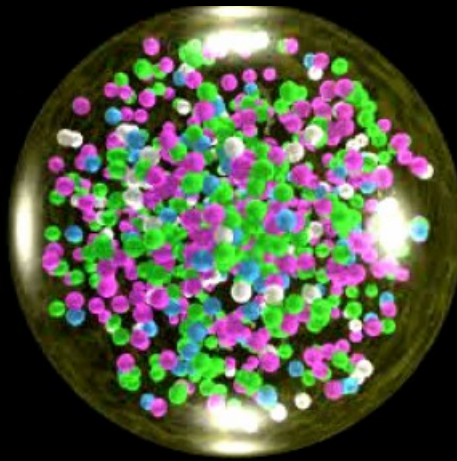


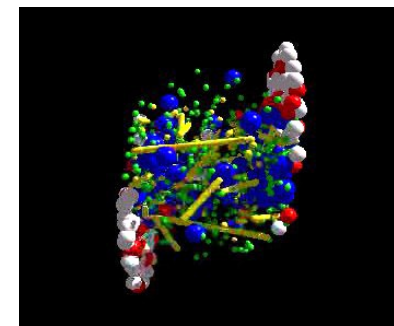
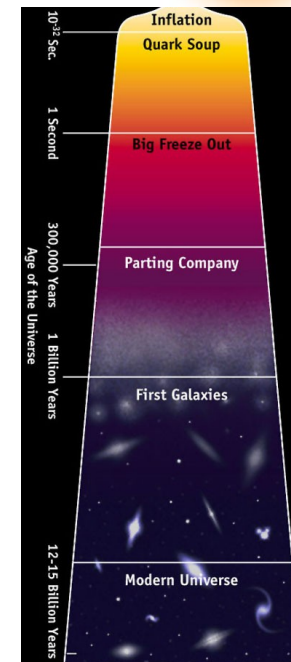
*The little bang: understanding
the quark gluon plasma*



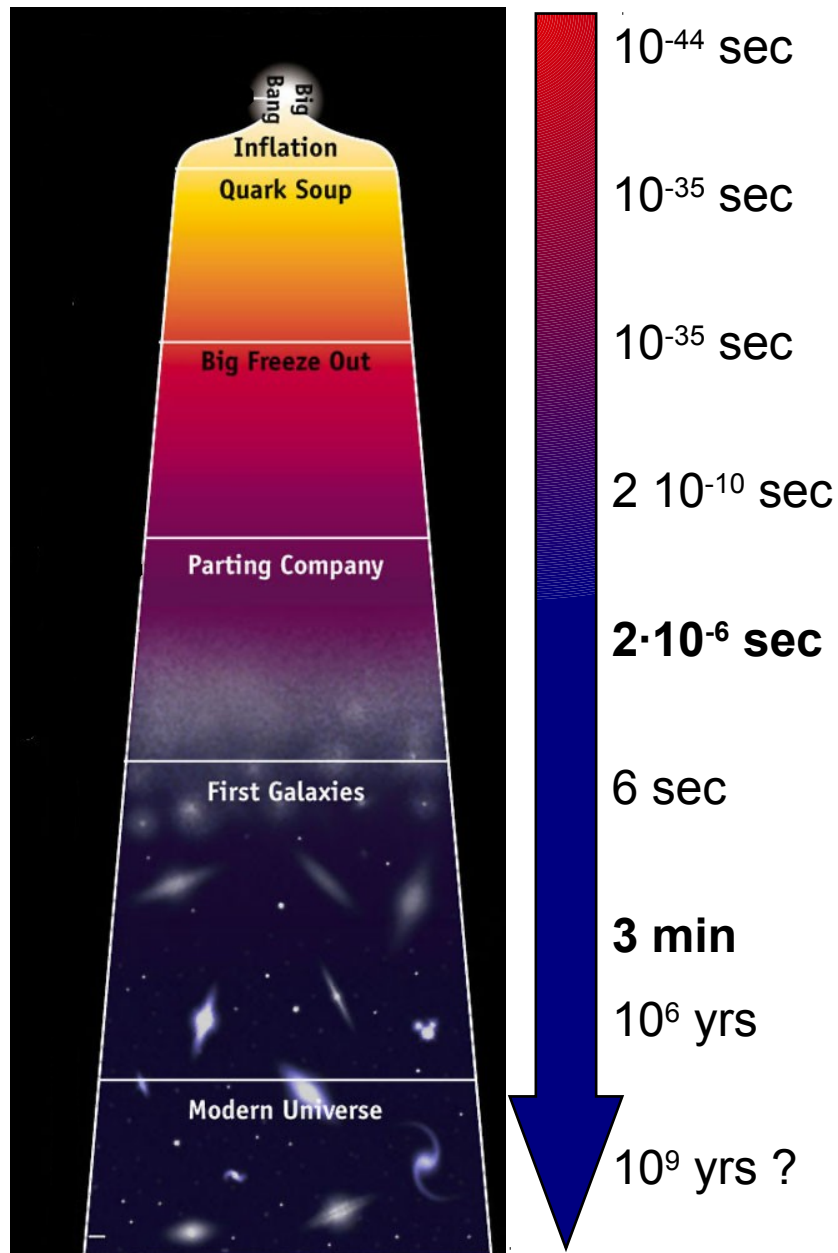
*Christine Nattrass
University of Tennessee at Knoxville*

Take home messages

- If we get nuclear matter dense enough, we make a new phase of matter
- This quark gluon plasma is similar to what was present in the early universe
- We can produce a QGP in high energy heavy ion collisions



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

Nucleons – the proton and neutron



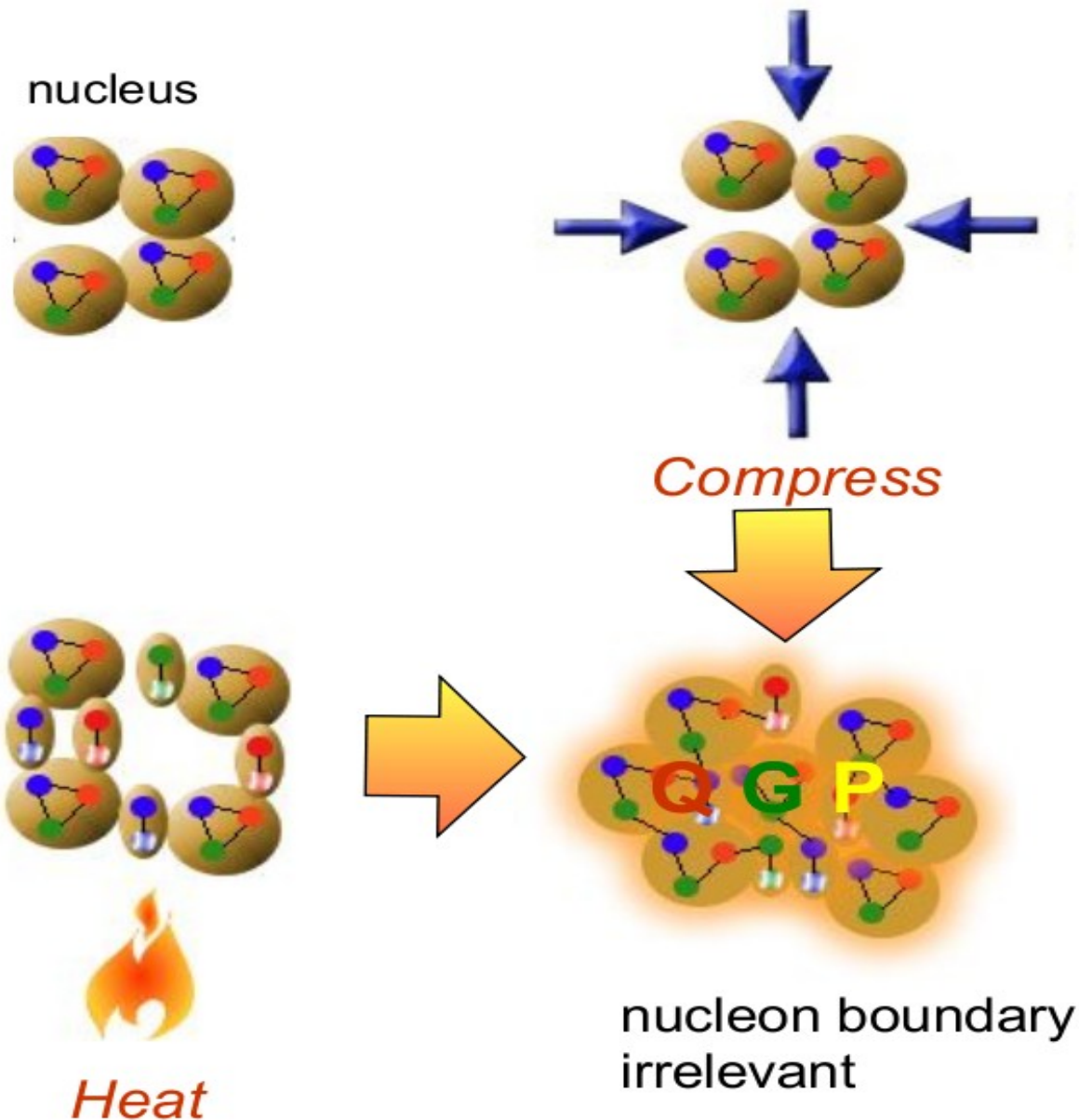
Neutron

Proton

http://en.wikipedia.org/wiki/Image:Quark_structure_neutron.svg

http://en.wikipedia.org/wiki/Image:Quark_structure_proton.svg

How can we see “free” quarks?

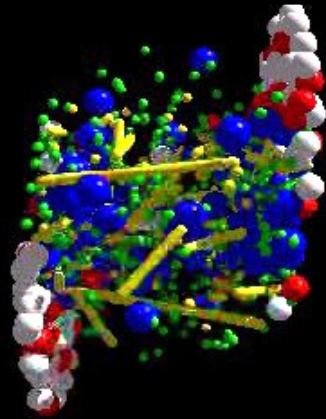


Making a QGP in the laboratory

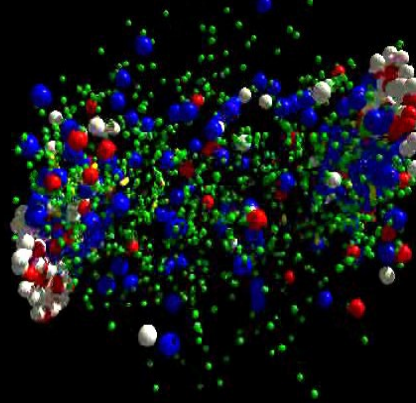
Relativistic pancakes

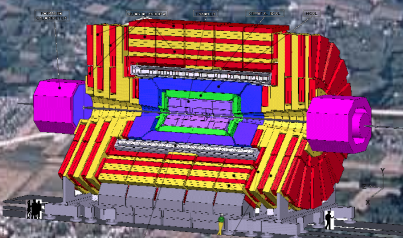


Quark soup



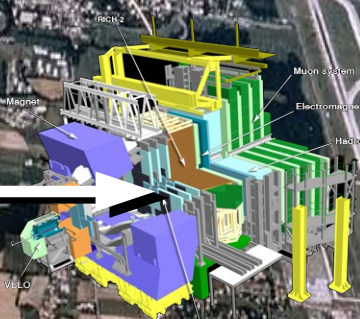
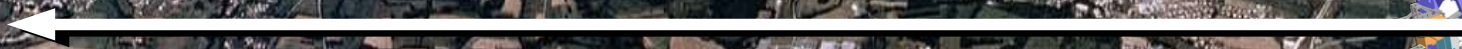
Explosive hadron soda





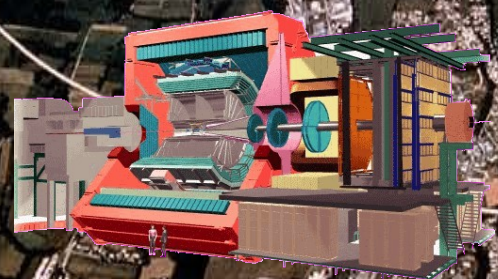
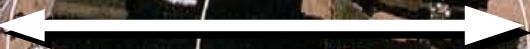
CMS

5.3 miles

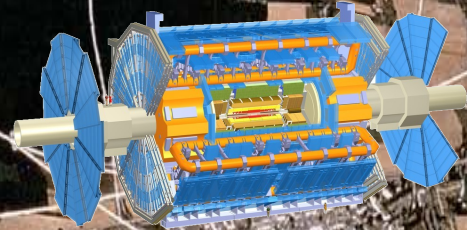


LHCb

1.4 miles

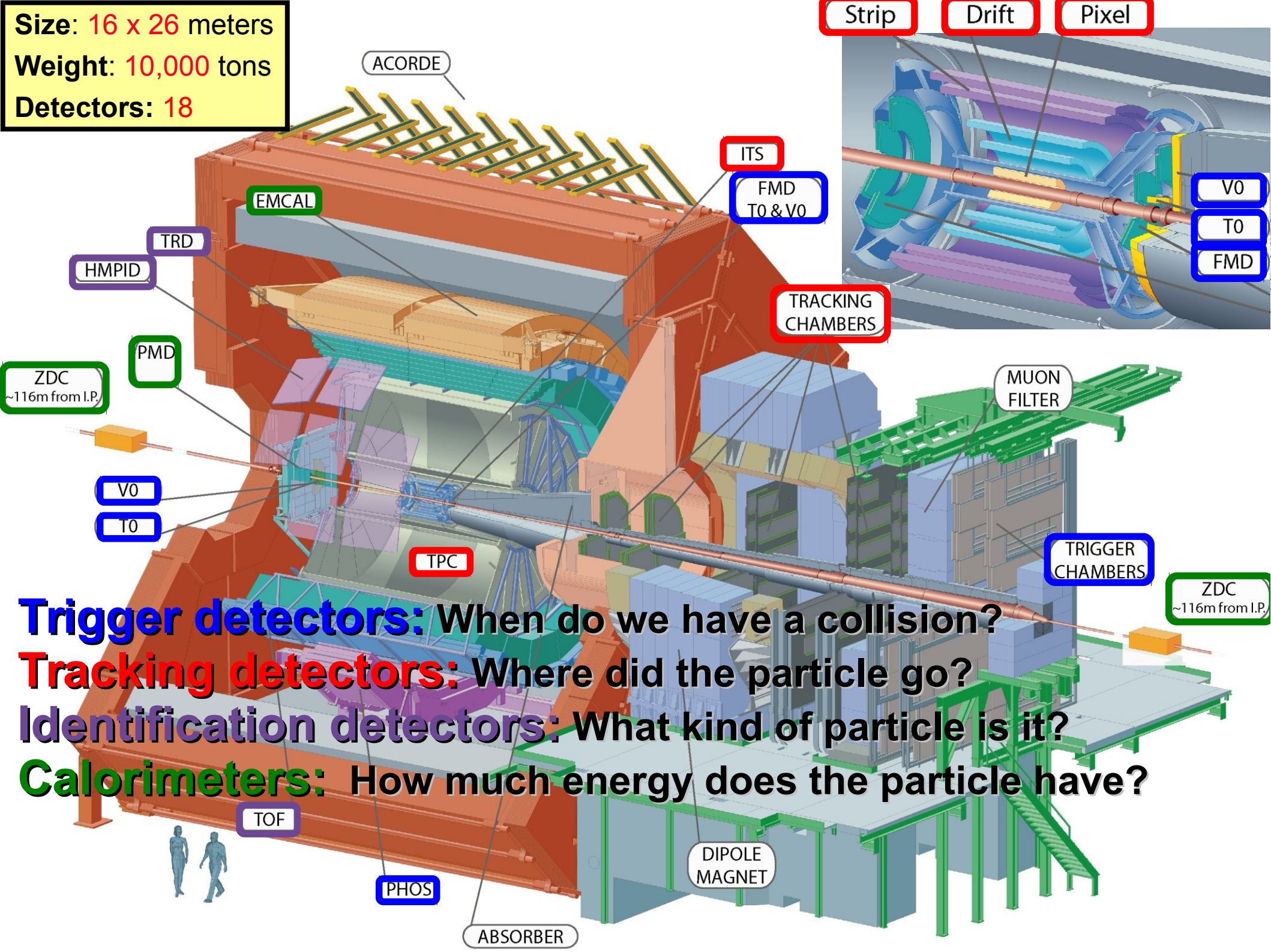


ALICE

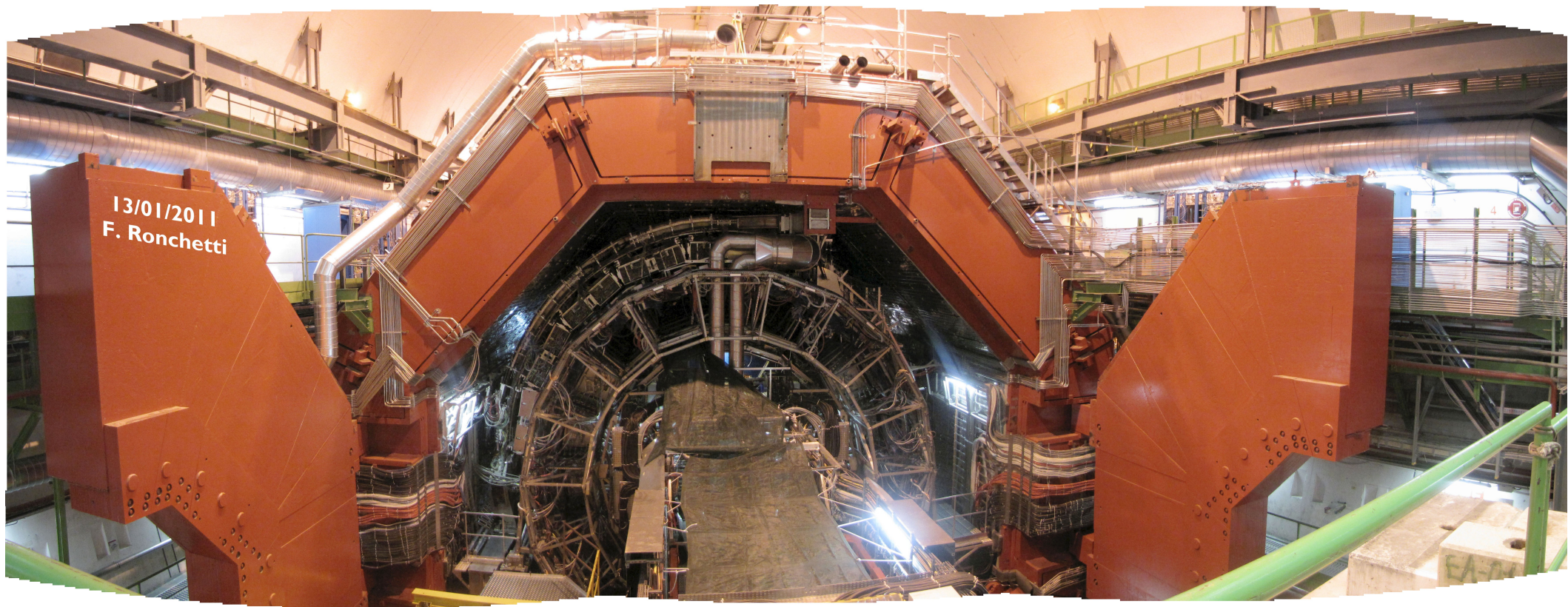


**ATLAS
LHCf**

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

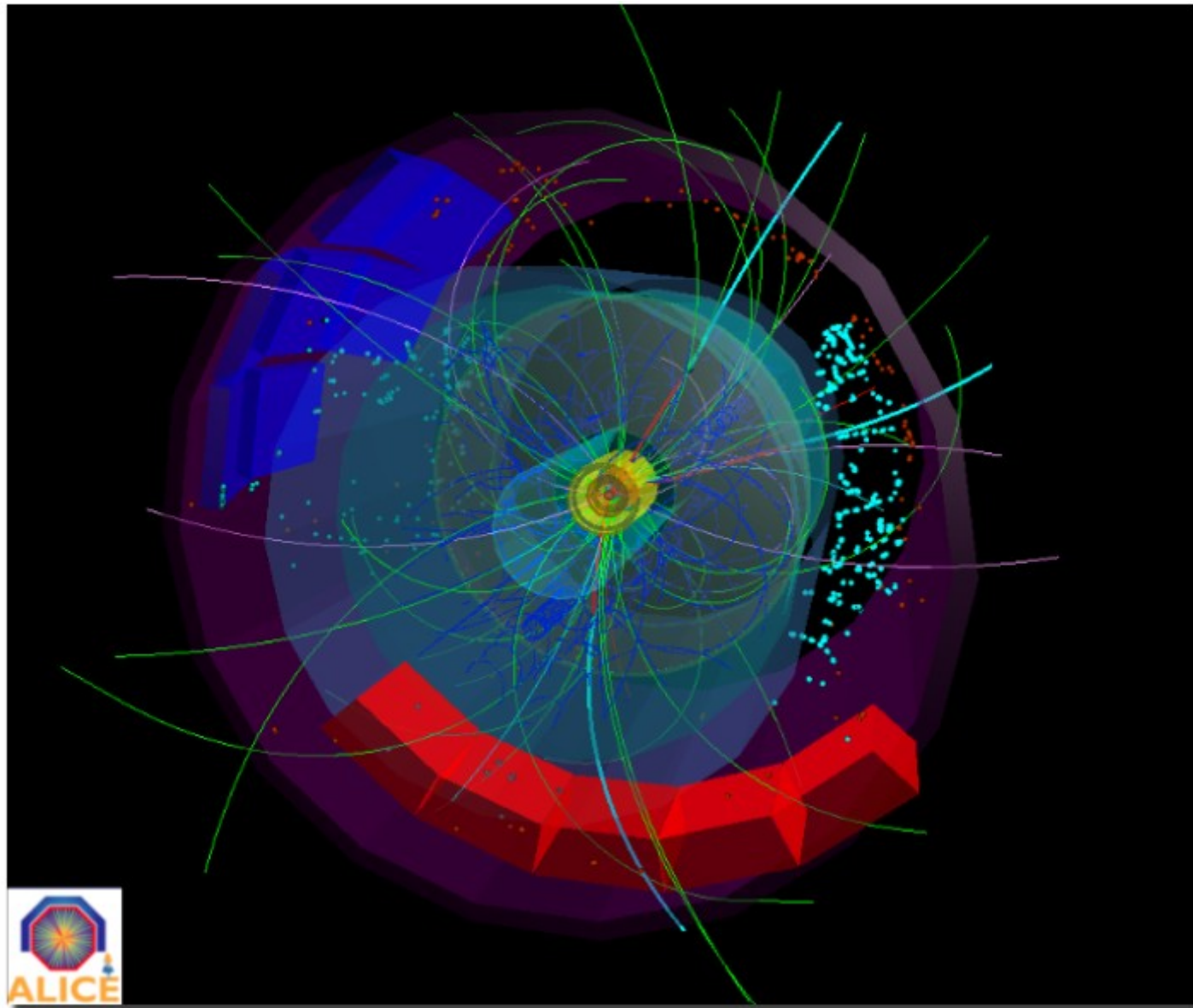


Trigger detectors: When do we have a collision?
Tracking detectors: Where did the particle go?
Identification detectors: What kind of particle is it?
Calorimeters: How much energy does the particle have?

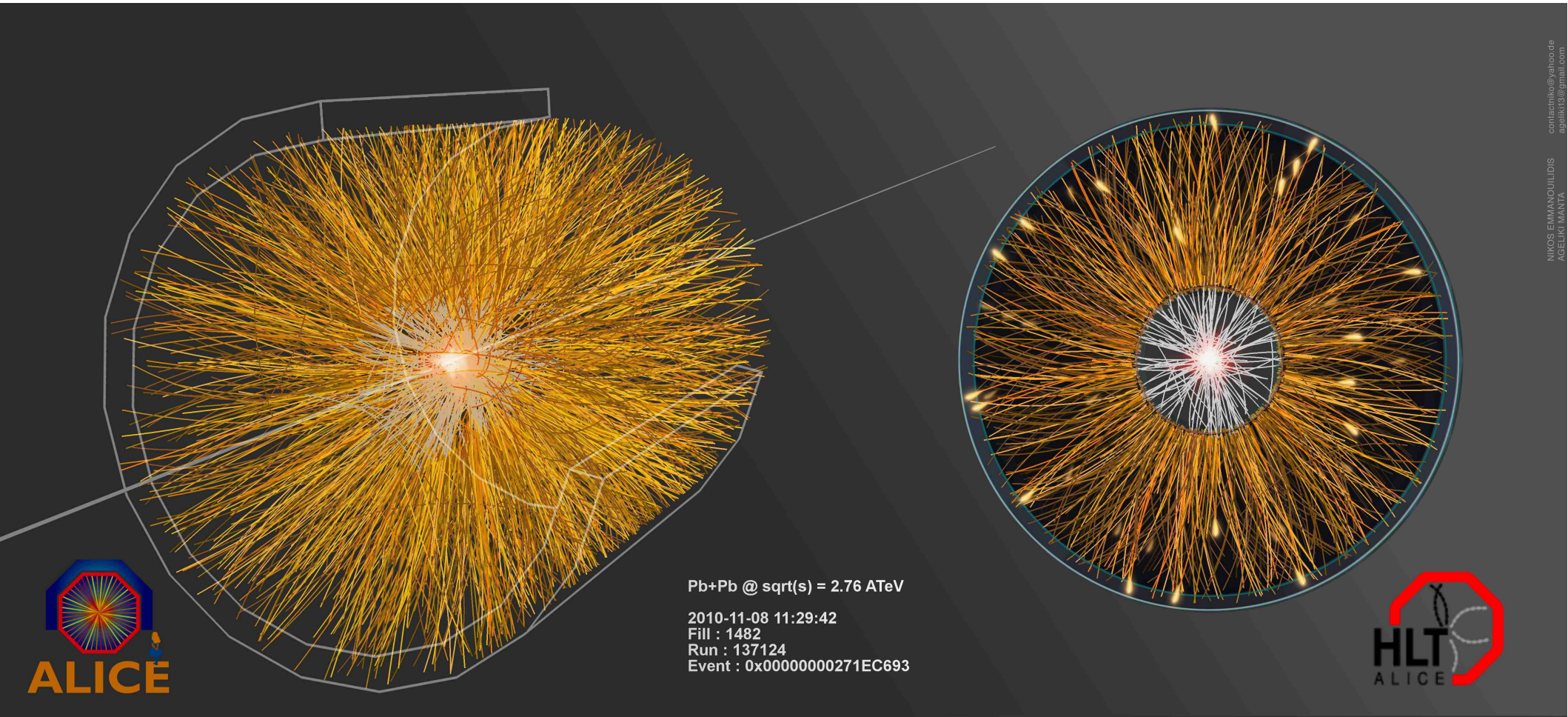




p+p collisions



Pb+Pb collisions



Scales

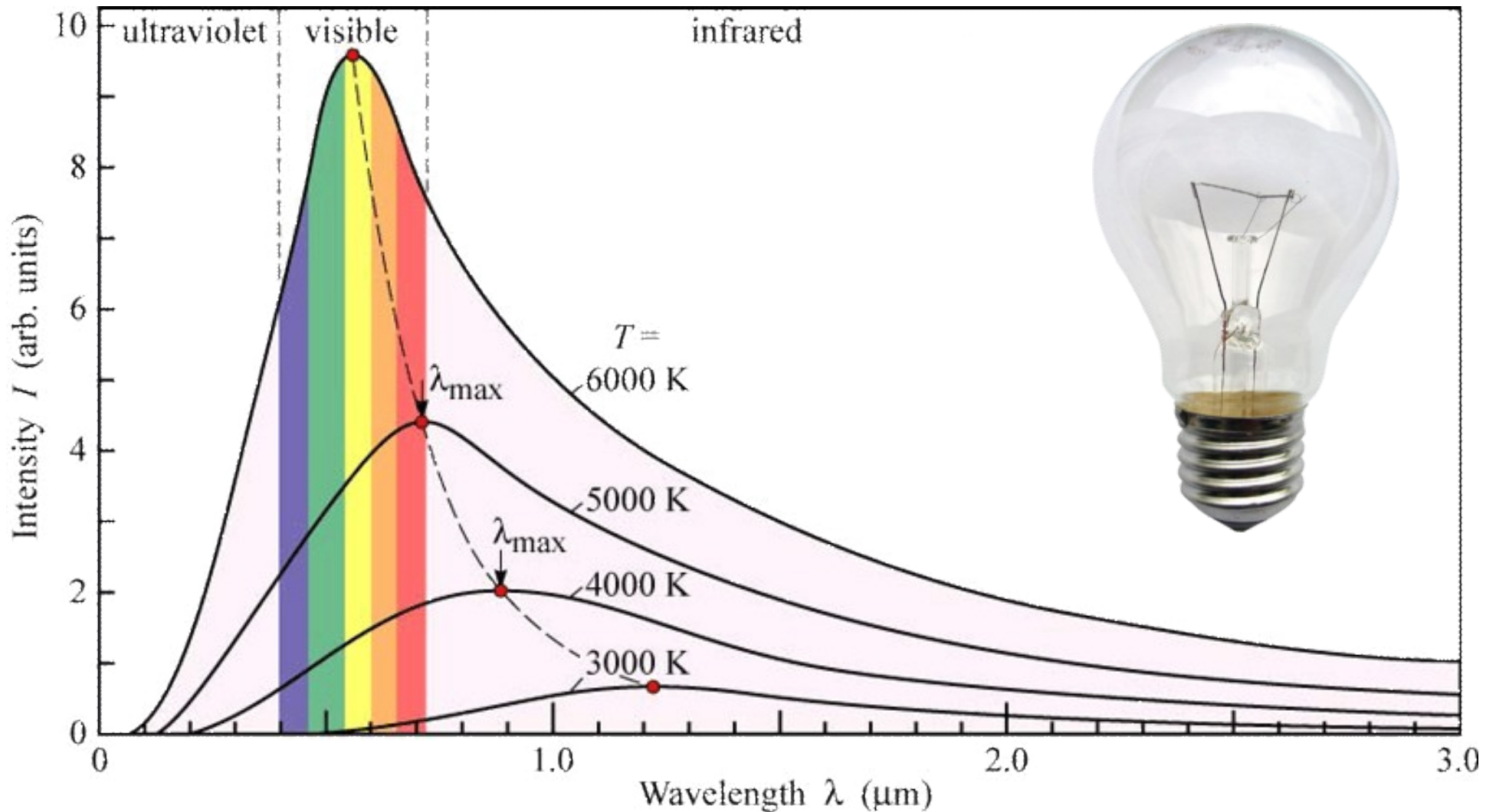
- Time: $\sim 10^{-23}$ seconds
 - 1 minute for us $\sim 1,000,000$ lifetimes of the universe for QGP
- Energy: 1 TeV ~ 10 trillionths (10^{-11}) of a Calorie
 - About the amount of energy if two mosquitoes collide
 - About 1 trillionth of a candy bar
- Energy density: $\sim 6-8 \text{ GeV}/\text{fm}^3$
 - 10^{35} times that of a candy bar (\sim trillion trillion trillion candy bars)
 - About the energy density if you packed the energy that could be released from a million kg of fuel for a nuclear power plant into a cube with each side the width of a hair
- Temperature: ~ 1.5 billion Kelvin
 - A million times hotter than the core of the sun

Scales

- Number of particles: $\sim 2000-3000$
 - Same number as in $1 \mu\text{m}^3 = 1/16 \text{ in}^3$ of air
- Size of QGP: $1 \text{ fm}^3 = 10^{-45} \text{ m}^3$
 - If this room were the size of the solar system, the QGP could fit in 1 cm^3
- Data volume: PB $\sim 1,000,000 \text{ GB}$
- Data rates: $\sim 1 \text{ PB/month}$ written to disk, a few GB/second

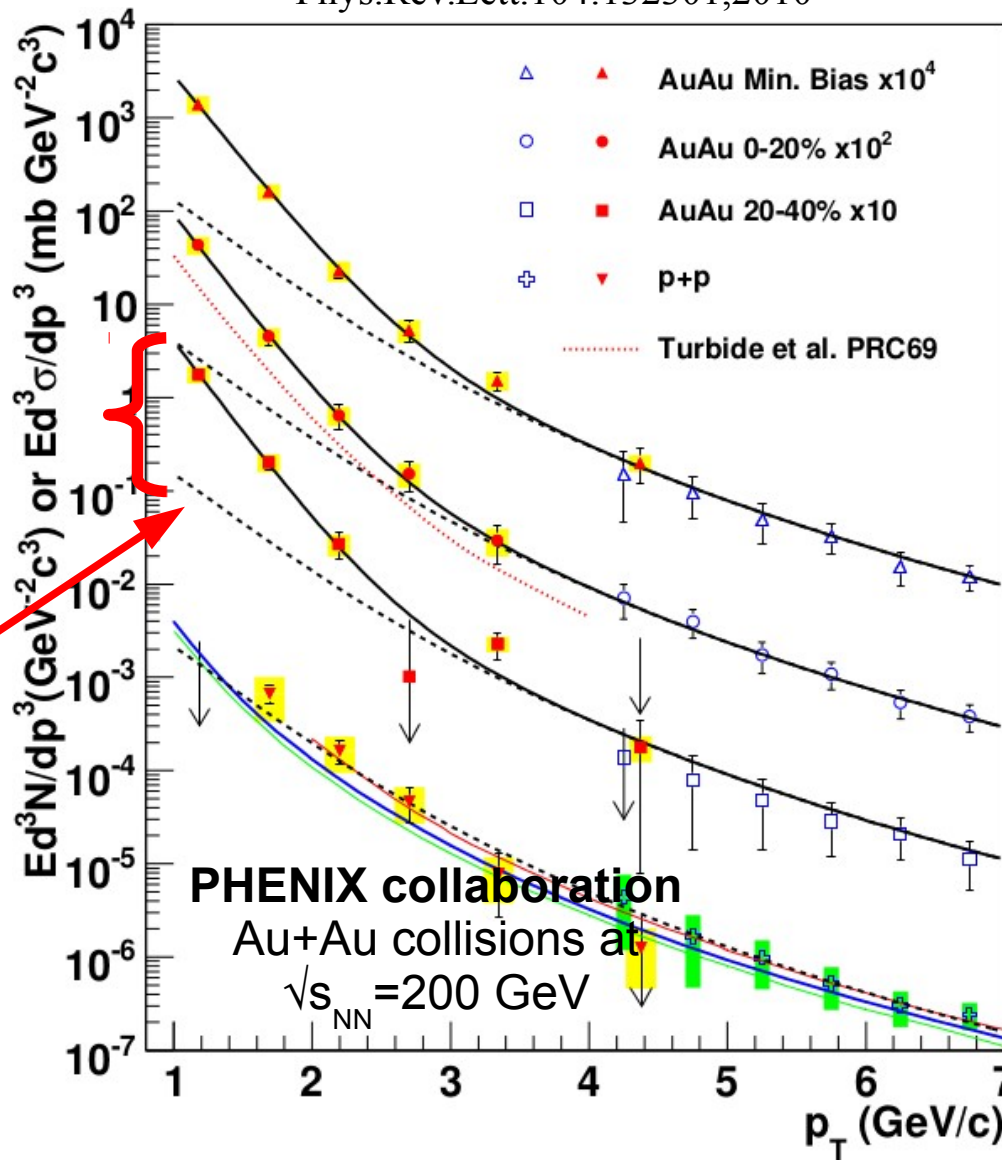
Measuring temperature

Thermal photons



Thermal photons

Phys.Rev.Lett.104:132301,2010



Thermal photons

Other processes

Inverse slope:
 $T = 221 \pm 19 \text{ (stat)} \pm 19 \text{ (syst)} \text{ MeV}$

Consistent with models with
 $T = 300\text{-}600 \text{ MeV}$

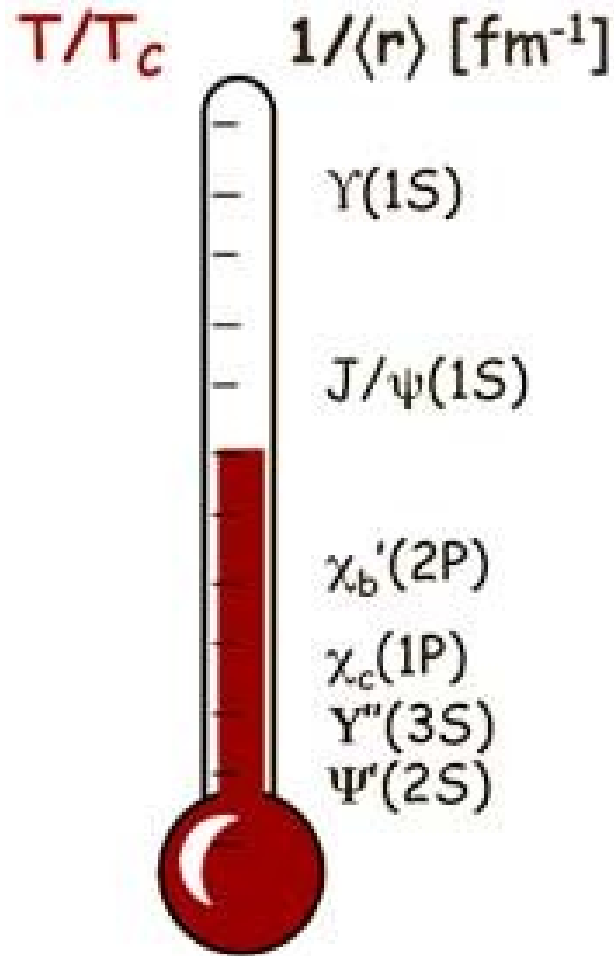
$T_c \sim 170 \text{ MeV}$

PHENIX collaboration

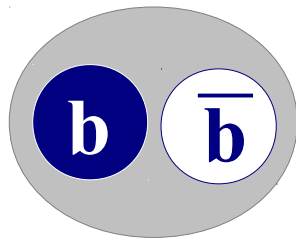
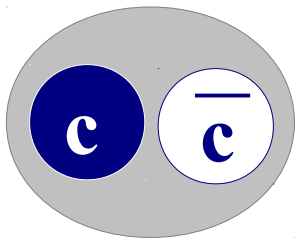
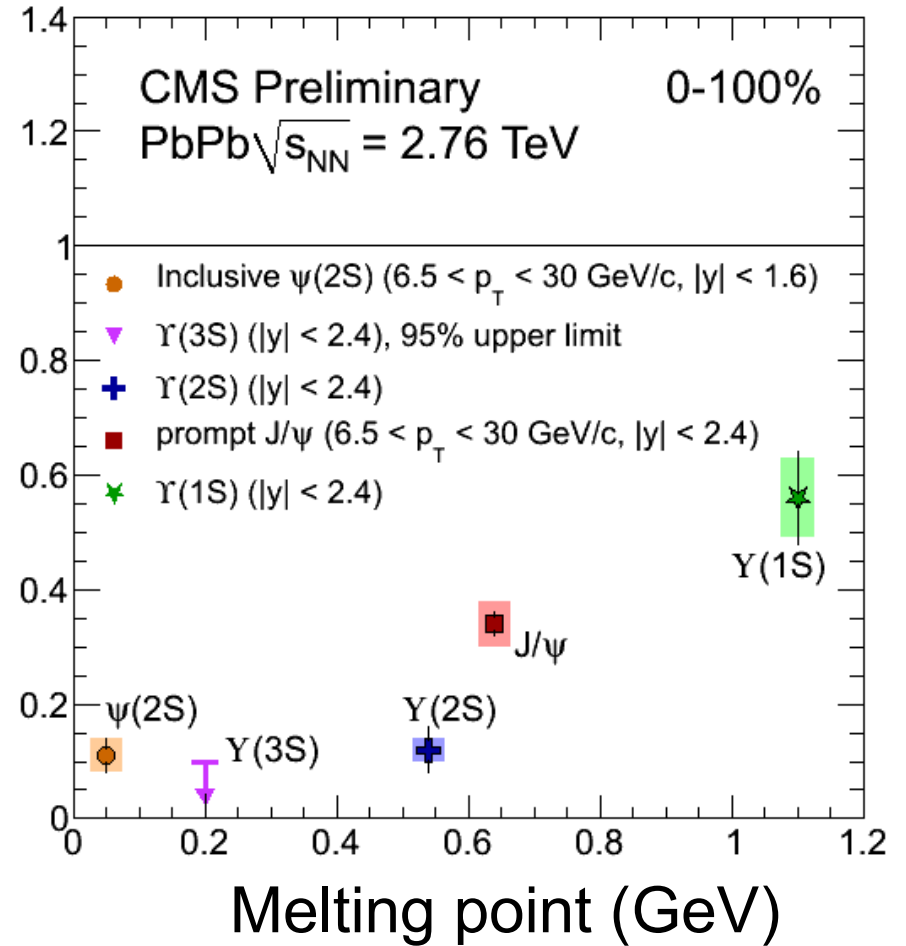
Au+Au collisions at

$\sqrt{s_{NN}} = 200 \text{ GeV}$

Quarkonium-thermometer



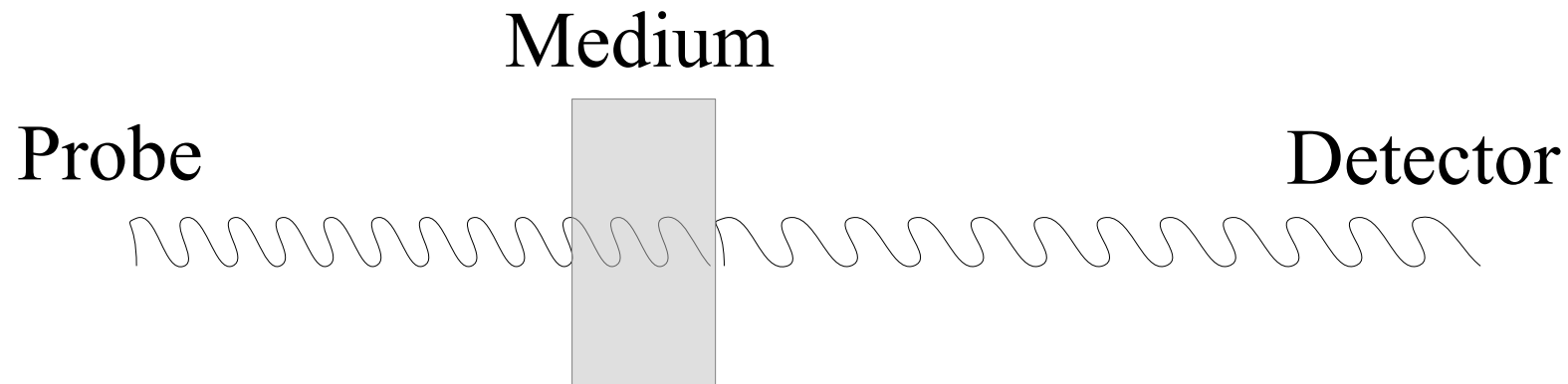
Number of particles seen/number of particles created



CMS-PAS HIN-12-014, HIN-12-007

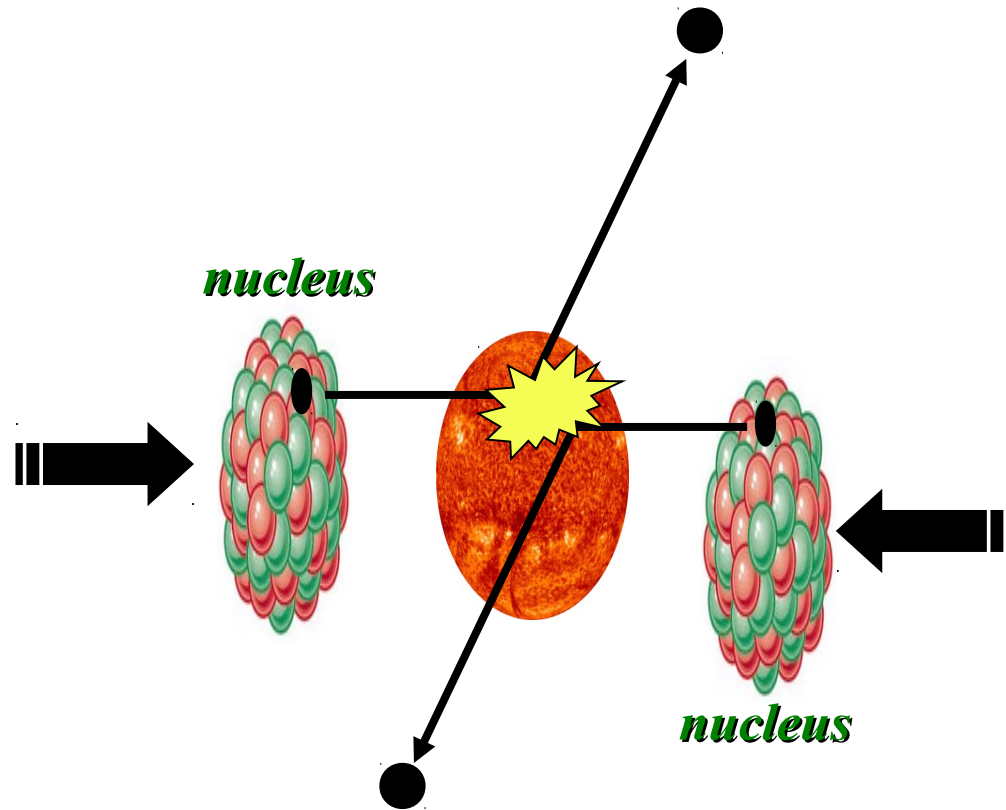
Imaging the Quark Gluon Plasma

Probing the Quark Gluon Plasma



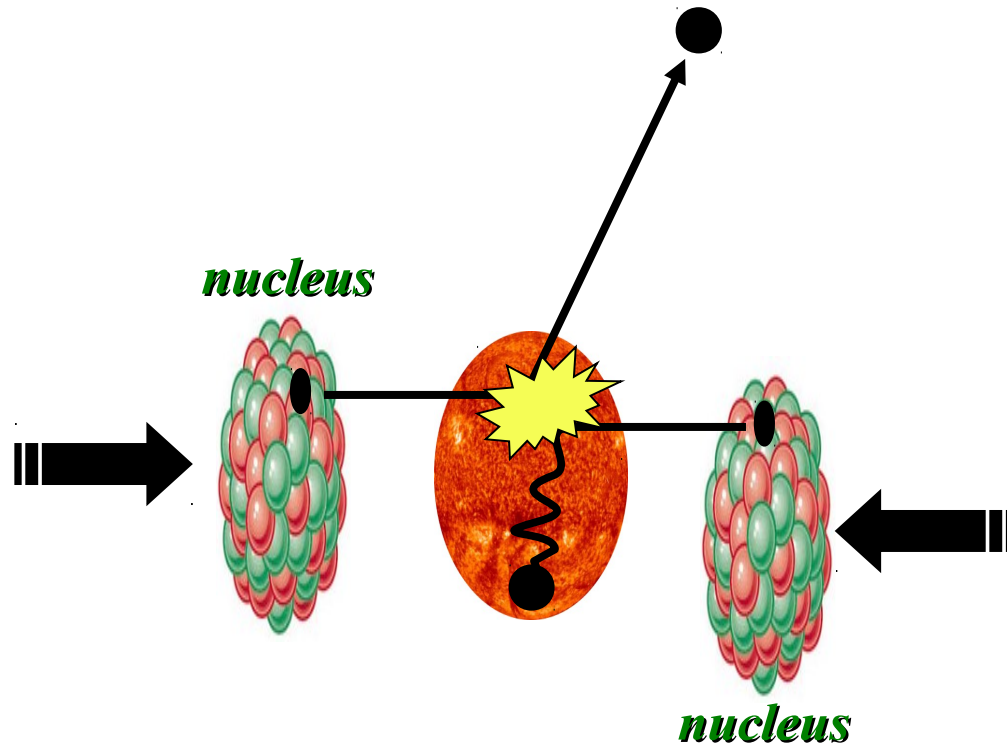
Want a probe which traveled through the collision
QGP is very short-lived ($\sim 1-10$ fm/c) \rightarrow
cannot use an external probe

Probes of the Quark Gluon Plasma



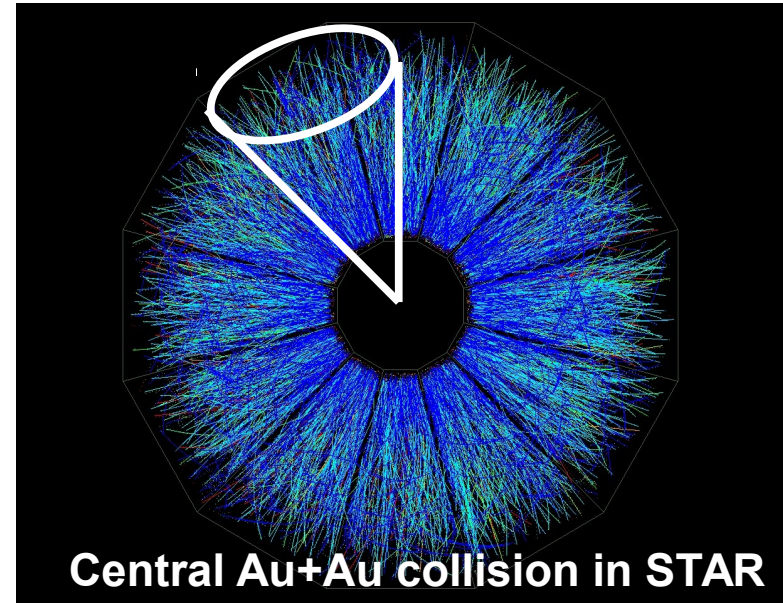
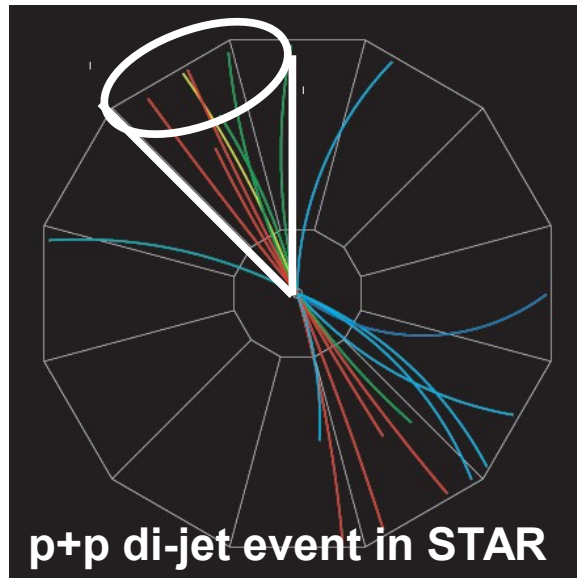
Want a probe which traveled through the medium
QGP is short lived \rightarrow need a probe created in the collision

Probes of the Quark Gluon Plasma



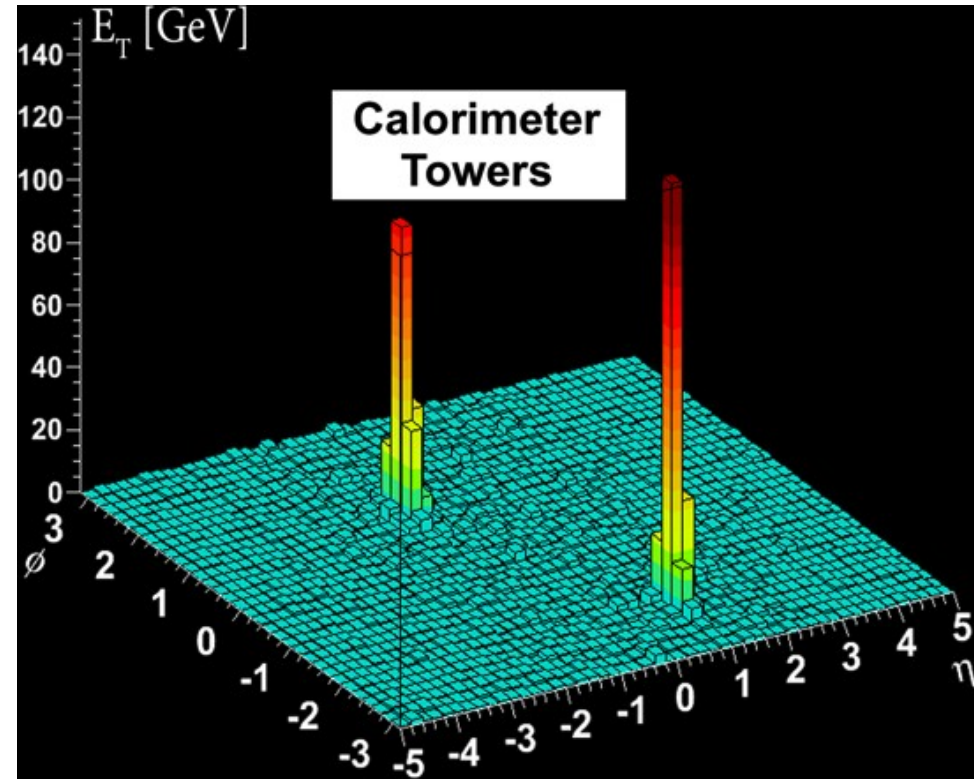
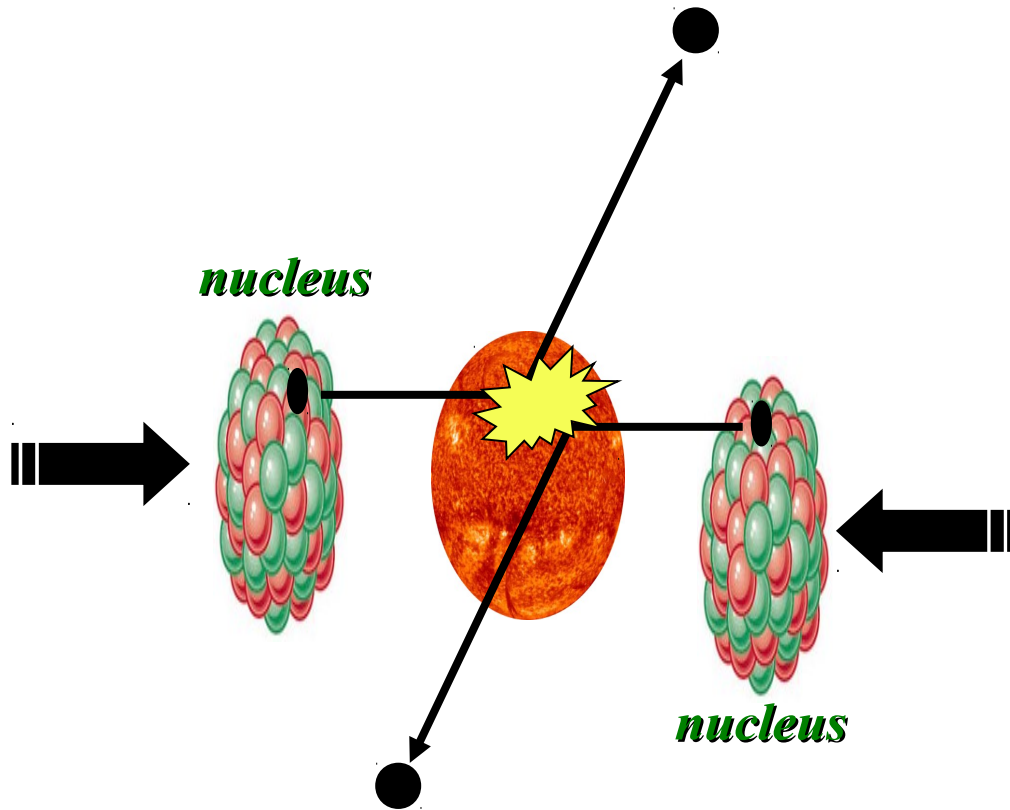
Want a probe which traveled through the medium
QGP is short lived \rightarrow need a probe created in the collision
We expect the medium to be dense \rightarrow absorb/modify probe

Jet reconstruction



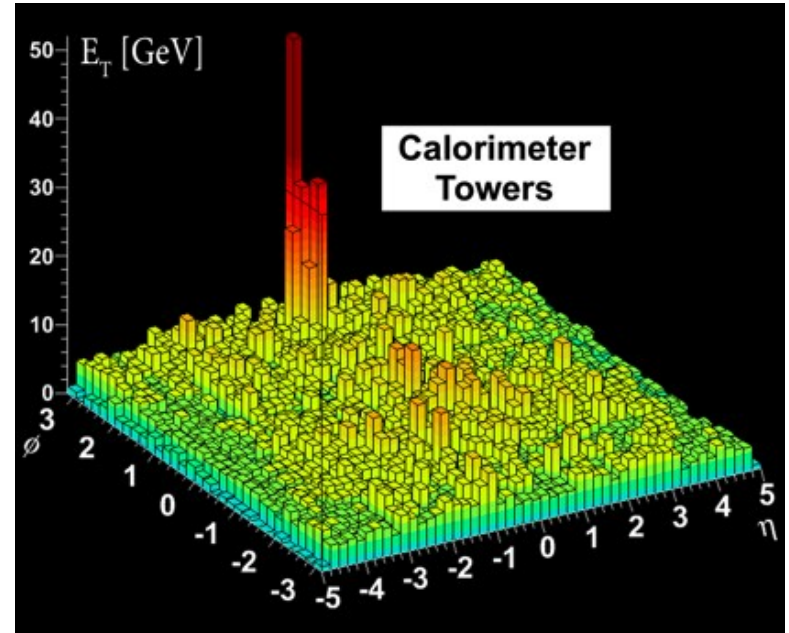
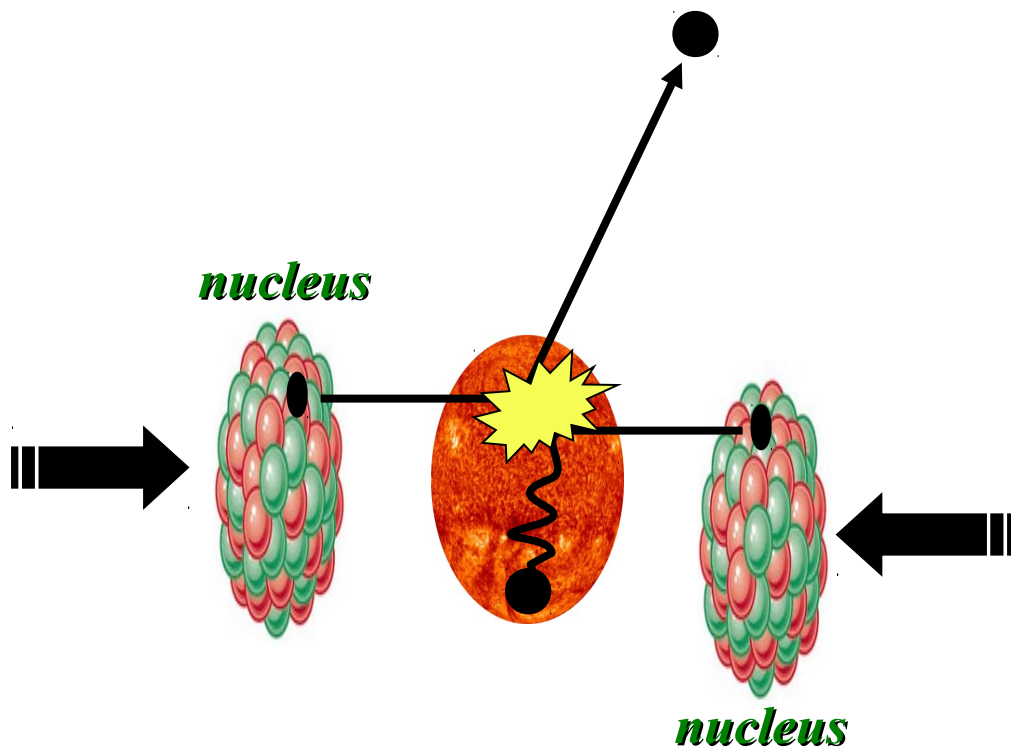
- Identify all of the particles in the jet \rightarrow parton energy, momentum
- Difficult in heavy ion collisions – but possible!

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

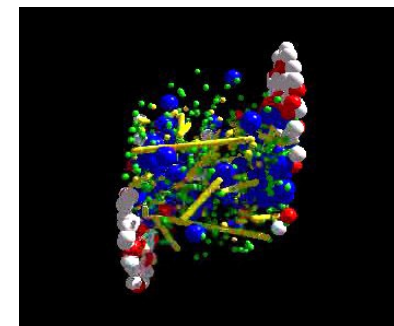
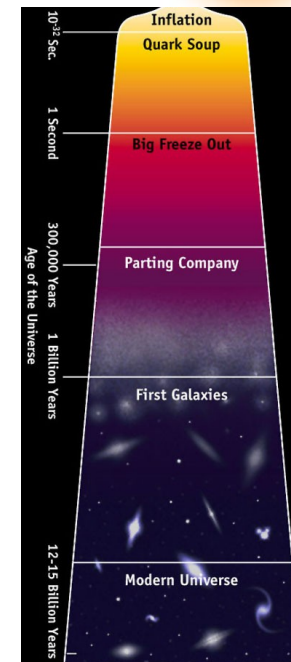
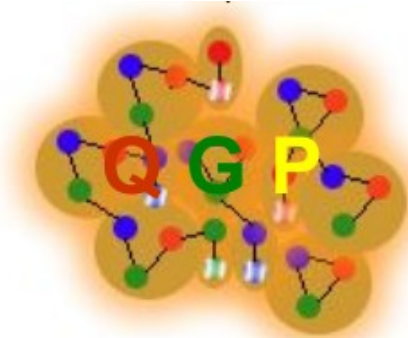
Quenched jets



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

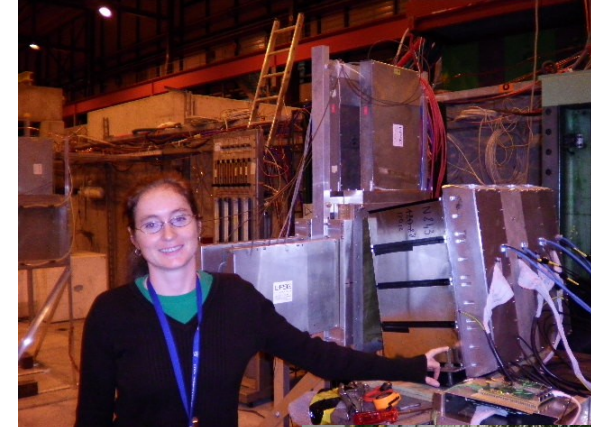
Take home messages

- If we get nuclear matter dense enough, we make a new phase of matter
- This quark gluon plasma is similar to what was present in the early universe
- We can produce a QGP in high energy heavy ion collisions



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











Christine Natrass(UTK





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](#)