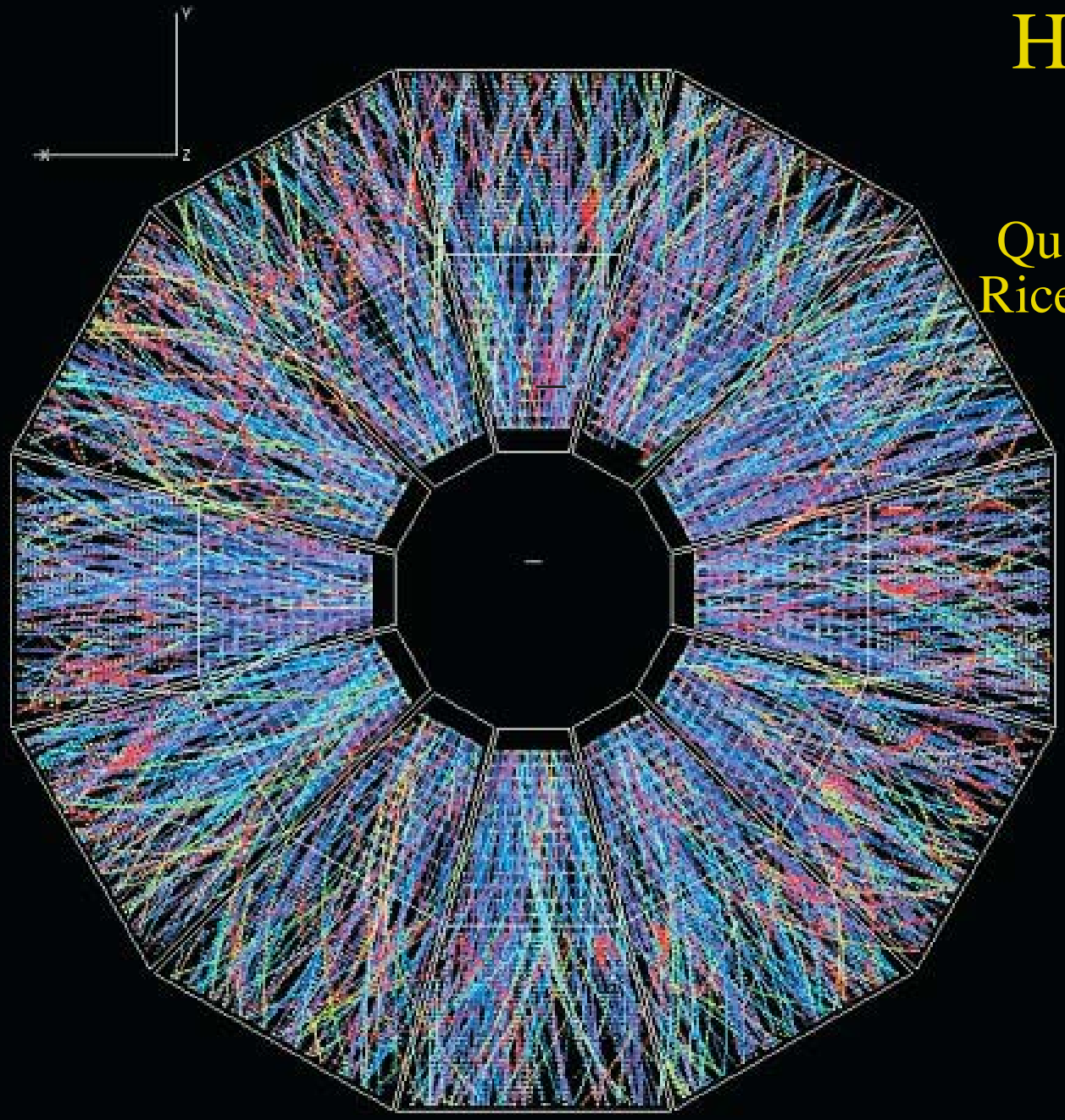


Heavy-Ion e-Lab

W.J. Llope
Quarknet Saturday Physics
Rice U. & the U. of Houston
October 7, 2006
Rice University

Phases of Matter as of ~500 B.C.

Anaxagoras:

All things have existed from the beginning.

But originally they existed in infinitesimally small fragments of themselves, endless in number and inextricably combined.

Democritus:

everything which is must be eternal

"the void" is not nothing

there are various basic elements, called "atoms" (indivisible) which always existed but can be rearranged into many different forms.

atoms only had several properties

size, shape, and (perhaps) weight.

all other properties that we attribute to matter,

e.g. color and taste,

are the result of complex interactions between the atoms in our bodies and the atoms of the matter that we are examining.

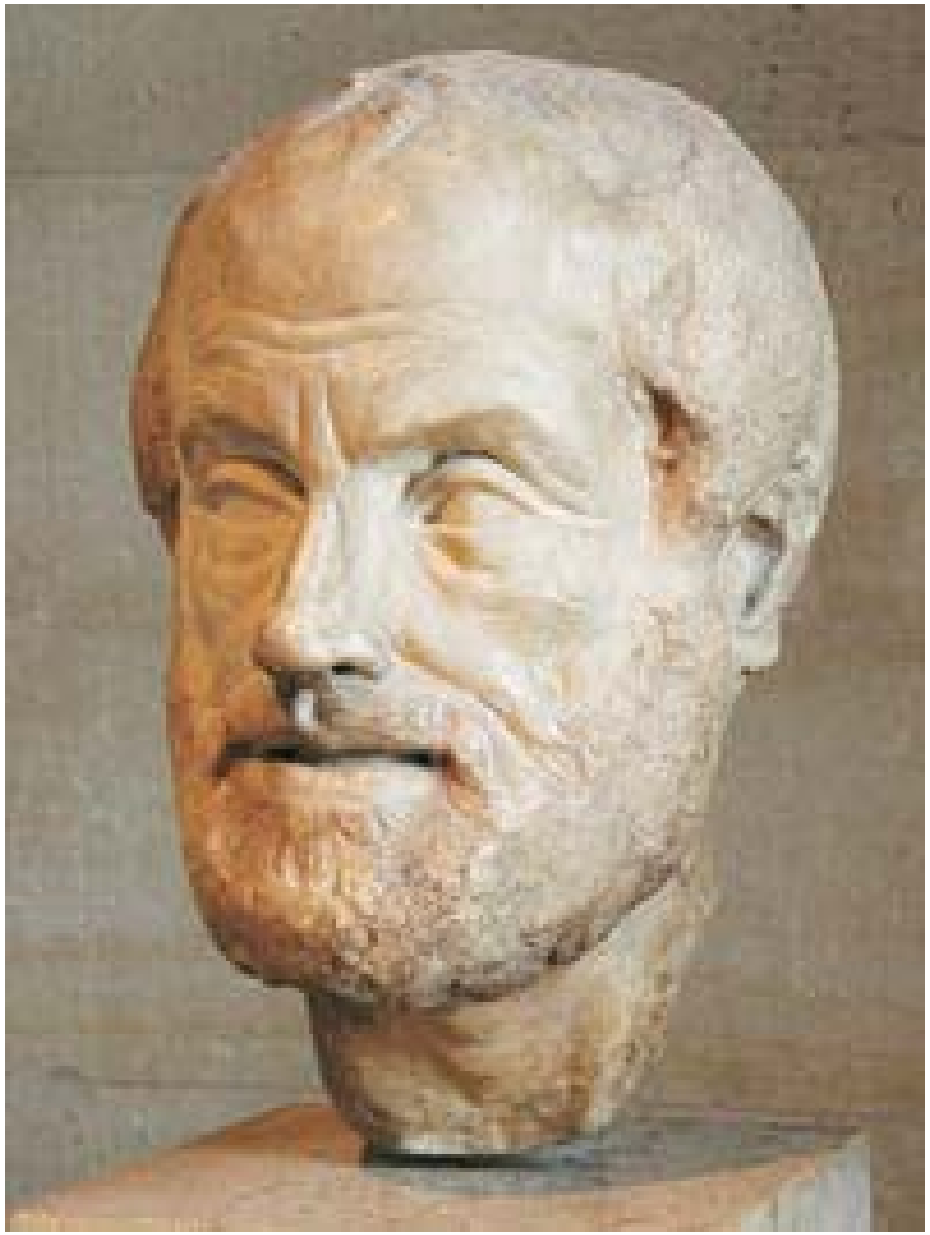
Empedocles:

All is made up of four elements (which he called roots):

- Earth
- Water
- Air
- plus one more.

Attraction: "Philia" (love)

Dissociation: "Neikos" (strife)



Aristotle:

There are also qualities such as
heat, cold, dryness, and moisture.

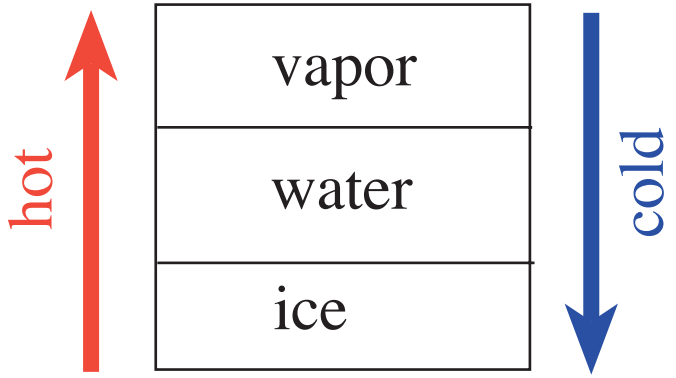
When two qualities were combined,
they formed the elements.

For example,

cold + wet = water

hot + wet = air

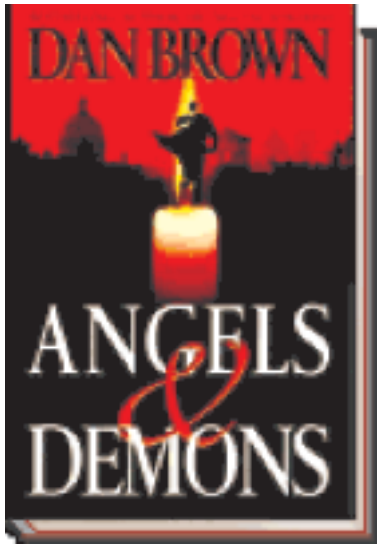
Earth's First Phase Diagram!



Then what's Empedocles' Fourth State of Matter?!?!?


FIRE:MANDOLUX

The Altars of Science (Rome)



four locations, each representing the four elements: Earth, Water, Air, Fire
define "the Path of Illumination," a trail to the meeting place of the Illuminati
The "altars" were hidden as religious artwork in order to avoid the wrath of the Vatican and to secure the secrecy of the Illuminati.
The artworks that make up the Four Altars were all sculpted by Gian Loranzo Bernini

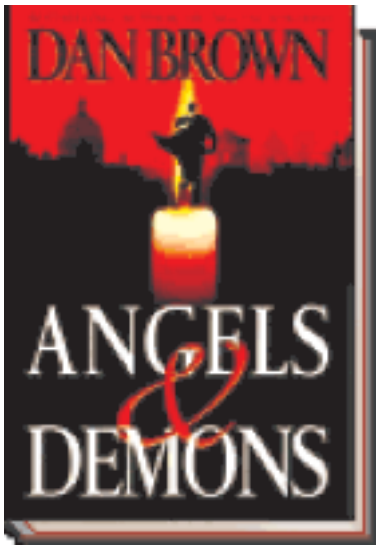
The facade of Santa Maria del Popolo. *Habakkuk and the Angel*, Altar of Earth is in Chigi Chapel of Santa Maria del Popolo.

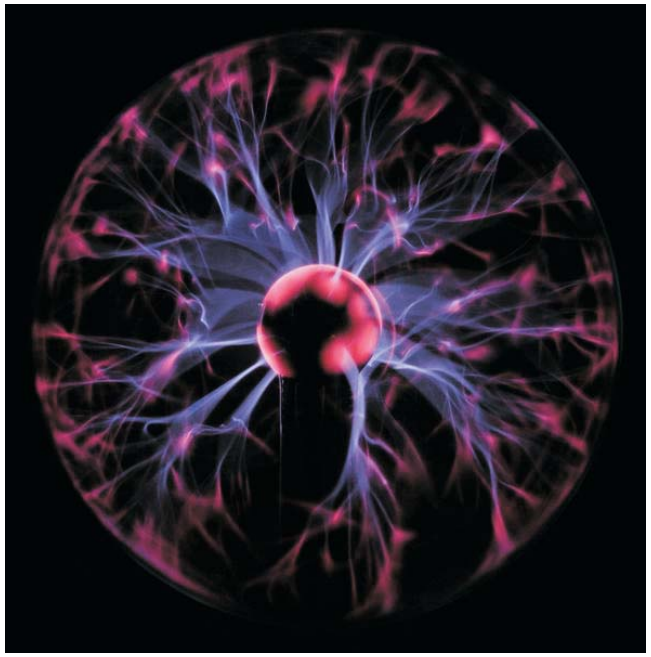
Obelisk in Saint Peter's Square, Altar of Air

Ecstasy of St Teresa, Altar of Fire

Fountain of Four Rivers, Altar of Water


earth
air
fire
water


DAN BROWN
ANGELS
&
DEMONS



“Atomic/Molecular” Plasmas.....

Democritus's view holds up for
~2300 years

until an experiment by Rutherford and Geiger published in 1911.

"*The Scattering of Alpha and Beta Particles by Matter and the Structure of the Atom*," E. Rutherford, Philosophical Magazine, 6th Series, 21:669 (1911).

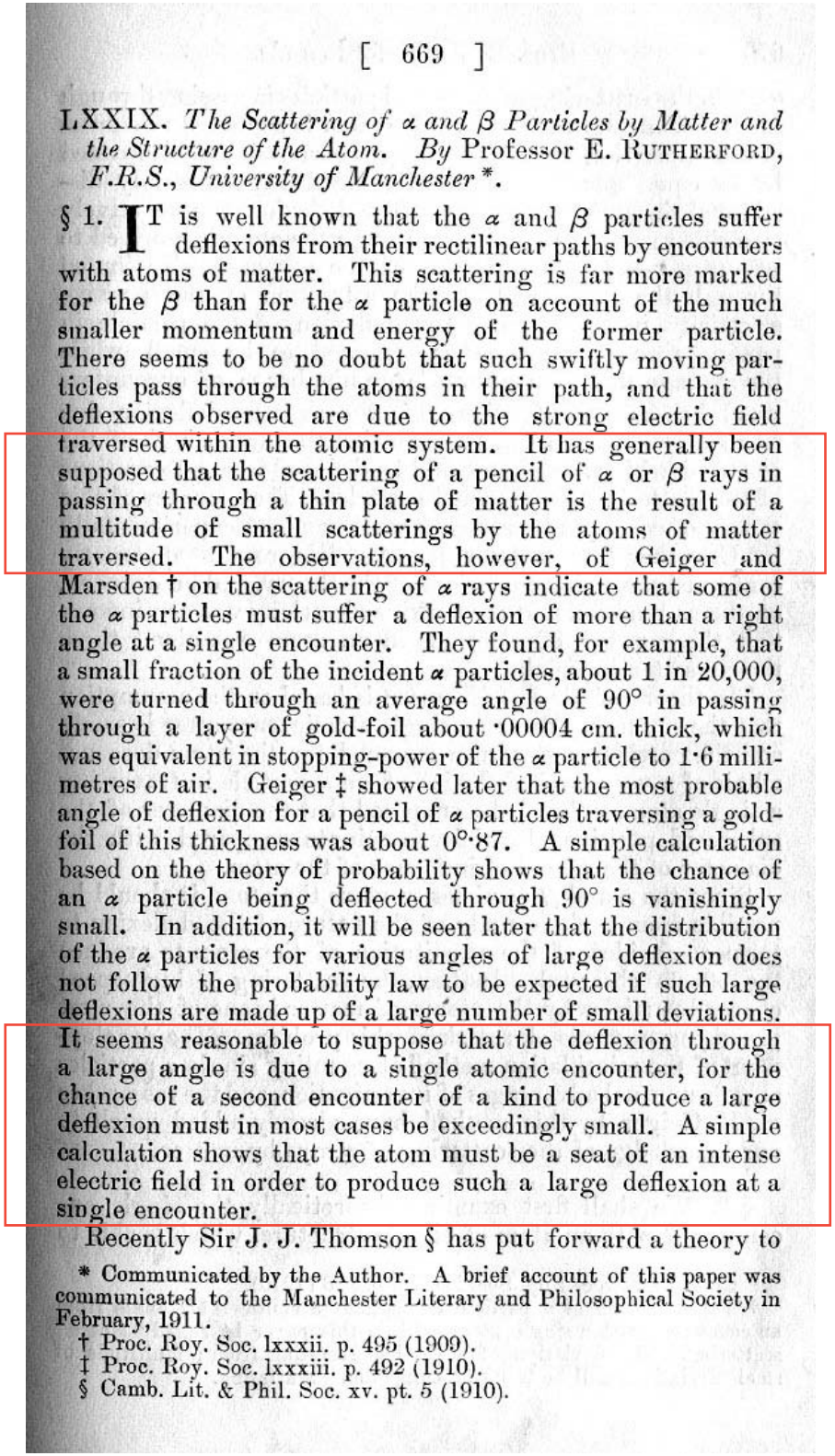
scattered α-particles off a gold (Au) foil and measured scattering angles

some bounce backwards!
(huh?!?)

→ new model of the atom
"Saturnian" or "Rutherford" atom

- atoms are not uniformly dense
- very dense **nucleus** inside every atom

nucleus = protons + neutrons
nucleons are quarks held together by gluons



[669]

LXXIX. *The Scattering of α and β Particles by Matter and the Structure of the Atom.* *By* Professor E. RUTHERFORD, *F.R.S., University of Manchester* *.

§ 1. IT is well known that the α and β particles suffer deflexions from their rectilinear paths by encounters with atoms of matter. This scattering is far more marked for the β than for the α particle on account of the much smaller momentum and energy of the former particle. There seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system. It has generally been supposed that the scattering of a pencil of α or β rays in passing through a thin plate of matter is the result of a multitude of small scatterings by the atoms of matter traversed. The observations, however, of Geiger and Marsden † on the scattering of α rays indicate that some of the α particles must suffer a deflexion of more than a right angle at a single encounter. They found, for example, that a small fraction of the incident α particles, about 1 in 20,000, were turned through an average angle of 90° in passing through a layer of gold-foil about ·00004 cm. thick, which was equivalent in stopping-power of the α particle to 1·6 millimetres of air. Geiger ‡ showed later that the most probable angle of deflexion for a pencil of α particles traversing a gold-foil of this thickness was about 0°·87. A simple calculation based on the theory of probability shows that the chance of an α particle being deflected through 90° is vanishingly small. In addition, it will be seen later that the distribution of the α particles for various angles of large deflexion does not follow the probability law to be expected if such large deflexions are made up of a large number of small deviations. It seems reasonable to suppose that the deflexion through a large angle is due to a single atomic encounter, for the chance of a second encounter of a kind to produce a large deflexion must in most cases be exceedingly small. A simple calculation shows that the atom must be a seat of an intense electric field in order to produce such a large deflexion at a single encounter.

Recently Sir J. J. Thomson § has put forward a theory to

* Communicated by the Author. A brief account of this paper was communicated to the Manchester Literary and Philosophical Society in February, 1911.

† Proc. Roy. Soc. lxxxii. p. 495 (1909).

‡ Proc. Roy. Soc. lxxxiii. p. 492 (1910).

§ Camb. Lit. & Phil. Soc. xv. pt. 5 (1910).

Fire as we know it:

Uses: grilling burgers
heating homes
birthday parties
clearing rainforests
→ fantastically useful stuff!

but what is it?

a hot soup (a "plasma") consisting of the components of molecules+atoms:
electrons and photons (light & heat) and ions

energy is released from the breaking of (molecular) bonds in the
wood, propane, gasoline, or whatever is burning...

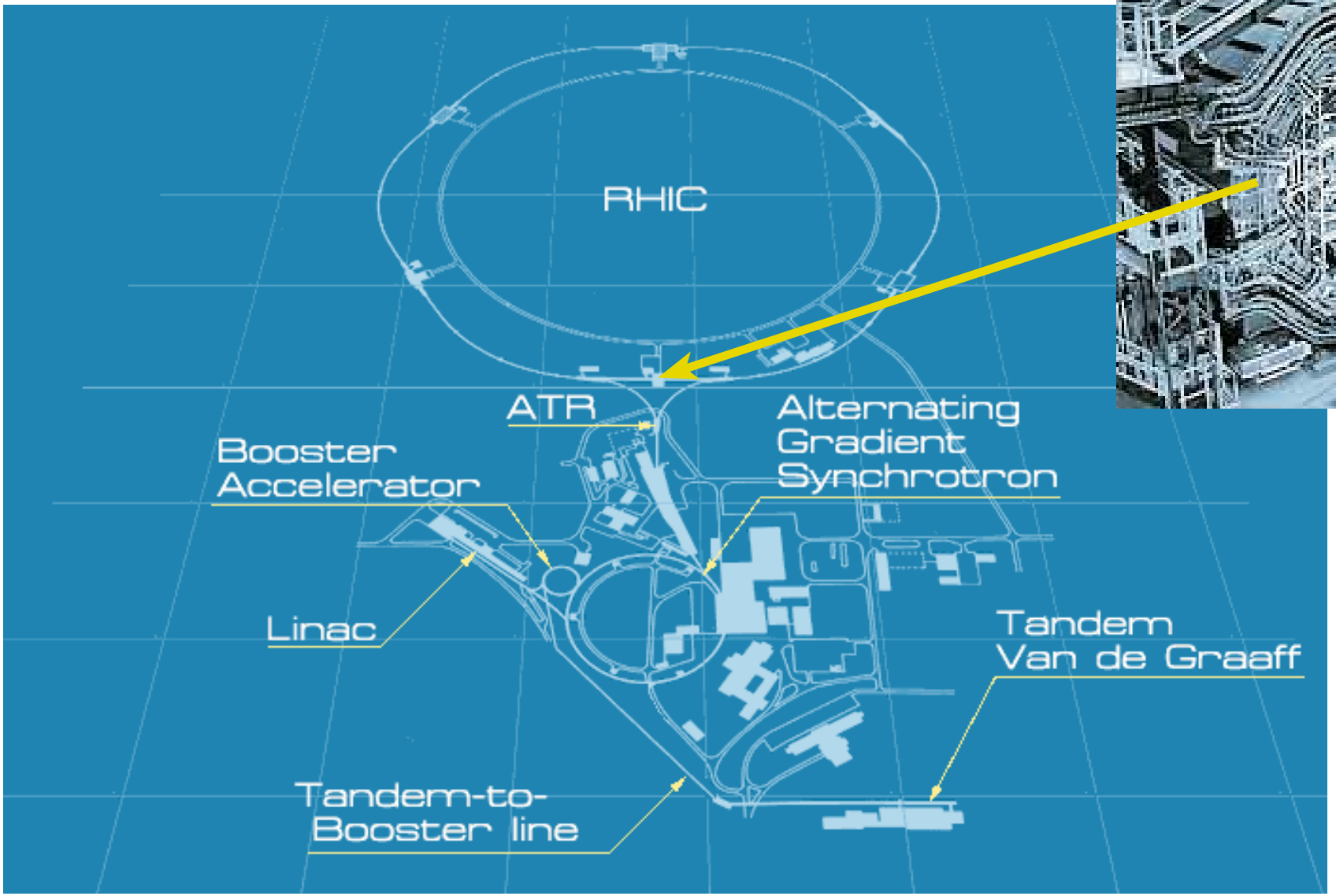
so how about a *"nuclear" plasma*?

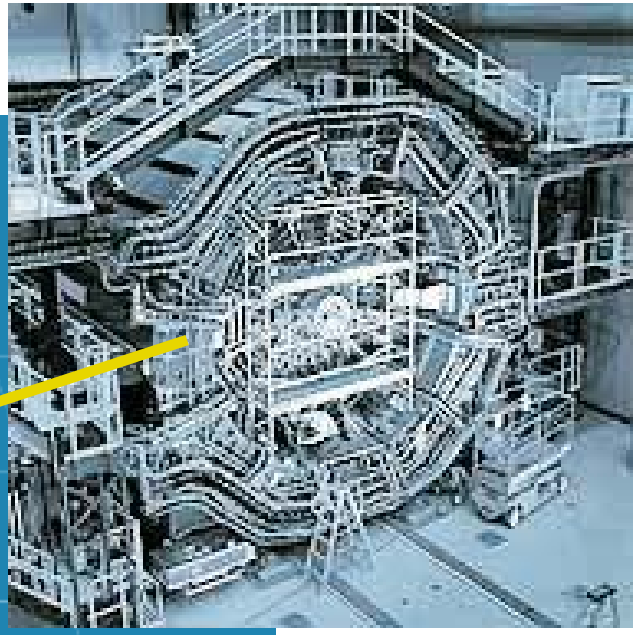
i.e. a hot soup consisting of the components of *nuclei*....
protons and neutrons (really "quarks" and "gluons")

bonds here are ~10,000 times stronger than atomic/molecular bonds...

Quark-Gluon Plasma == the whole universe at an age of a few μsec?

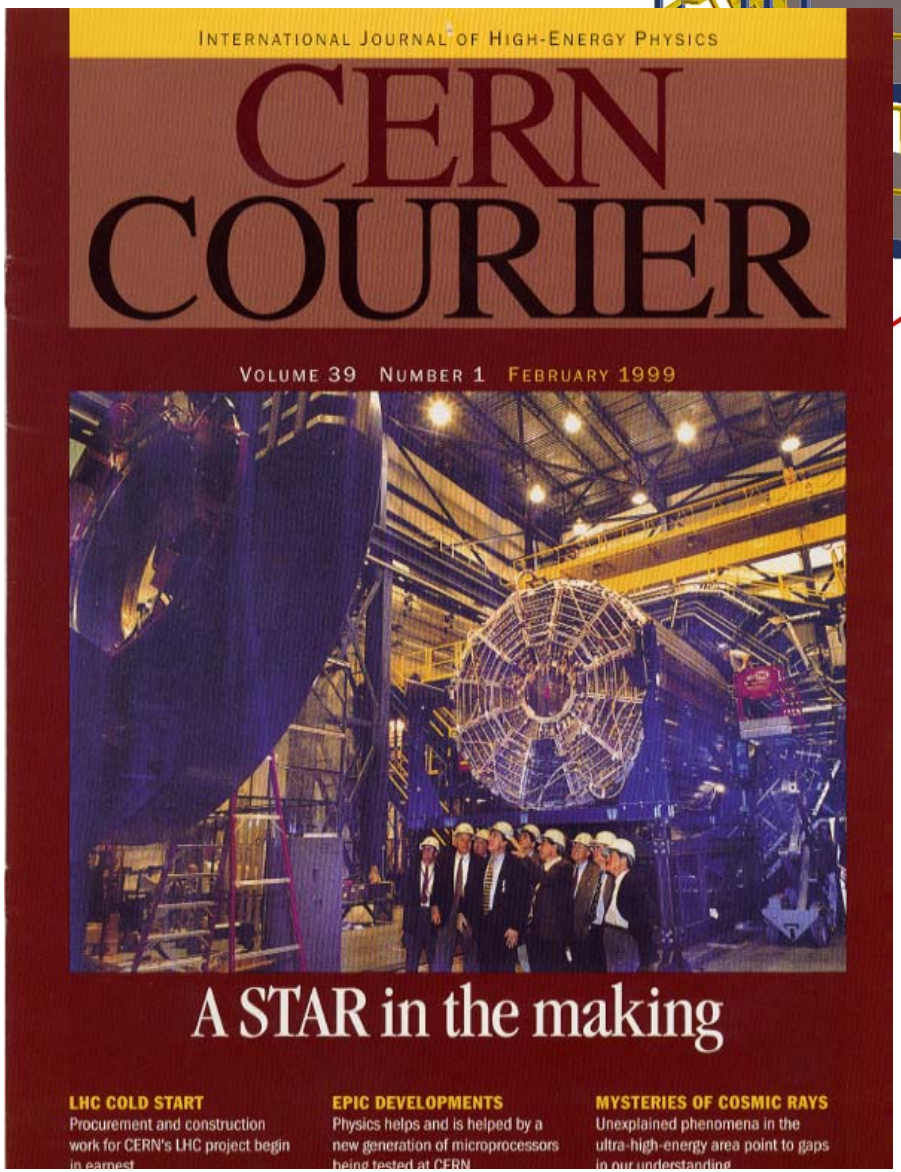
Now less than 100 years later, we can accelerate Au nuclei to the speed of light and collide them with other Au nuclei!!!

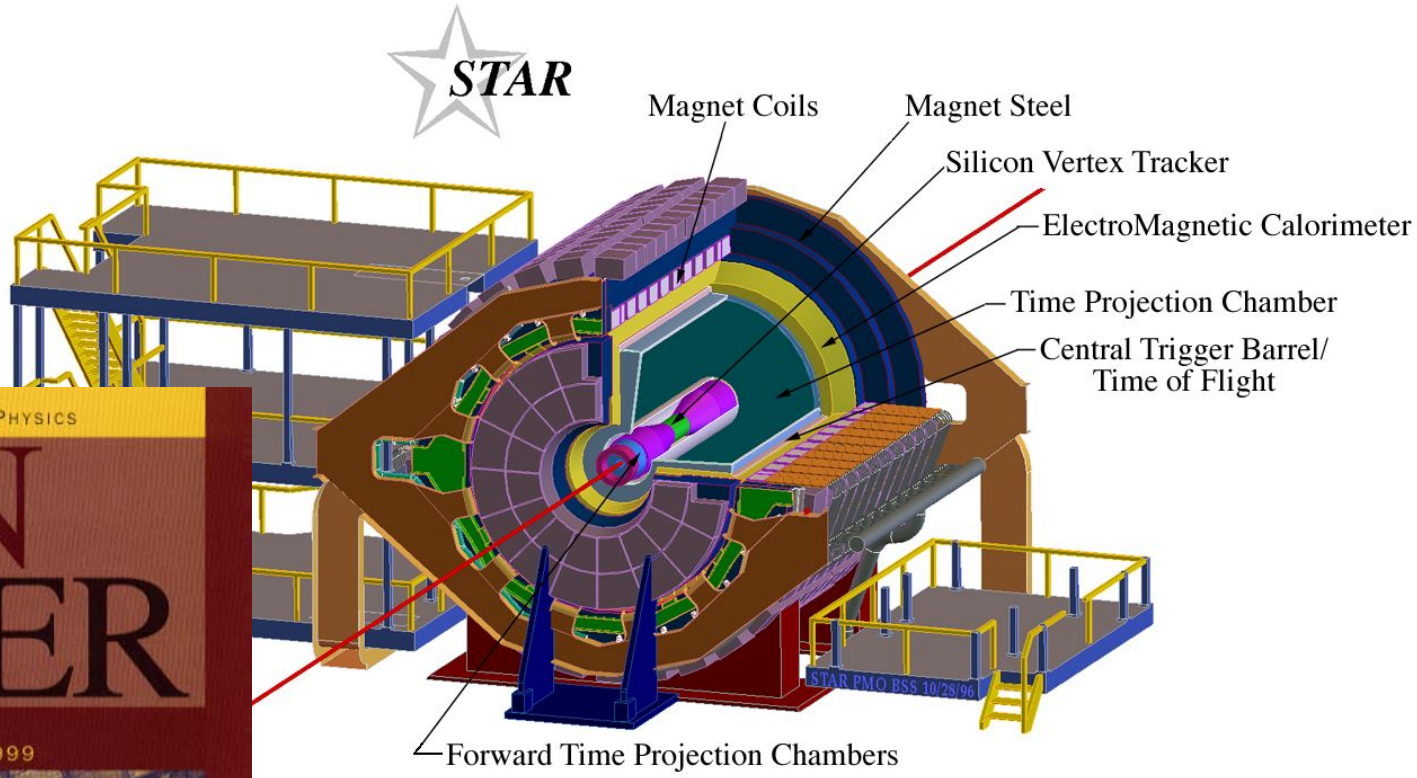




http://www.bnl.gov/rhic/RHIC_complex.htm

Solenoidal Tracker at RHIC





"tracking"

measure paths of charged particles
infer momenta and trajectories

"calorimetry"

dense detector to stop particles
measure energy

"time of flight"

measure flight times for known momenta and path lengths

QuarkNet - Associate Teacher Institute at Rutgers University -
Summer 2002

STAR and its Time Of Flight (TOF) system....

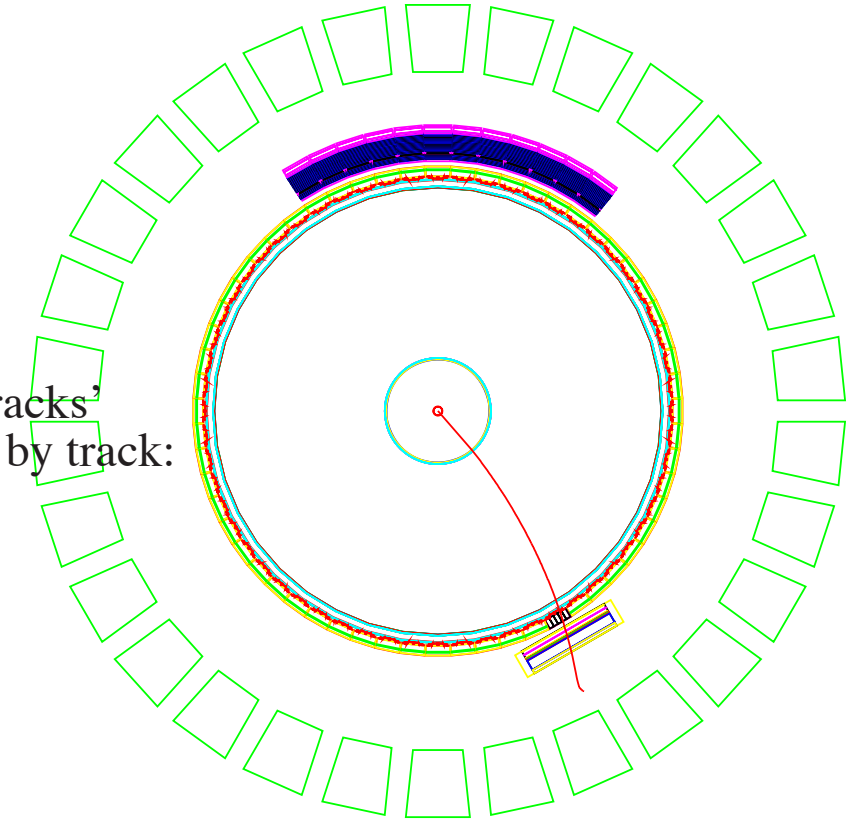
TPC provides

momenta of tracks to $\Delta p/p \sim 1\text{-}2\%$

track total **path length**s to a few millimeters

over 2.1-2.9m flight path...

surrounding the TPC with a detector that can measure the tracks' time of flight (TOF) allows the following calculation, track by track:



p from TPC tracking

s from TPC tracking, & STAR geometry

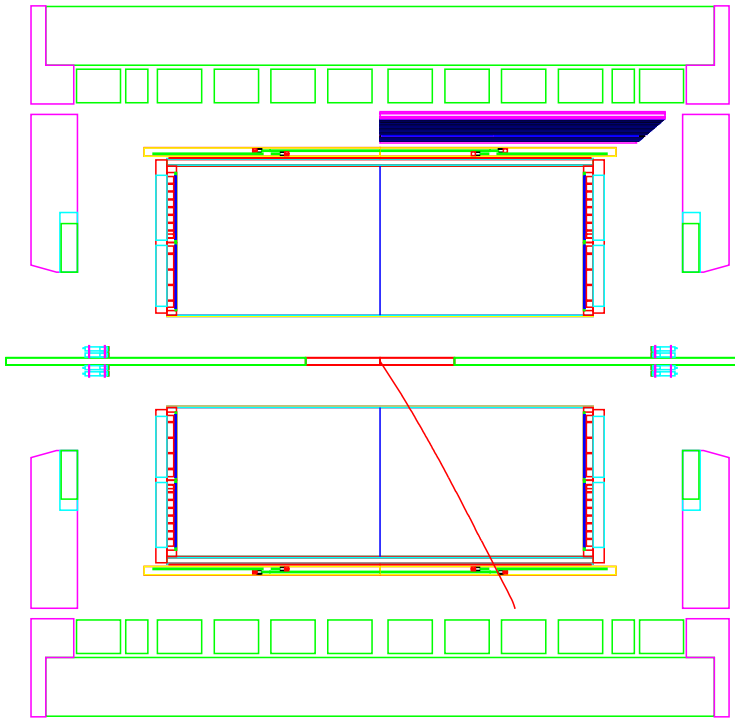
$\Delta t = t_{stop} - t_{start}$ from TOF

$s = \beta c \Delta t$ and $\gamma = 1/\sqrt{(1-\beta^2)}$

$\rightarrow m = p/\gamma\beta c$ $\rightarrow$ Particle Identification!

Mass resolution of a TOF system is:

$\Delta M/M = \Delta p/p \oplus \gamma^2 [\Delta s/s \oplus \Delta t/t]$



Then, with the TPC tracking & a $\Delta t = 100$ps TOF system:

- π/K/p direct PID: ~0.3 GeV/c < p < 1.7-1.9 GeV/c
- (π+K)/p direct PID: ~0.3 GeV/c < p < 2.8-3.0 GeV/c

i.e. just what STAR needs....