedly sloshy.
"Every substance known to mankind before would evaporate and become a gas at two million, three million degrees," said Dr. Dmitri Kharzeev, a theoretical physicist at Brookhaven. "So the big surprise here is the matter created at RHIC is a liquid."

Gas vs. Liquid



How to Probe the Matter that is Produced?

Ideal Experiment:

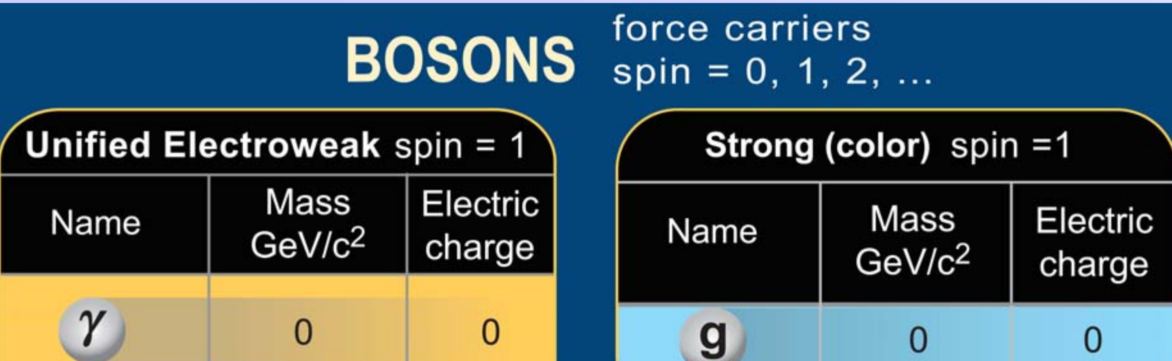


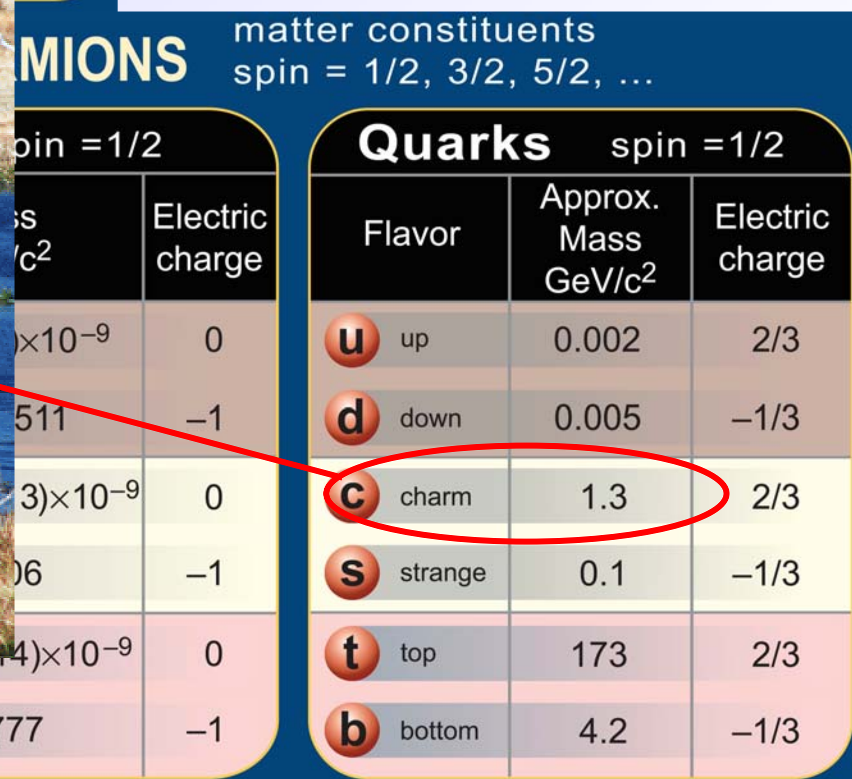
But QGP only exists ~ 10^{-23} seconds

How can we probe a state that exists for such a short time?

Charm Quarks in QGP

6 fermions and 6 leptons come in 3 identical generations
(only masses are different)
Plus they have antiparticles.

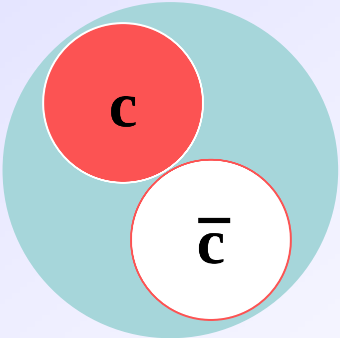


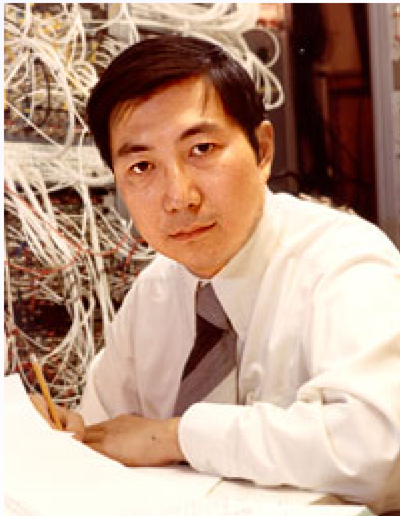


Lep
the
qua
cha
strong force.

Nobel Prize - 1976

- **Discovery of the J/psi Particle ("charmonium")**
- **The 1976 Nobel Prize in physics was shared by a Massachusetts Institute of Technology researcher, Samuel C.C. Ting (right), who used Brookhaven's Alternating Gradient Synchrotron (AGS) to discover a new particle and confirm the existence of the charmed quark.**

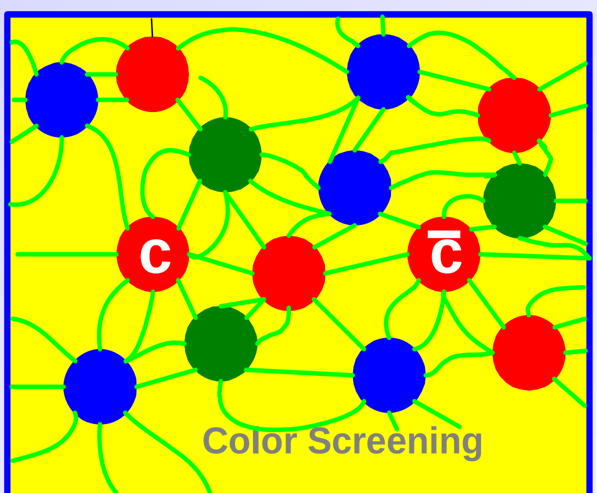




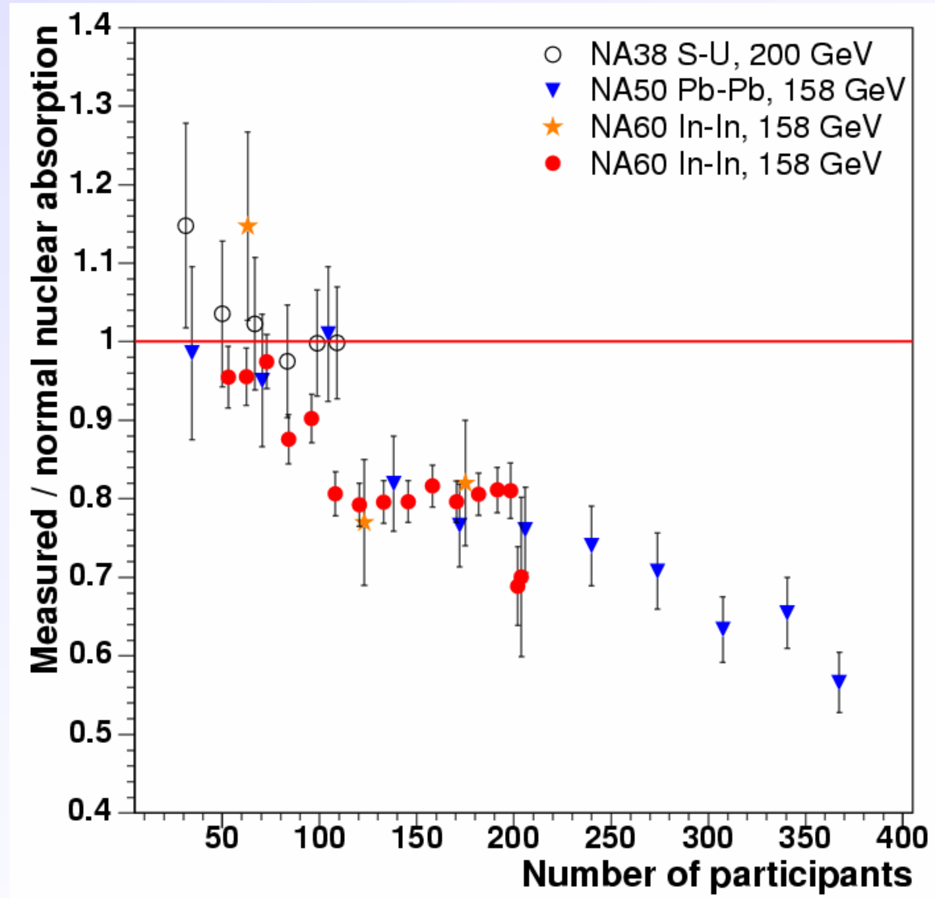
What do we expect from J/Y in QGP?

In a hot QCD medium, when the temperature is raised well beyond the deconfinement temperature, the J/ψ and its excitations are expected to melt.

→ We expect a suppression of bound states due to color screening in the Quark Gluon Plasma. (Matsui and Satz, 1986)



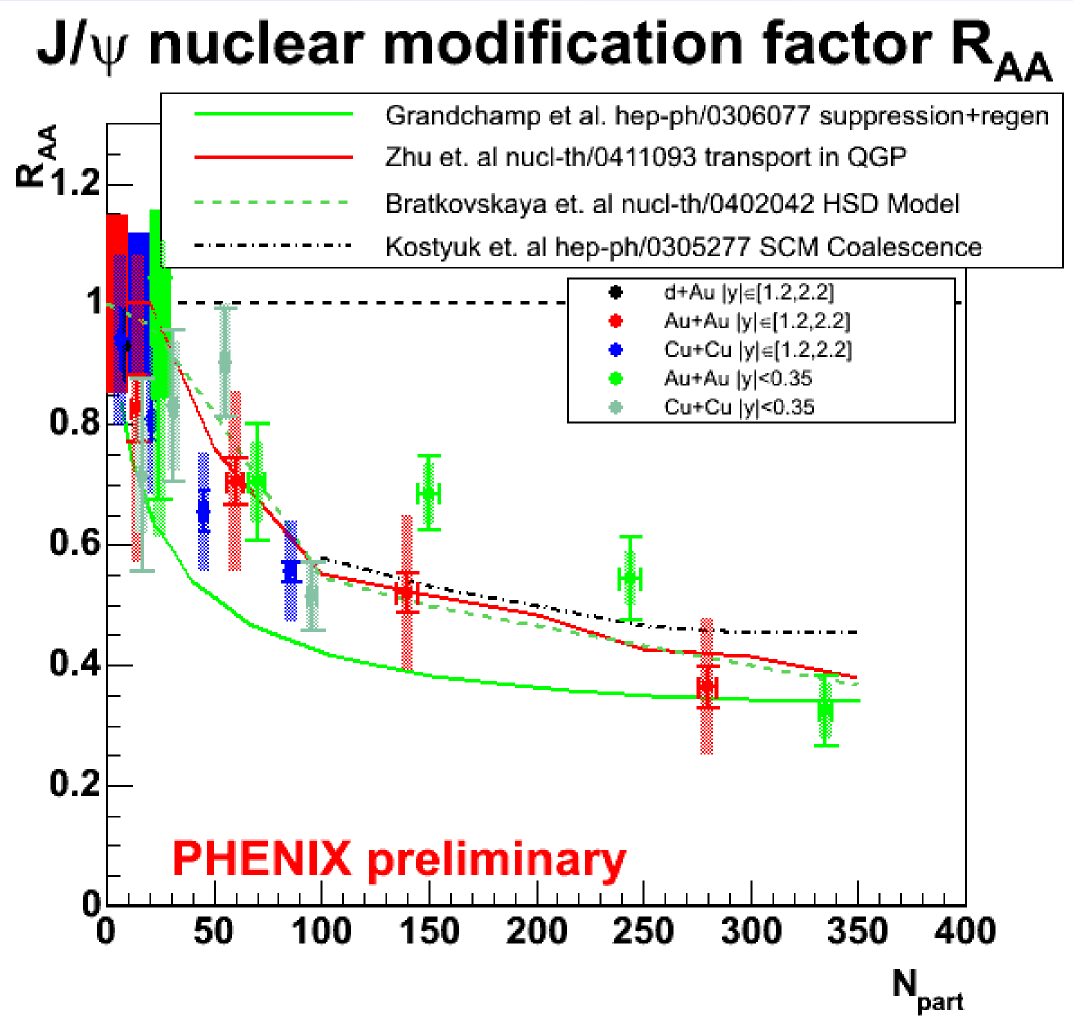
Data from SPS



Deconfinement via J/Ψ Suppression at RHIC

- Lattice calculations predict J/Ψ survives in plasma up to ~2 T_c
- Suppression at RHIC should be larger than SPS because of larger energy density
- Charm cross-section larger at RHIC than SPS – ~ 20 $c\bar{c}$ pairs produced per collision
- We have evidence that charm may be partially thermalized at RHIC → Could we have recombination of $c\bar{c}$ pairs to regenerate J/Ψ ?

J/Ψ – Data Comparison to Theory



Models implementing suppression and regeneration: reasonable agreement with the data

Summary

- Goal at RHIC is to create Quark-Gluon Plasma (deconfinement of quarks)
- RHIC has collided Au+Au, p+p, and d+Au
- There are 4 RHIC experiments (2 large, 2 small)
- Results imply that we have created a very dense medium in Au+Au collisions
- Wealth of data – only one physics topic shown today – J/Ψ data consistent with melting and regenerating in plasma