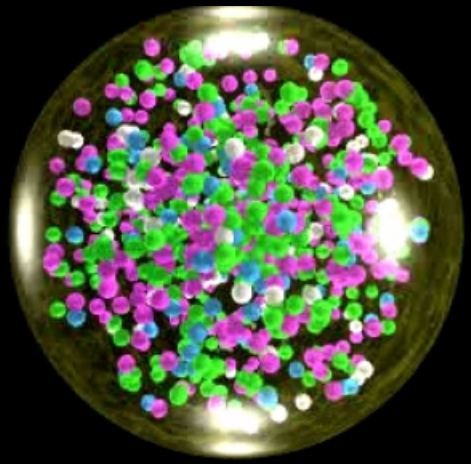
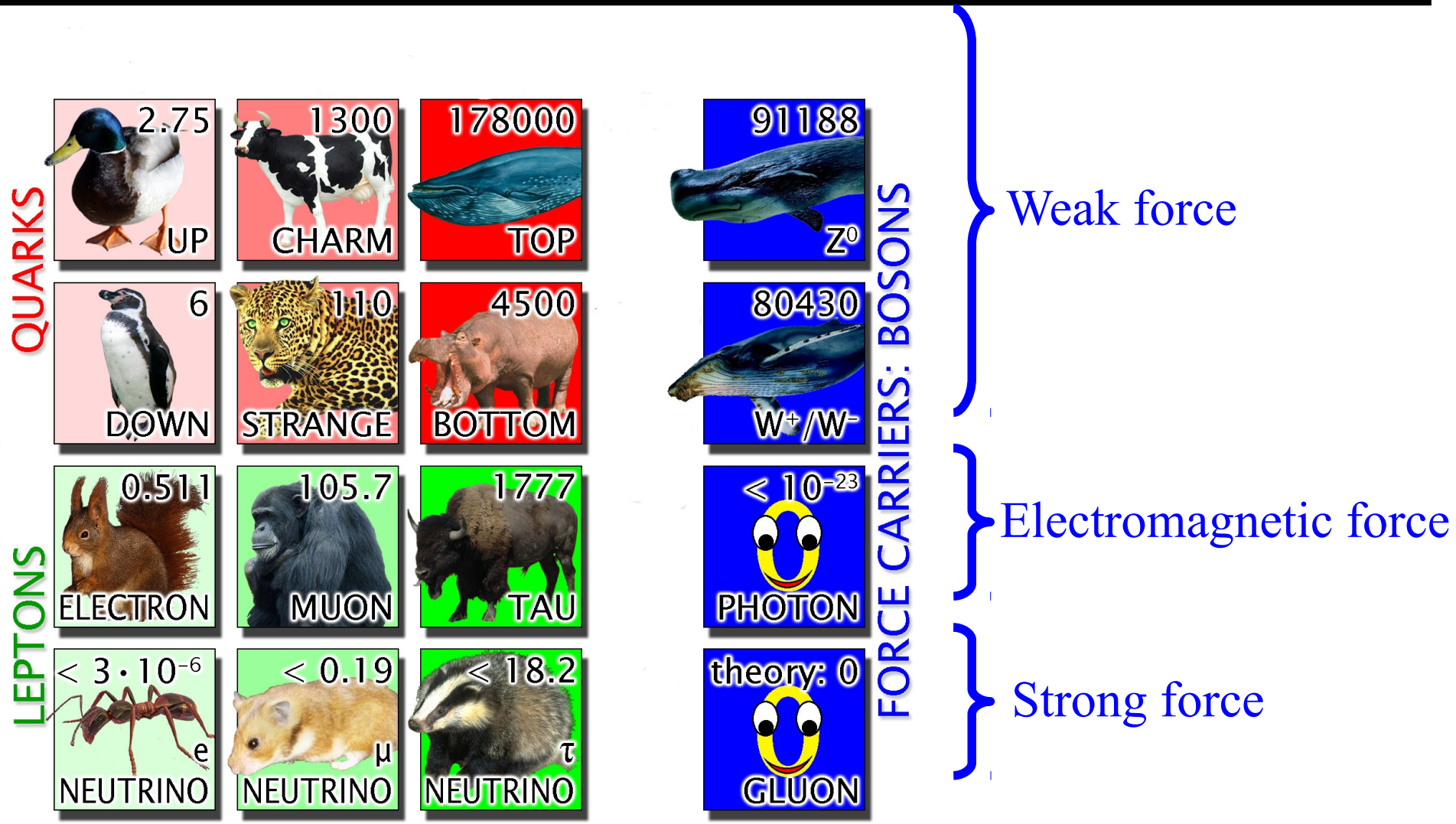
The little bang: understanding the quark gluon plasma



Christine Nattrass
University of Tennessee at Knoxville

The Standard Model

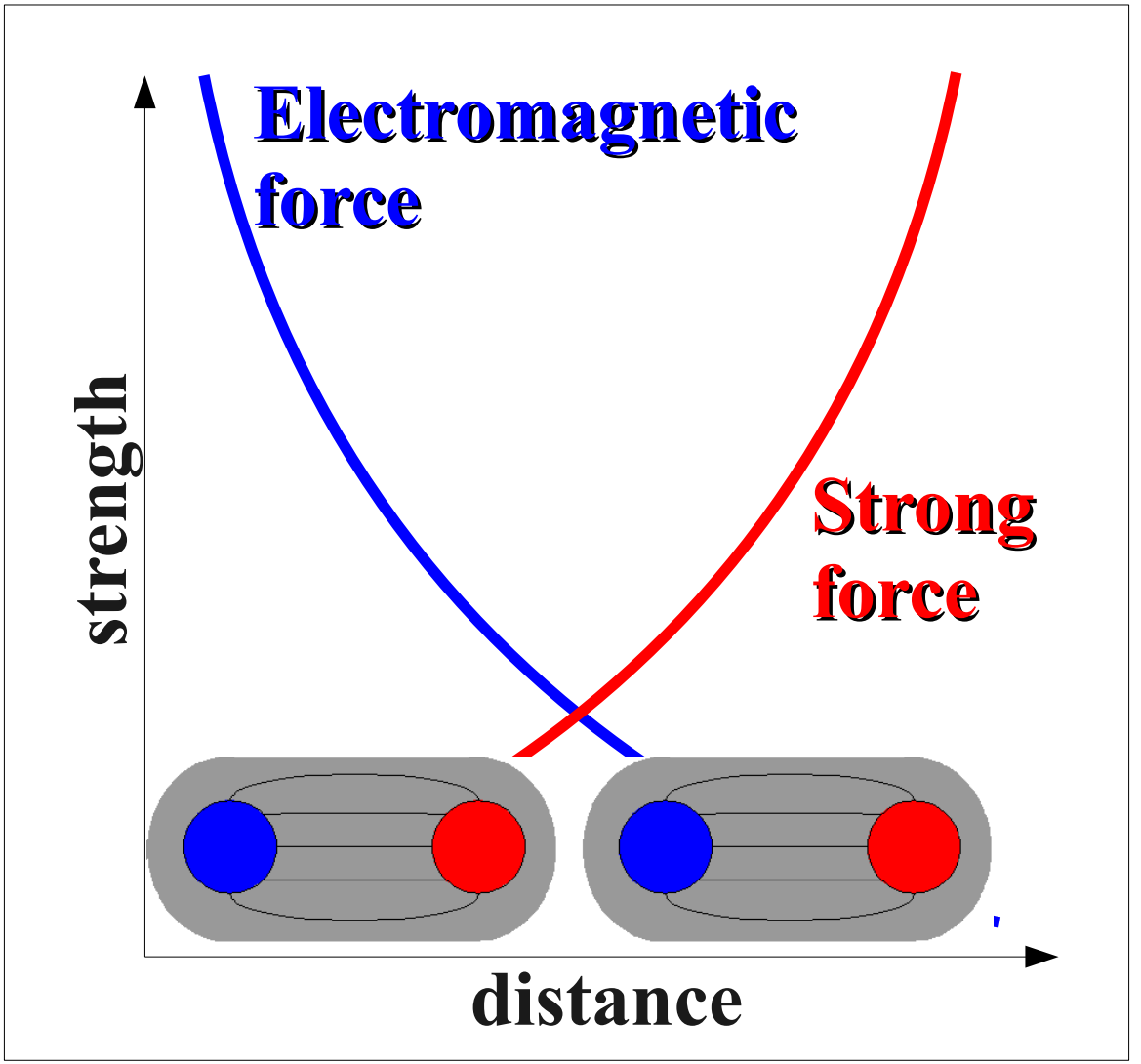


The Standard Model
fundamental particle zoo

http://e4.physik.uni-dortmund.de/bin/view/ATLAS/SmBilder?PhotoarchivePlugin_page=1&PhotoarchivePlugin_view=detailed

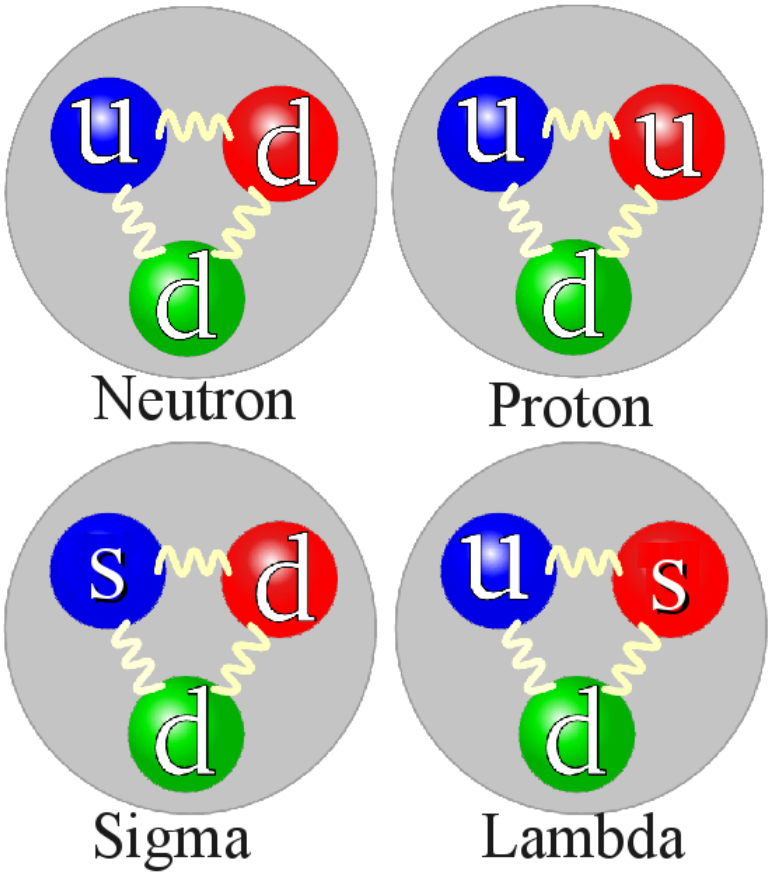
What keeps the nucleus together?

- Electric force: gets weaker as two objects get pulled apart
- Strong force: gets *stronger* as two objects get pulled apart – like a rubber band
- As we pull apart the quark and antiquark in a meson, at some point it takes less energy to make a quark-antiquark pair than to pull them further apart
- No free quarks - **confinement**

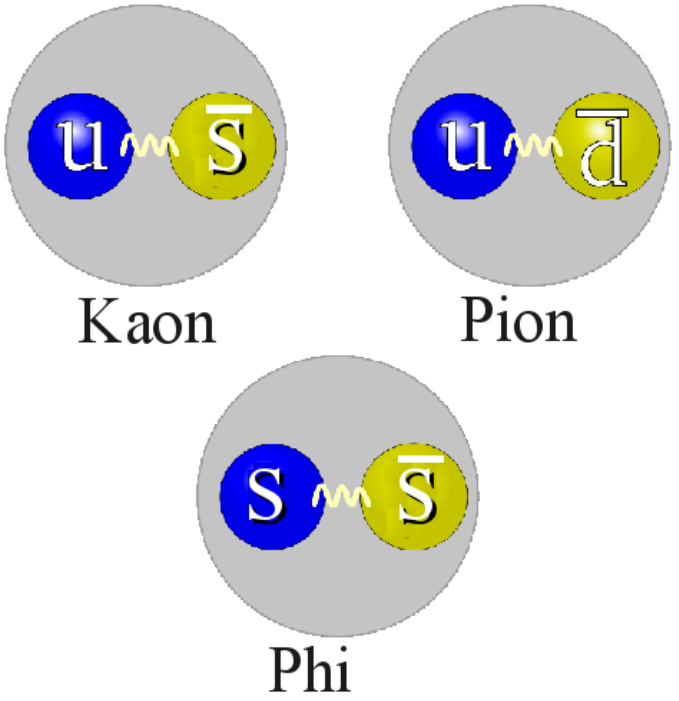


Hadrons

Baryons



Mesons



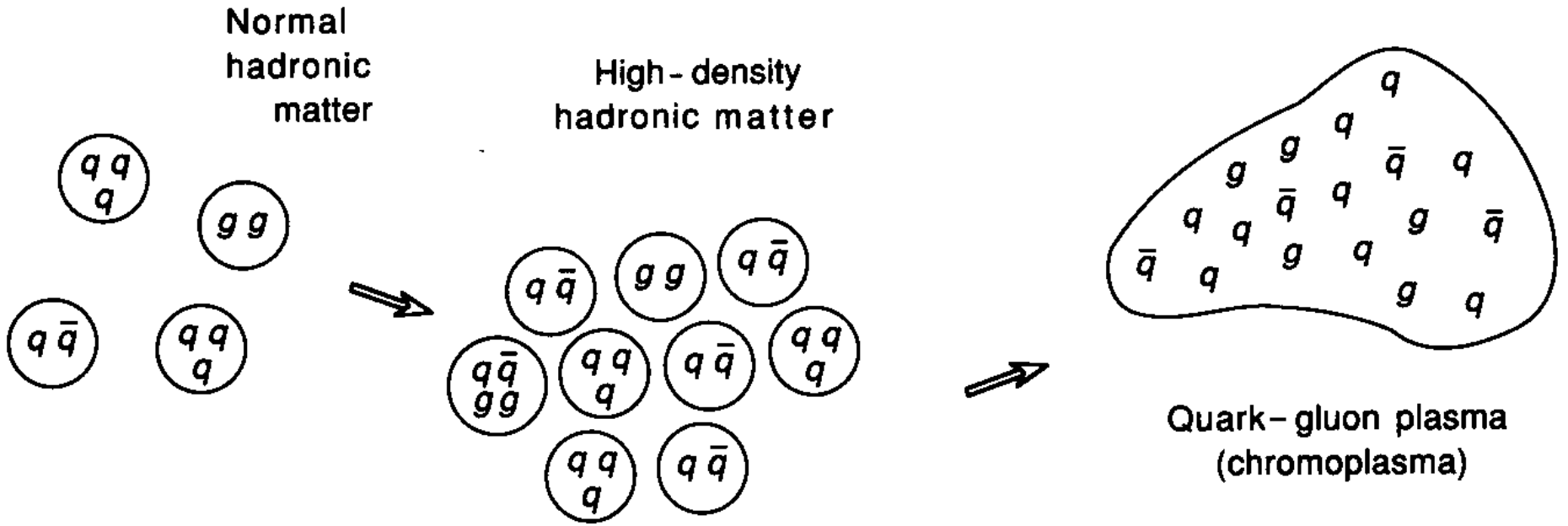
- 3 quarks/antiquarks
- Color charge: red-green-blue

- Quark-antiquark
- Color charge: blue - anti-blue

Is there way we can "free" the quarks?

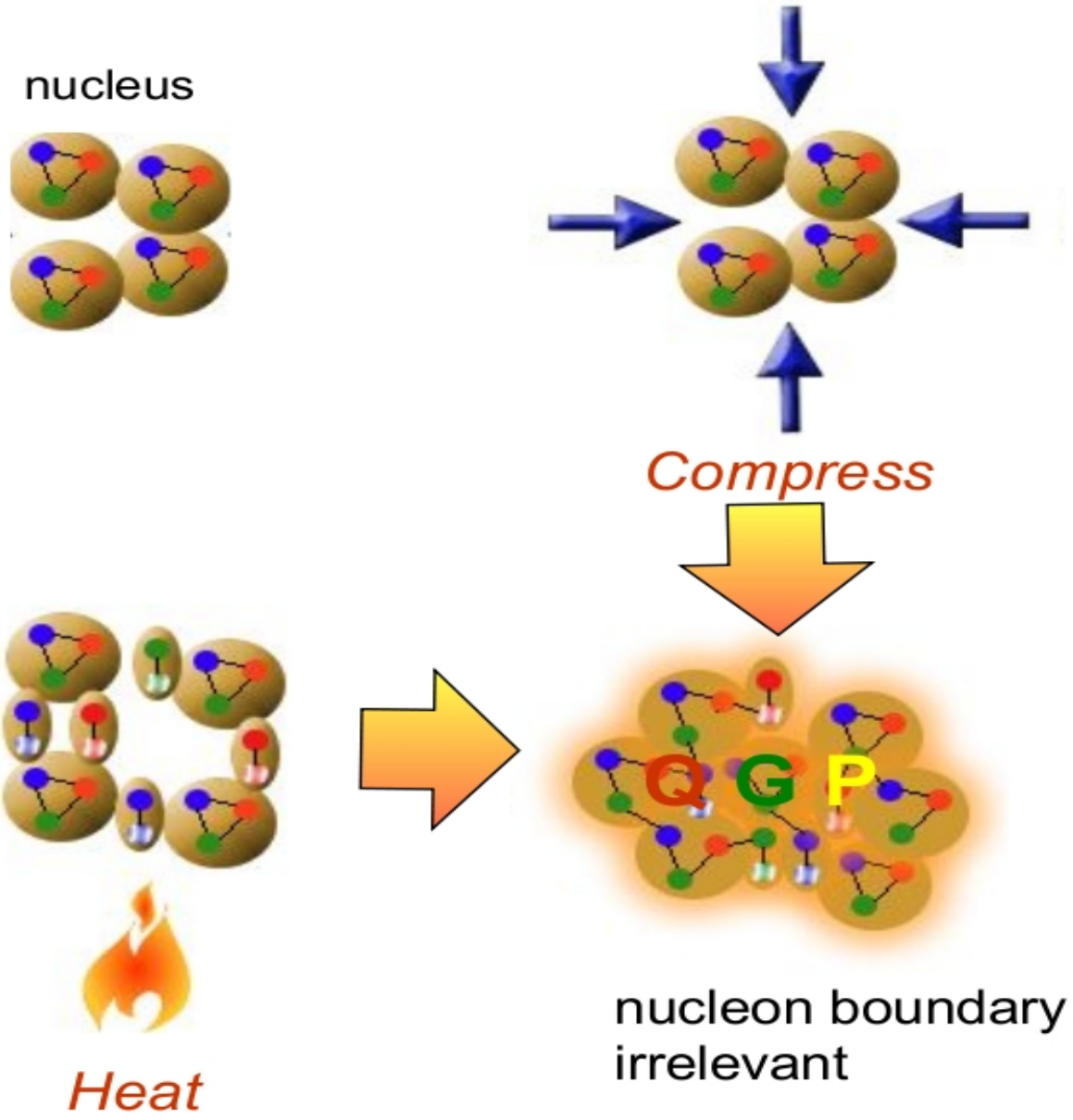
Normal Nuclear Matter

Quark Gluon Plasma

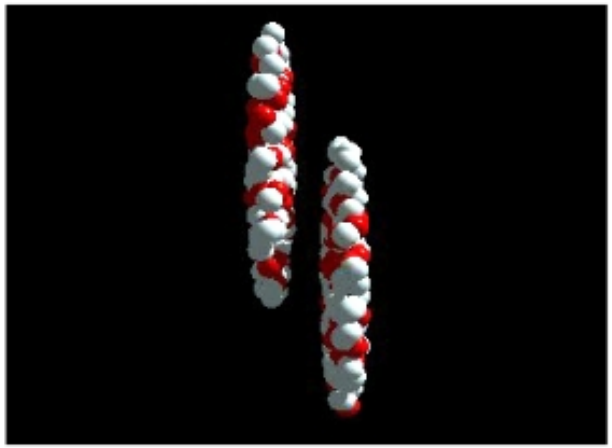


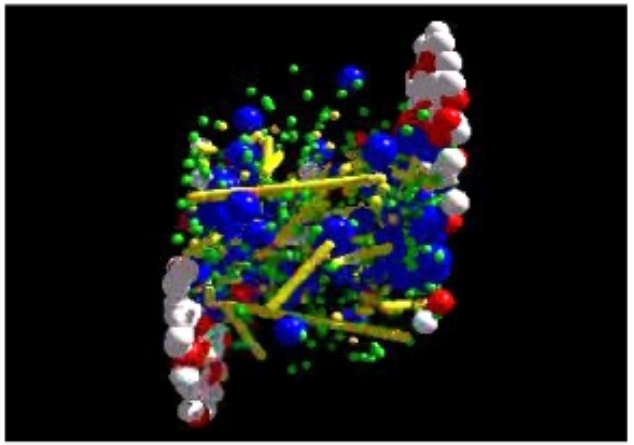
This figure and several others in this talk are copied from "Gauge Field Theories" by Mike Guidry

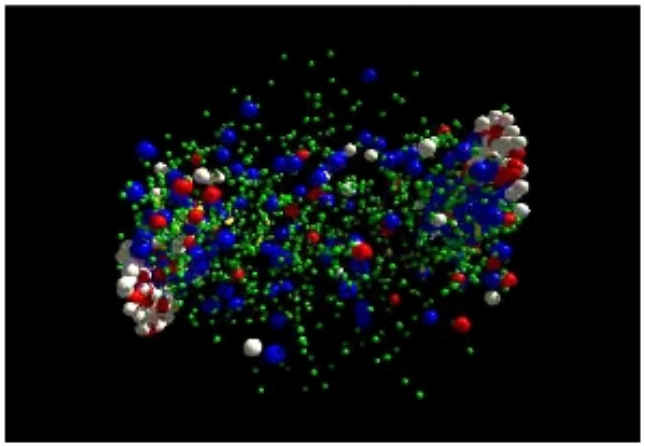
How can we do this?

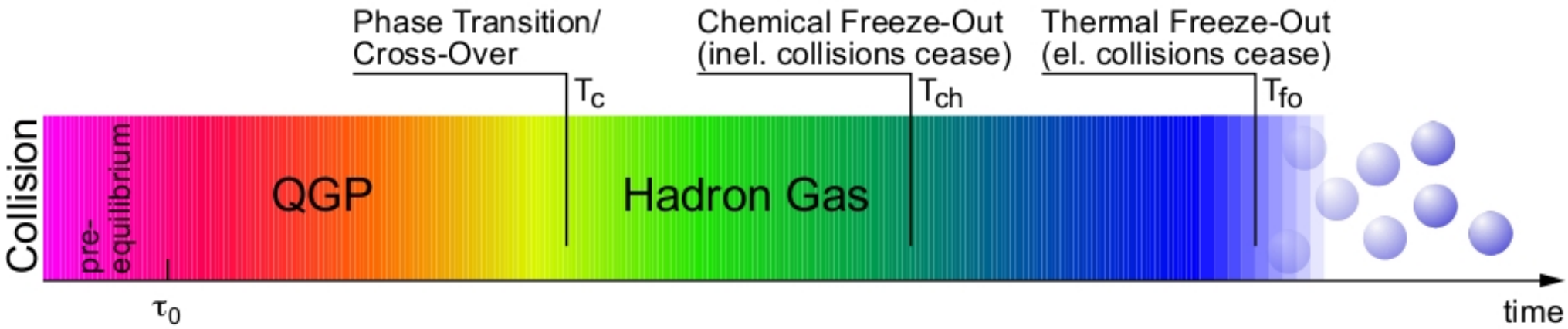


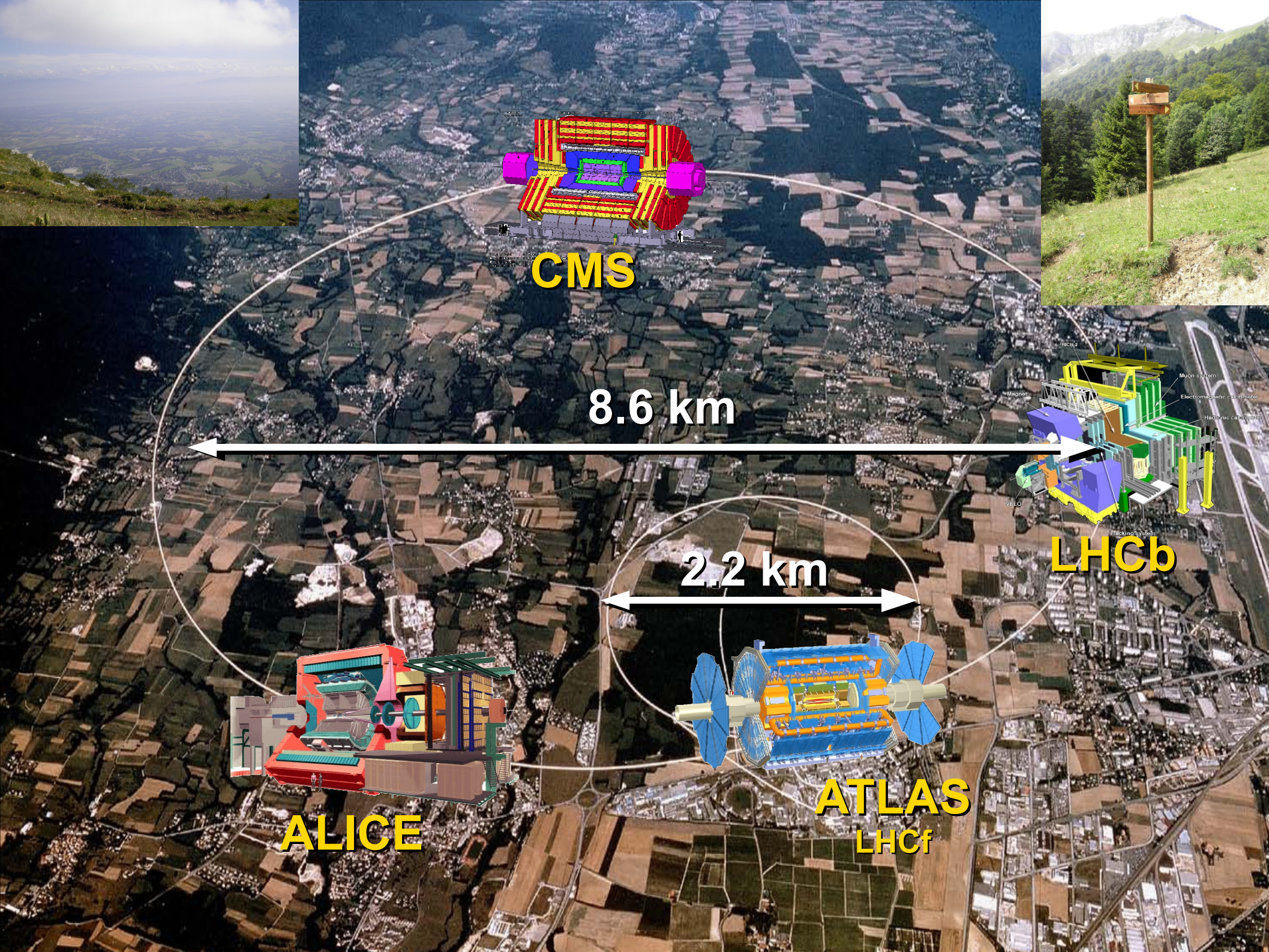
The phase transition in the laboratory



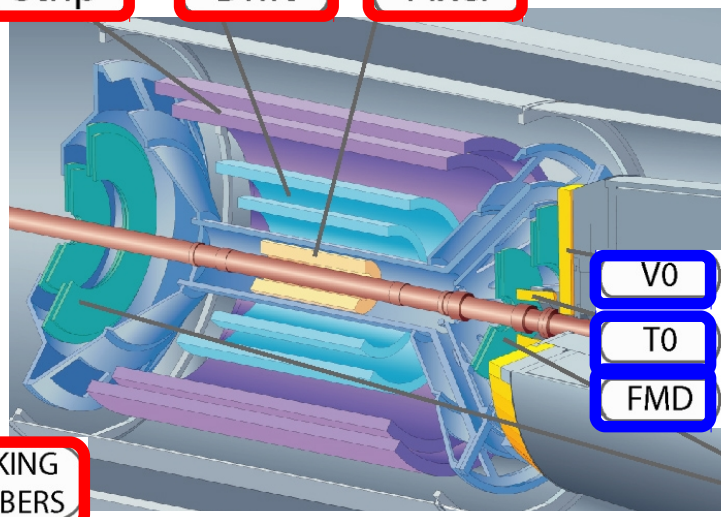







CMS
8.6 km
LHCb
2.2 km
ALICE
ATLAS
LHCf

Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18



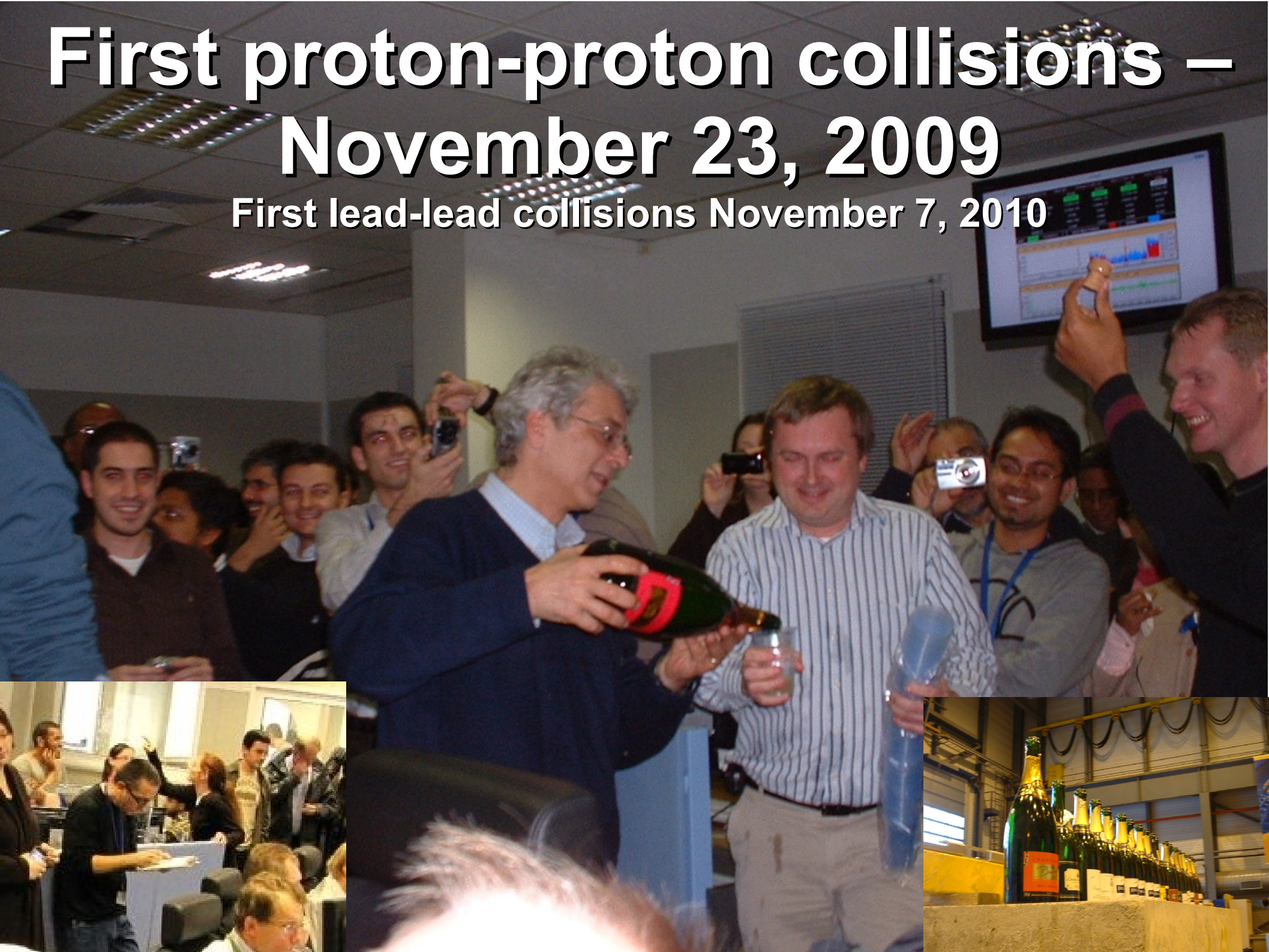
ACORDE
ITS
FMD
T0 & V0
EMCAL
TRD
HMPID
TRACKING
CHAMBERS
PMD
ZDC
~116m from I.P.
MUON
FILTER
V0
T0
TPC
TRIGGER
CHAMBERS
ZDC
~116m from I.P.

Trigger detectors: When do we have a collision?
Tracking detectors: Where did the particle go?
Identification detectors: What kind of particle is it?
Calorimeters: How much energy does the particle have?

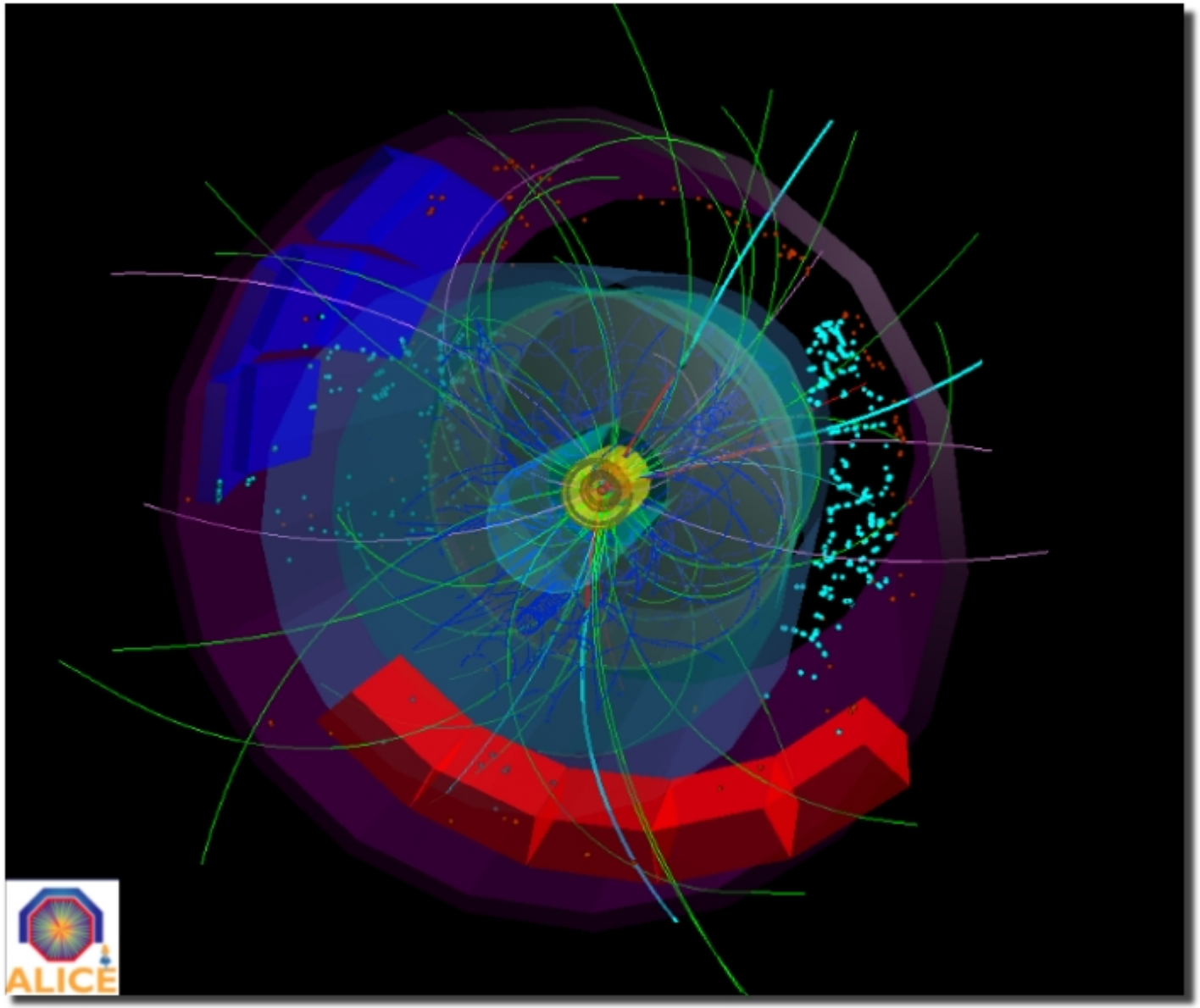
TOF
PHOS
DIPOLE
MAGNET
ABSORBER

First proton-proton collisions – November 23, 2009

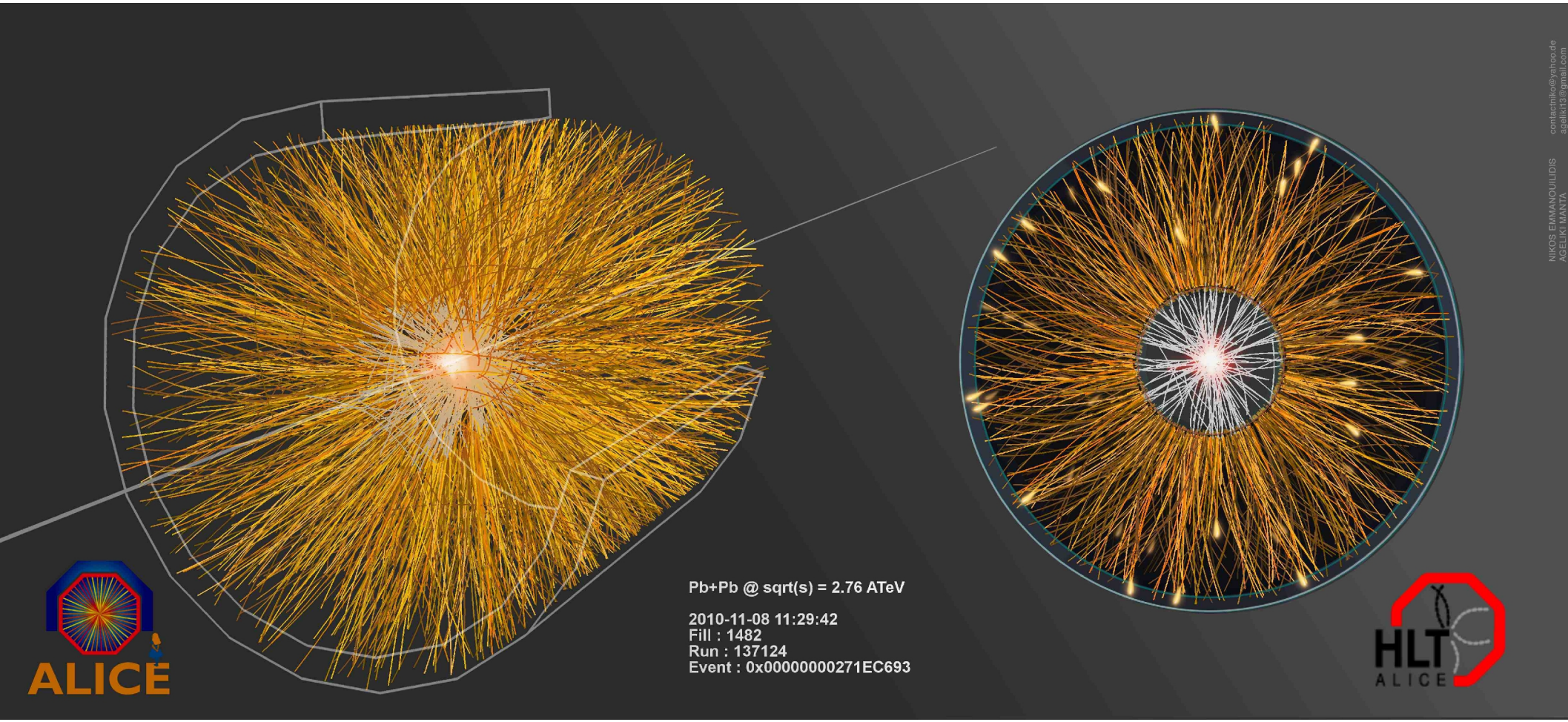
First lead-lead collisions November 7, 2010



p+p collisions



Pb+Pb collisions



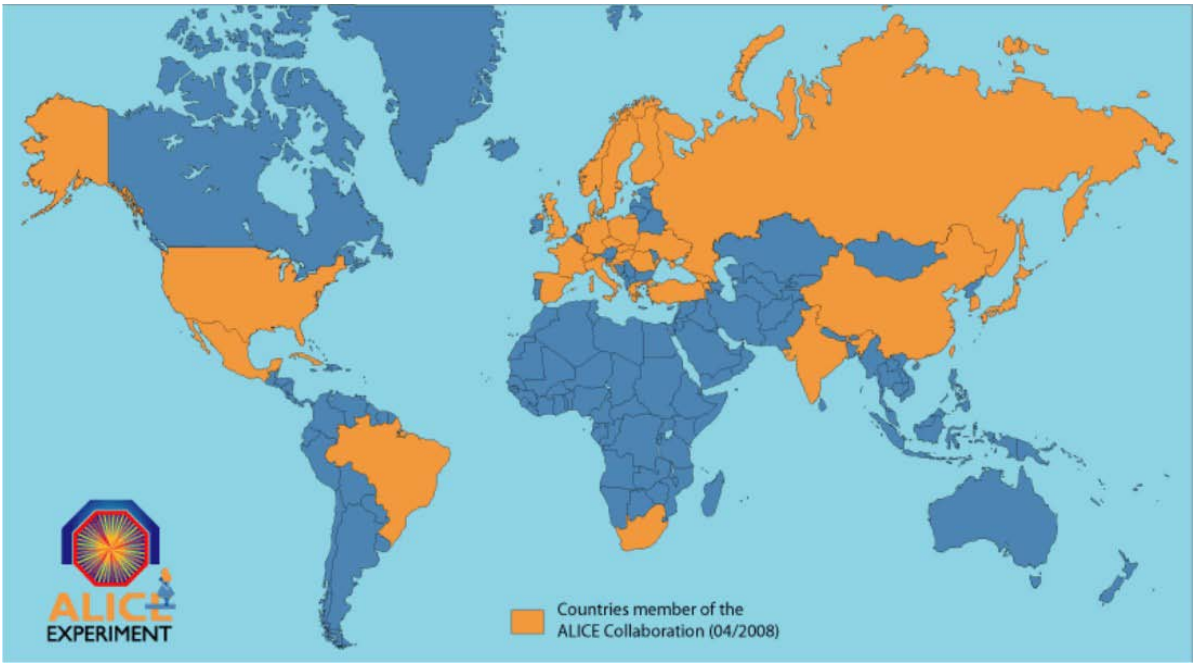
The ALICE Collaboration

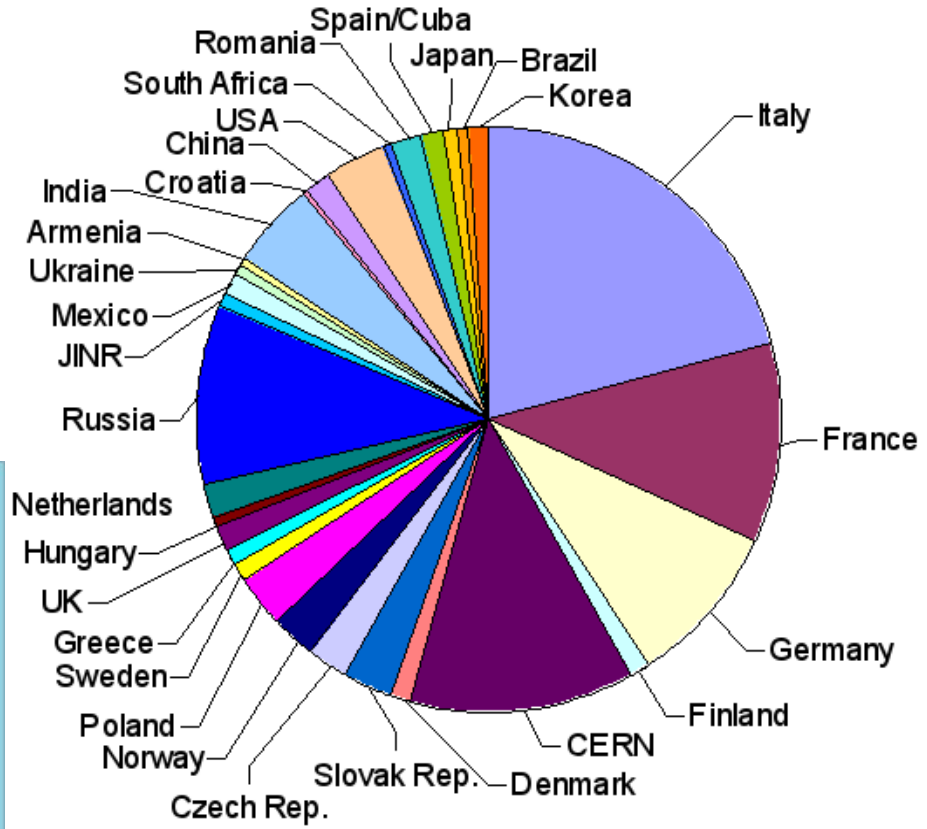
~1000 Members
63% from CERN member states

~30 Countries

~100 Institutes

~150 MCHF capital cost (+magnet)

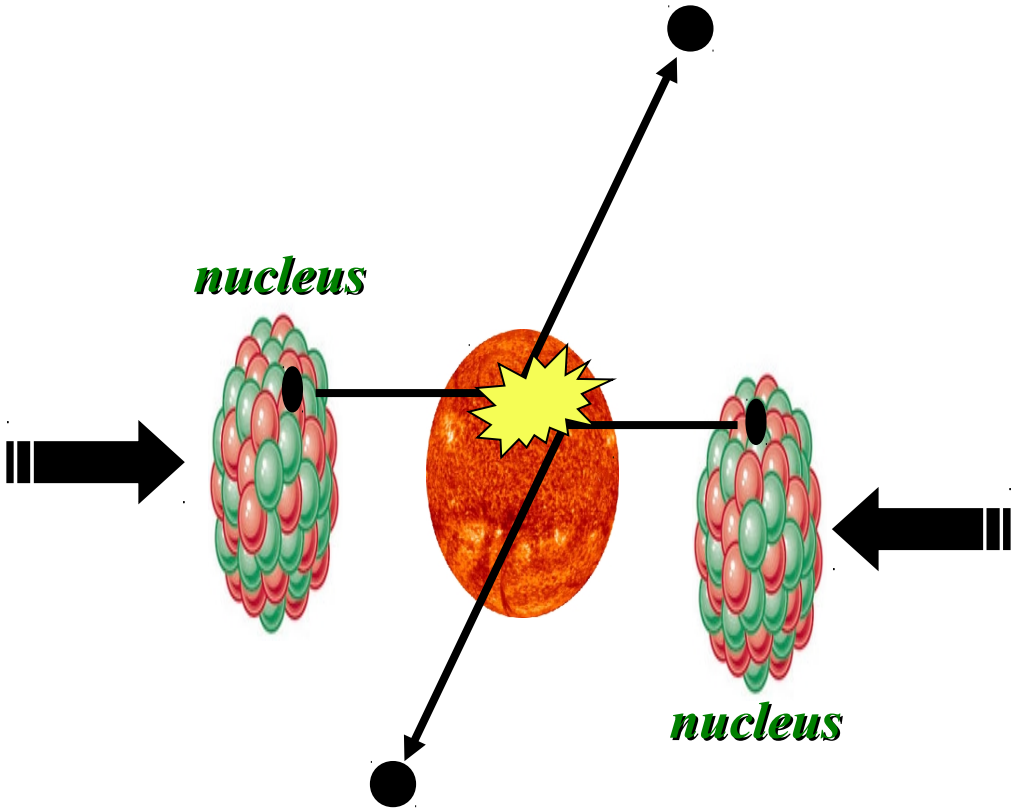


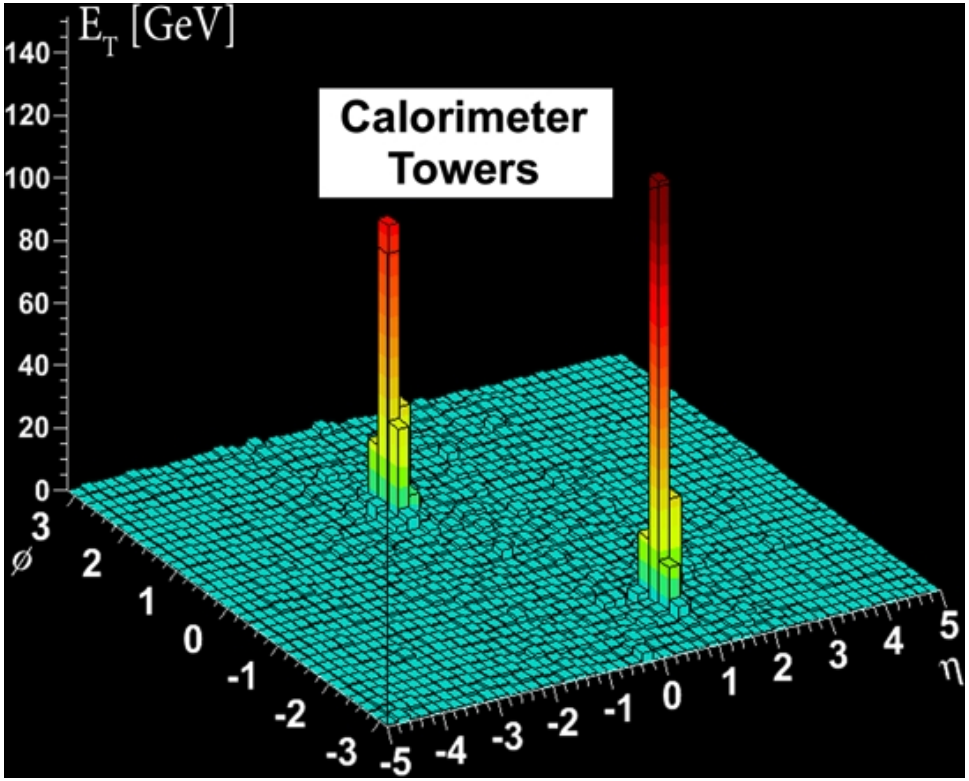


How do we know it's a QGP?

- Jet quenching – high momentum quarks and gluons get stopped in the medium
- Hydrodynamical flow – it moves like a fluid of quarks and gluons
- Chemistry – what we produce is roughly at equlibrium
- Temperature – it is hot enough to match where we think it should be

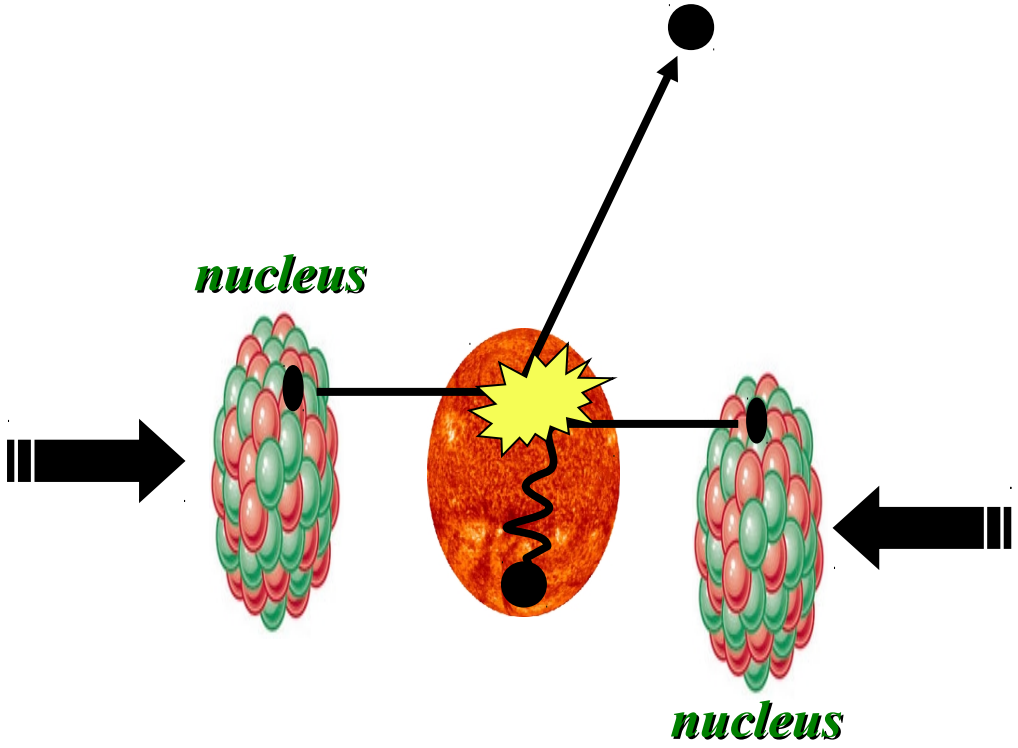
Jets

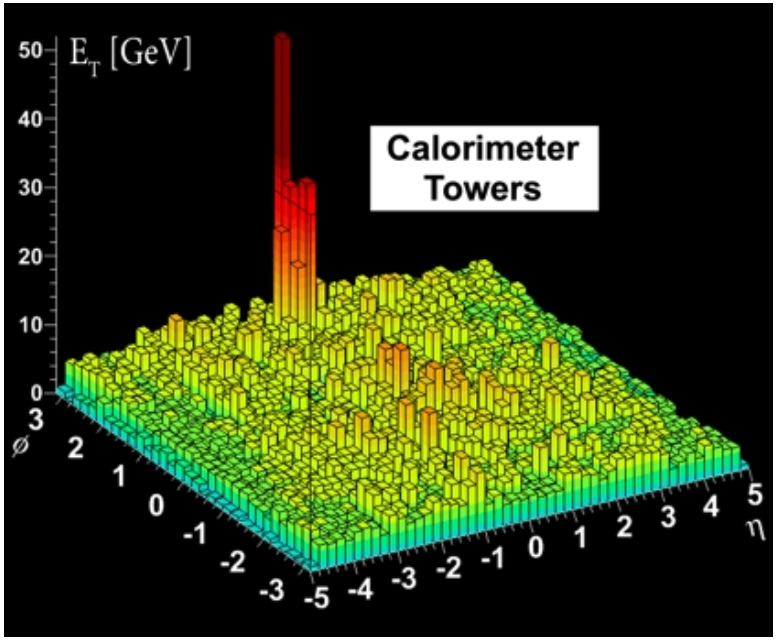




- Quarks and gluons are confined – we don't see them outside of mesons and baryons
- Instead we see a cone of particles around the outgoing quark or gluon
- Looking at jets analogous to spectroscopy

Quenched jets





- One of the jets is absorbed by the medium
- The quark or gluon has equilibrated with the medium
- Phys. Rev. Lett. 105, 252303 (2010)

What we have learned so far

- The QGP is a dense, hot liquid of quarks and gluons
  - Lowest viscosity fluid ever measured
  - It is highly opaque – it stops even fast quarks
  - It's roughly at chemical equilibrium

A bit about me

- Current position: Post doctoral researcher at the University of Tennessee at Knoxville
  - On ALICE (LHC) & PHENIX (RHIC) experiments
- Degrees
  - B.S. Colorado State University, 2003: Physics, biochemistry, and physical science majors with minors in chemistry, math, and German
  - M.Phil., M.Sci., and Ph.D. Yale University, 2009: Physics on STAR (RHIC) experiment
- I did undergraduate research – at UNC Chapel Hill, Colorado State, University of Leiden (Netherlands), and CERN (Switzerland)
- I did not take physics or calculus in high school and only declared a physics major in my second year
- I started as a biochemistry major
- I paid off my undergraduate student loans in grad school by teaching extra
- I spent about 4 months out of the year out of town last year and racked up 40k airline miles
- My husband is a Czech nuclear physicist, he still lives in New York, and we we went to a nuclear reactor on our honeymoon
- Hobbies: running, cooking, brewing beer & wine, cello, biking, hiking

What I spend my time doing

- Programming (c++) - analyzing data
- Writing and giving talks – 3 research talks, 1 seminar, 2 posters, 1 software tutorial, and lots of talks (>30) at internal meetings in 2010
- Hardware work: assembling & testing the detector
- Working with graduate students
- Outreach: blogging for ALICE, giving tours of PHENIX to the public...
- Writing papers and conference proceedings
- Reviewing the work of my collaborators
- Running our journal club
- Reading papers
- Taking shifts – including being on call 24/7

Careers in high energy physics

- You should consider high energy physics if...
  - You like programming and working with computers
  - You're a people person – and don't mind working with 1000 people
  - You like to travel around the world – and work
  - You enjoy giving talks
- Common career options for people with a Ph.D. in high energy physics
  - Academia – research and teaching universities
  - Research at a National Laboratory
  - National security
  - Finance
  - Computer programming

Resources

- US LHC blog and Facebook page
- Experiments
  - Relativistic Heavy Ion Collider: STAR PHENIX
  - Large Hadron Collider: ALICE ATLAS CMS LHCb TOTEM
- Event displays and pretty pictures from ALICE
- Really cool ATLAS event animation
- Links to articles in the press on PHENIX
- Scientific American article

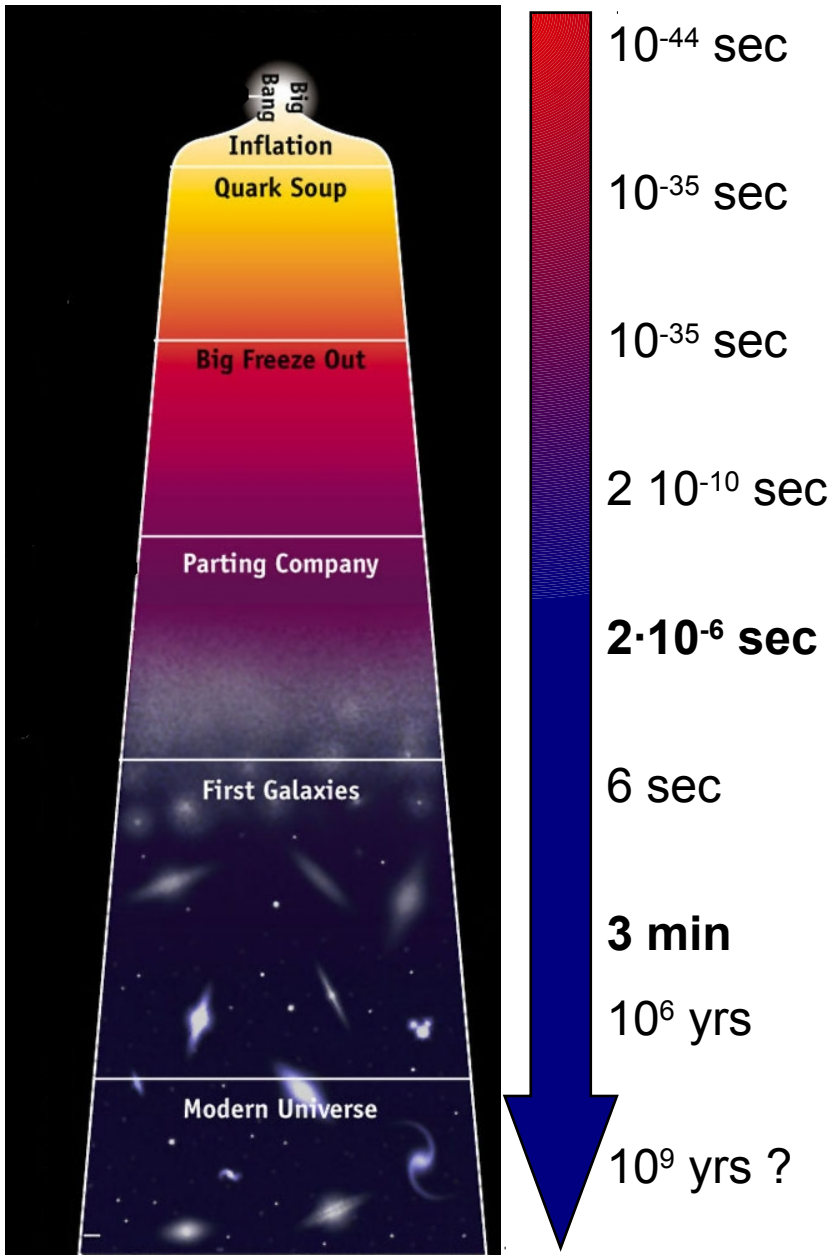
Relativistic Heavy Ion Collider

- STAR
  - University of California at Davis
  - University of California Los Angelos
  - University of Houston
  - University of Illinois at Chicago
  - Creighton University (masters only)
  - Kent State University
  - Michigan State University
  - Ohio State University
  - Purdue University
  - Texas A&M University
  - University of Texas Austin
  - University of Washington
  - Wayne State University
  - Yale University
- PHENIX
  - University of California Riverside
  - University of Colorado Boulder
  - Columbia University
  - Florida State University
  - Georgia State University
  - Iowa State University
  - Ohio University
  - State University of New York (Chemistry & Physics departments)
  - **University of Tennessee at Knoxville**
  - Vanderbilt University

Large Hadron Collider

- ALICE
  - University of Texas Austin
  - Chicago State University
  - Ohio State University
  - Wayne State University
  - University of Texas Houston
  - **University of Tennessee Knoxville**
  - Yale University
  - Creighton University (masters only)
  - Purdue University
- CMS
  - University of California Davis
  - University of Illinois Chicago
  - University of Kansas
  - University of Maryland
  - University of Iowa
  - Rutgers University
  - Massachusetts Institute of Technology
  - Vanderbilt University
- ATLAS
  - Columbia University

Evolution of the Universe



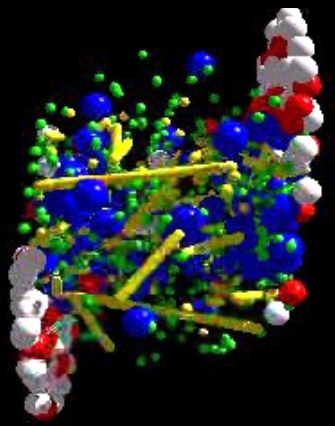
The universe gets cooler!

Reheating matter?
Need temperatures around $1.5{\cdot}10^{12}$ K
$\sim 10^{6}$ times hotter than the core of the sun

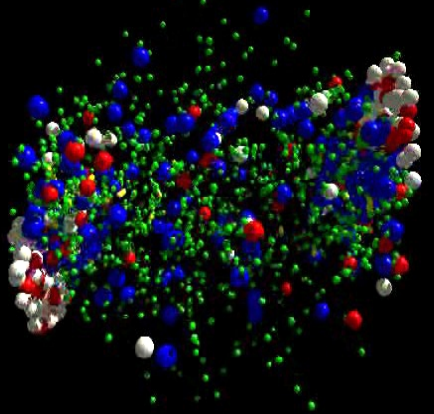
Making a QGP in the laboratory

Relativistic pancakes

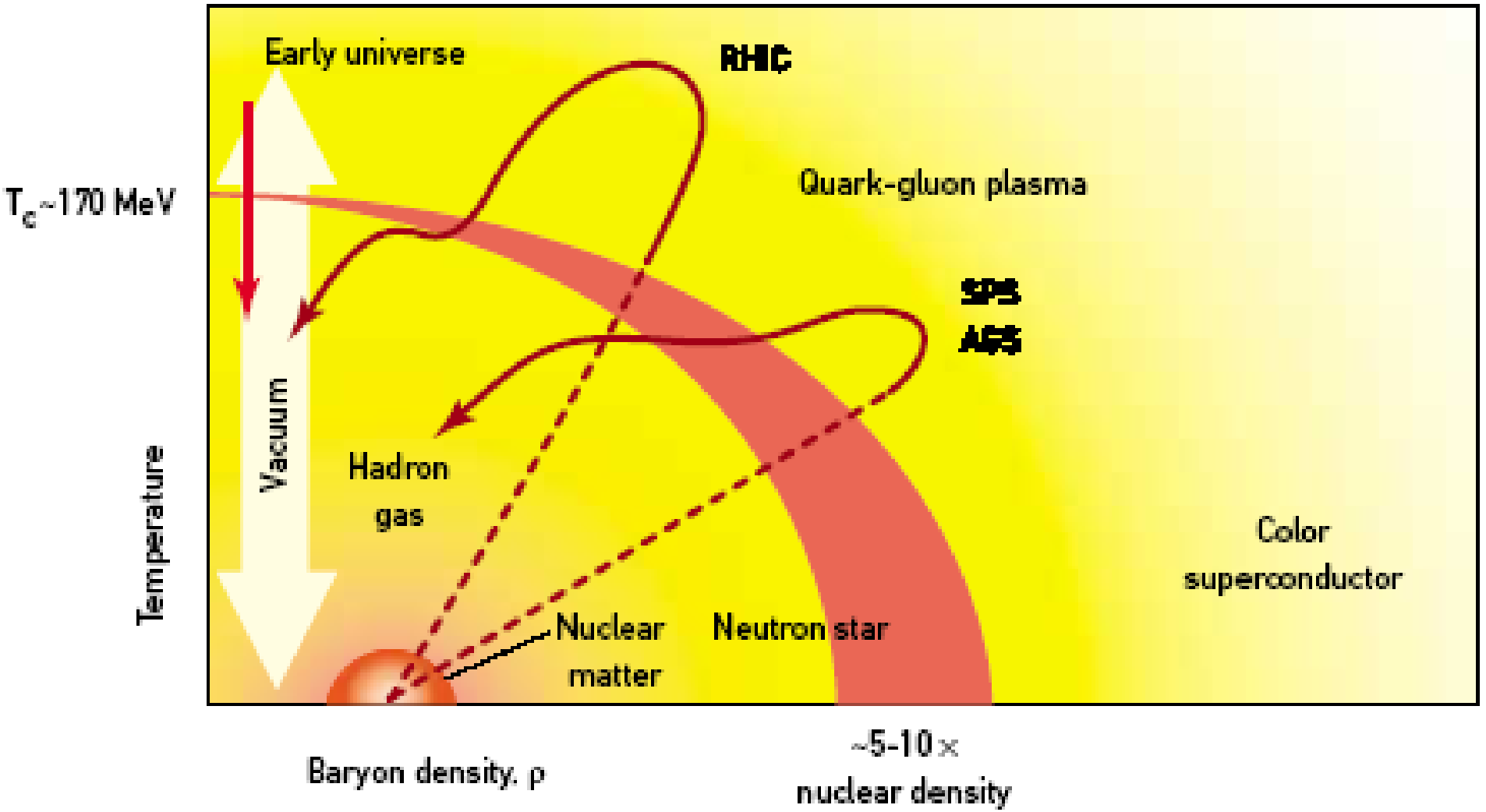
Quark soup



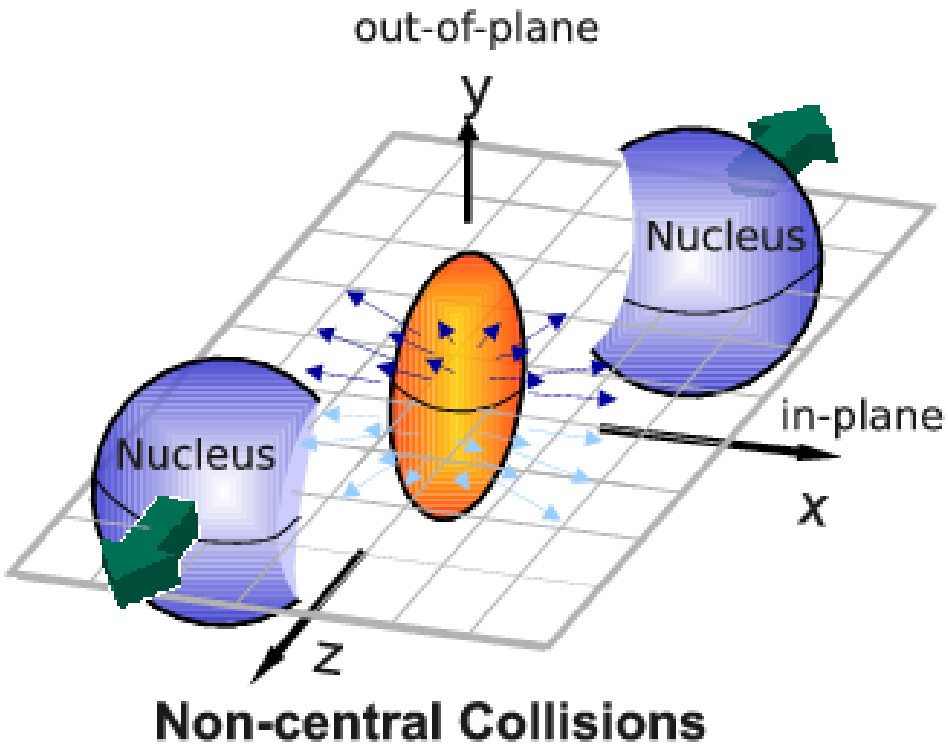
Explosive hadron soda



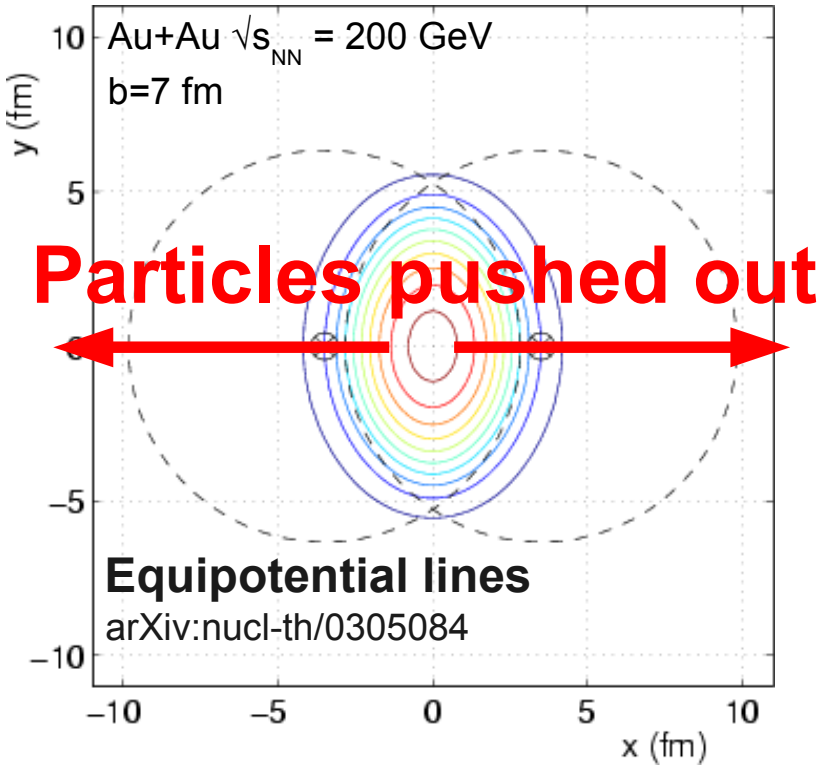
Phase Diagram of Nuclear Matter



Hydrodynamical flow

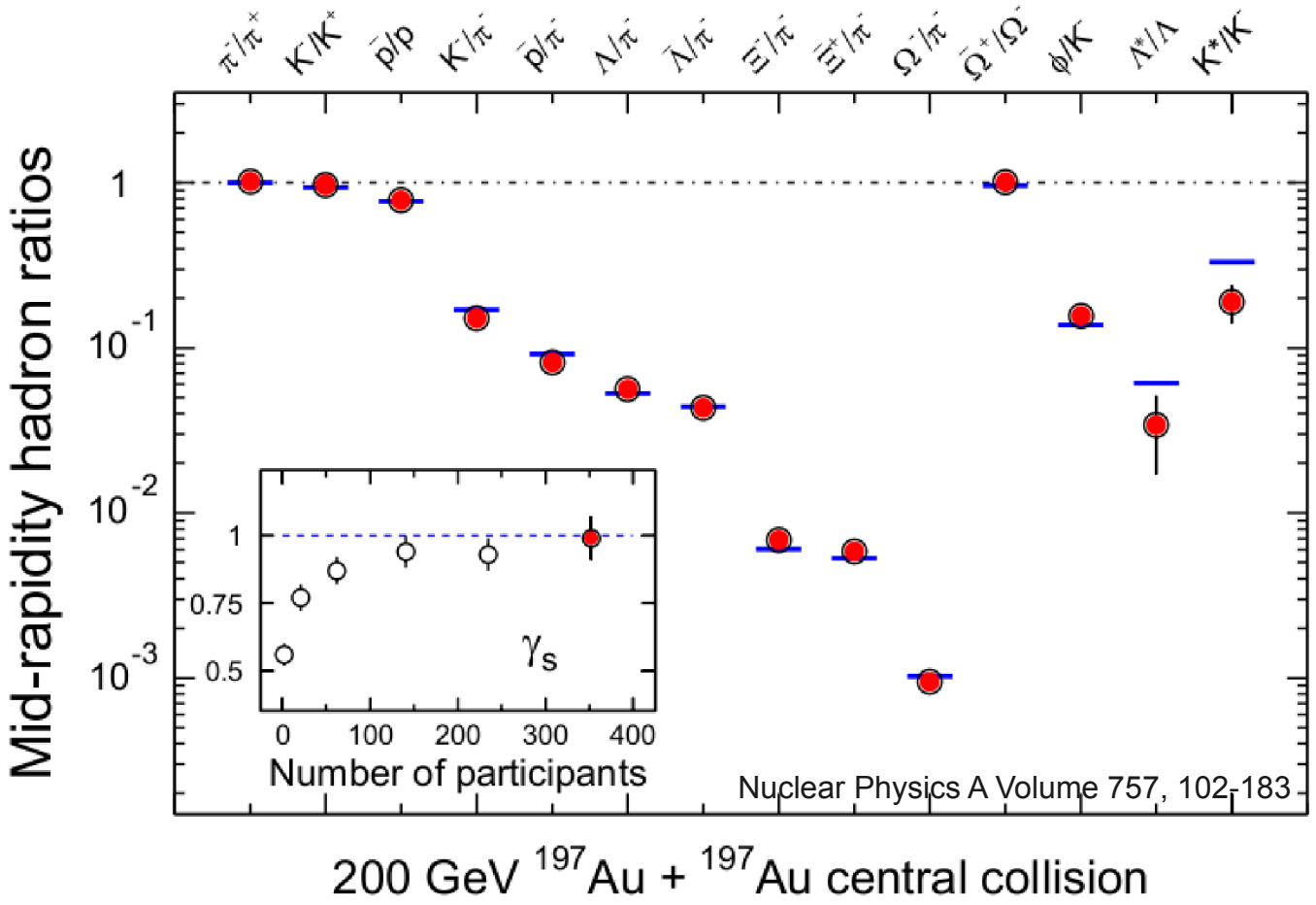


Non-central Collisions



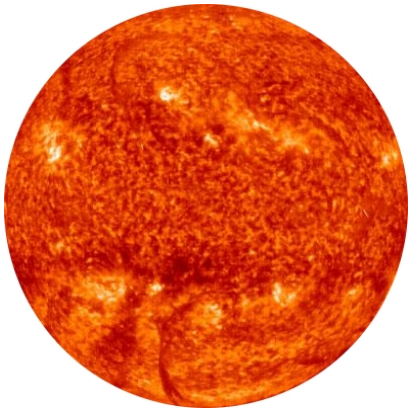
- When nuclei collide, the overlap region is roughly elliptical
- If we have a fluid when we collide nuclei, there will be pressure gradients, pushing particles out
- We have measured this – and the liquid is made of quarks and gluons

Chemistry - equilibrium

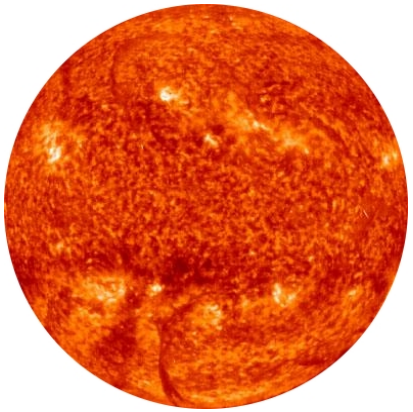


- Ratios of particles expected from a model
- Even strange quarks are at equilibrium!

A simple picture of a heavy ion collision



Jets as a probe of the quark gluon plasma



One jet “absorbed” by the medium