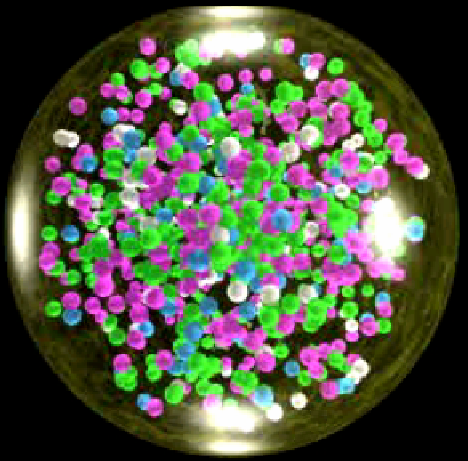
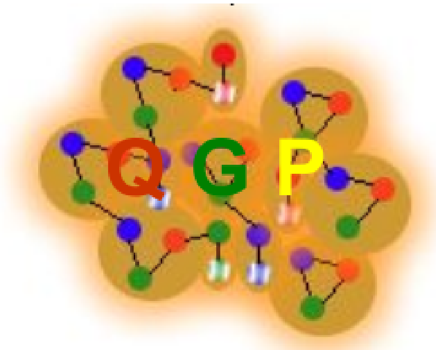
# *The little bang: understanding the quark gluon plasma*

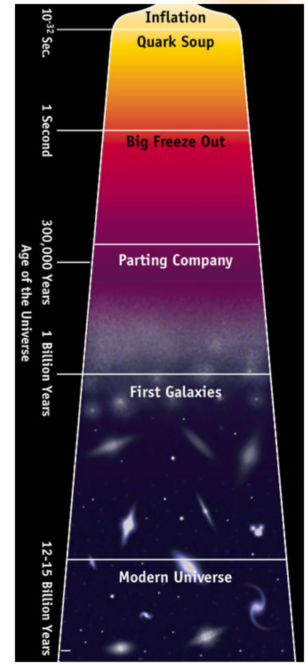


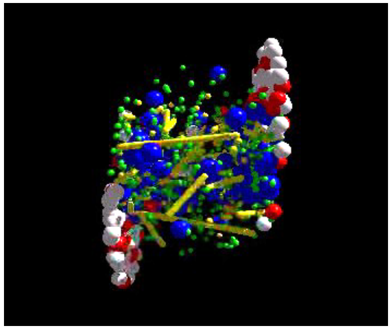
*Christine Nattrass*
*University of Tennessee at Knoxville*

# Take home messages

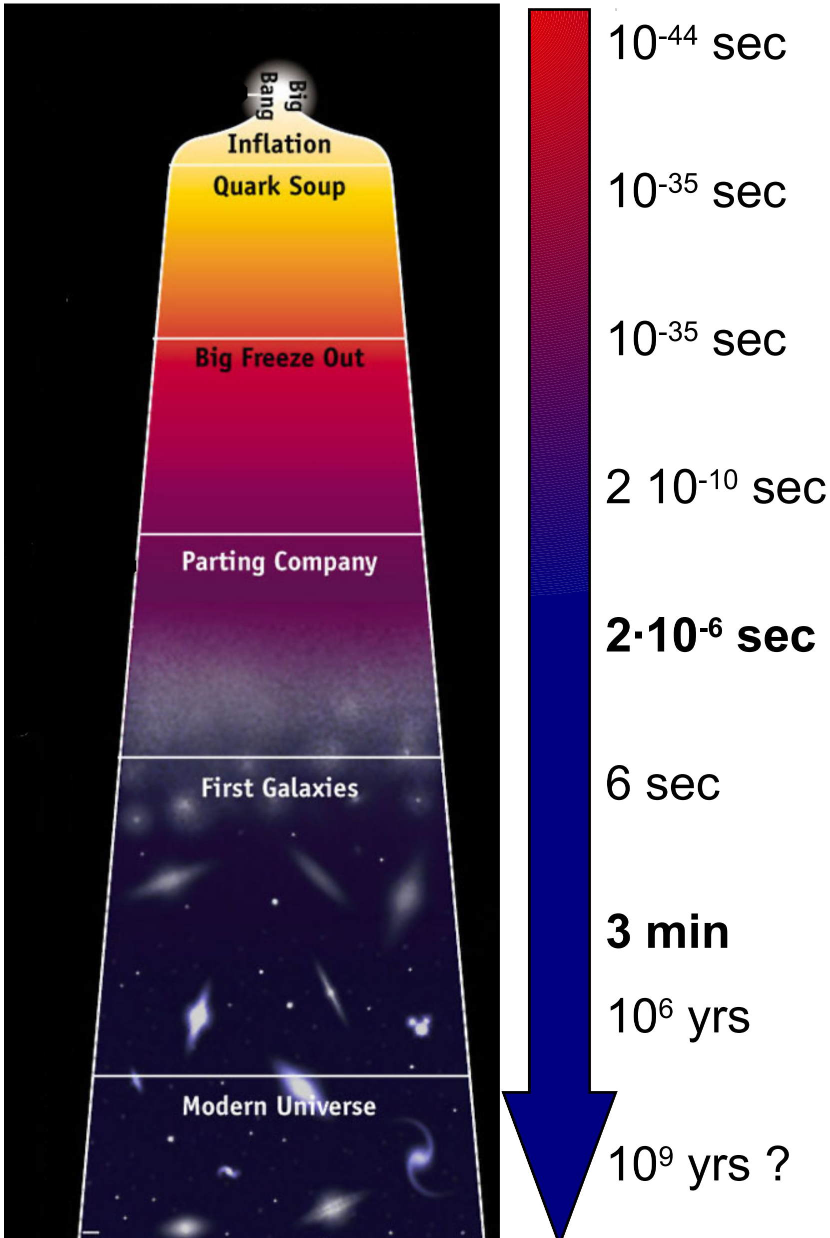
- If we get nuclear matter dense enough, we make a new phase of matter
- This quark gluon plasma is similar to what was present in the early universe
- We can produce a QGP in high energy heavy ion collisions



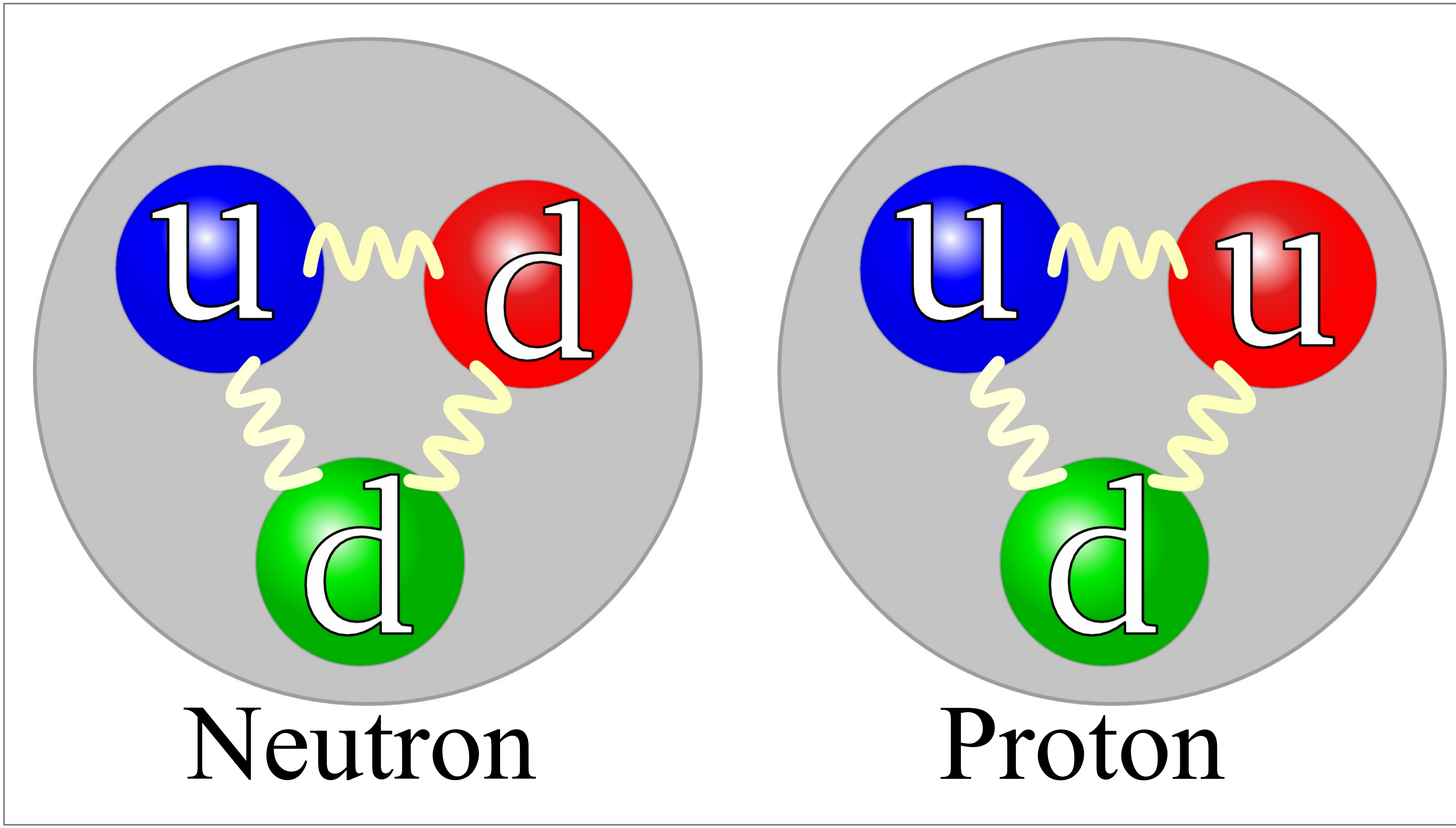
# Evolution of the Universe




## 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

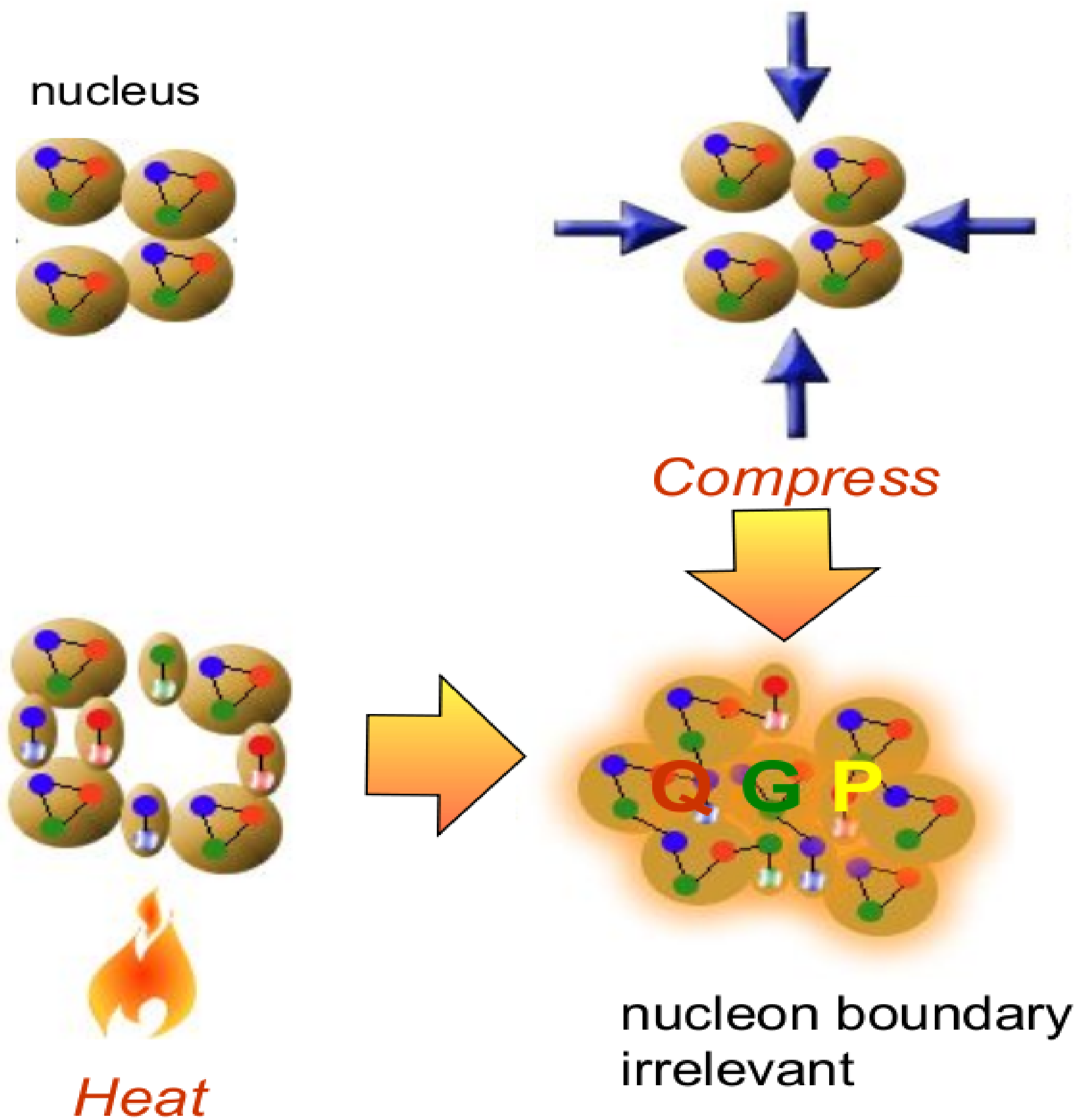
# Nucleons – the proton and neutron



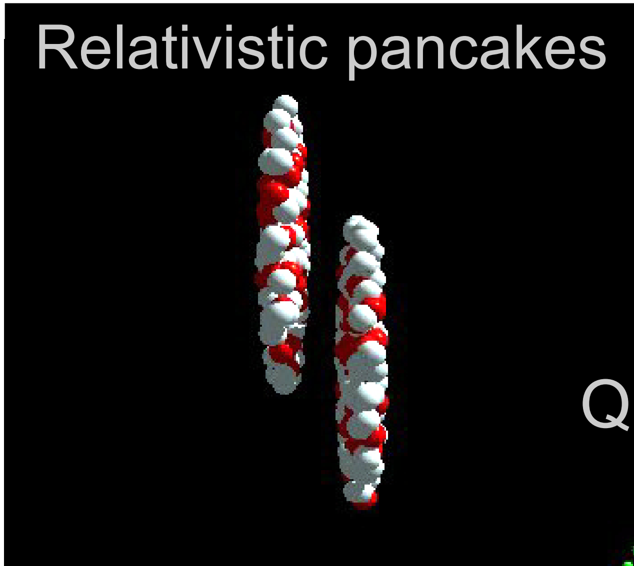

http://en.wikipedia.org/wiki/Image:Quark_structure_neutron.svg

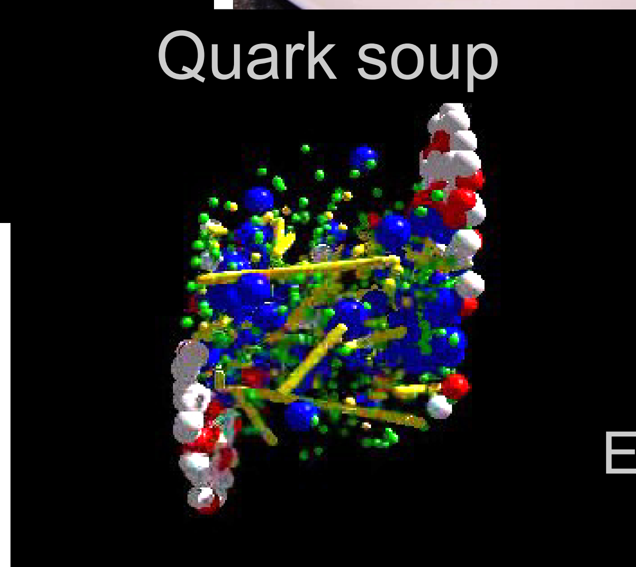
http://en.wikipedia.org/wiki/Image:Quark_structure_proton.svg

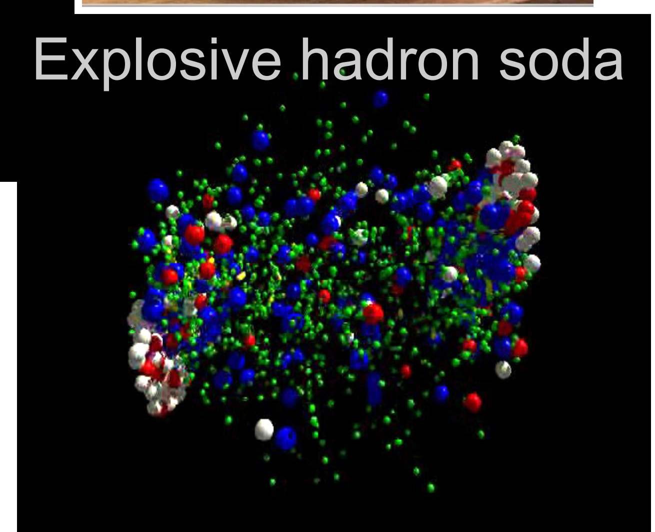
# How can we see “free” quarks?



# Making a QGP in the laboratory



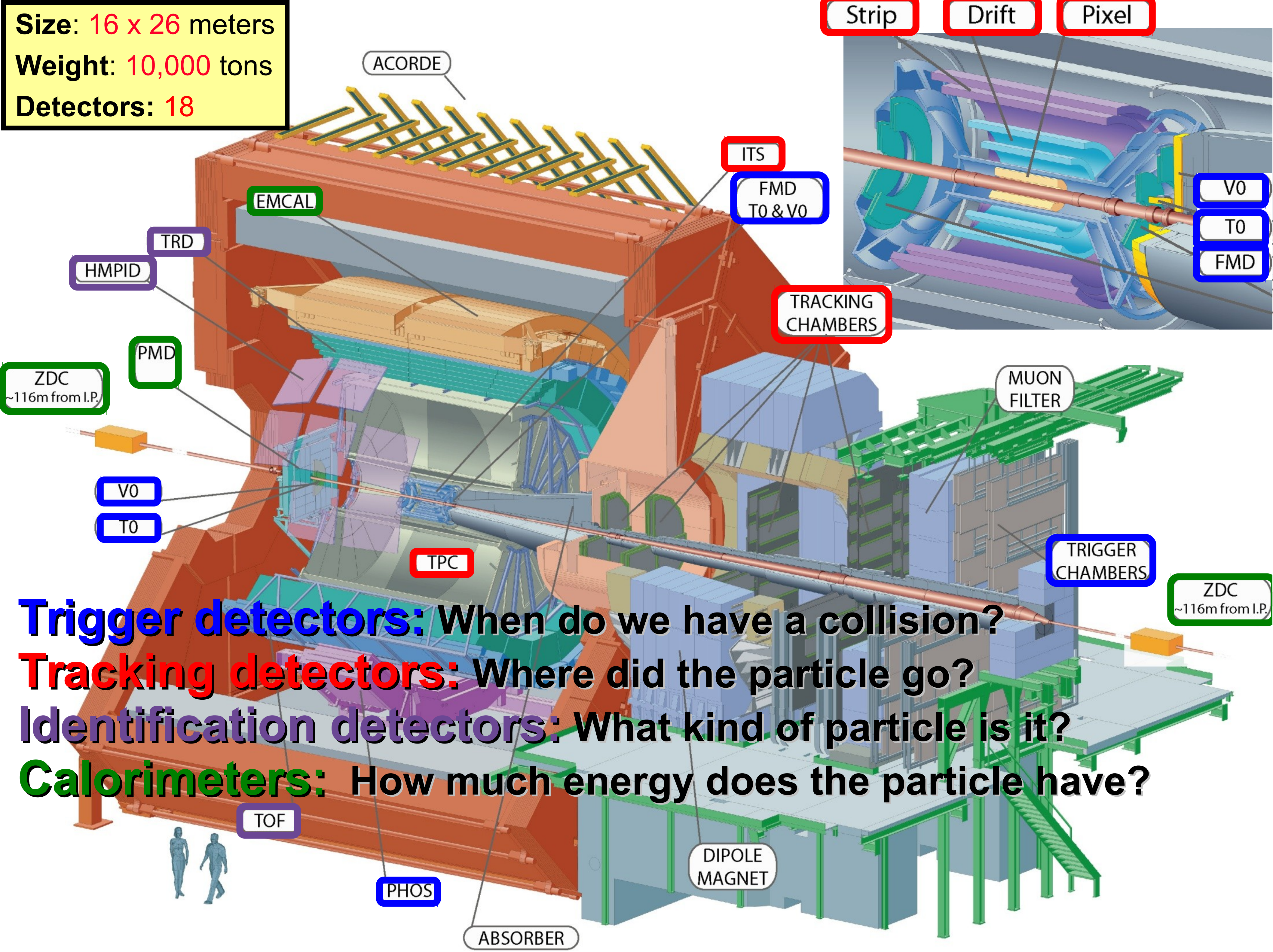





CMS
5.3 miles
LHCb
1.4 miles
ATLAS
LHCf
ALICE

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

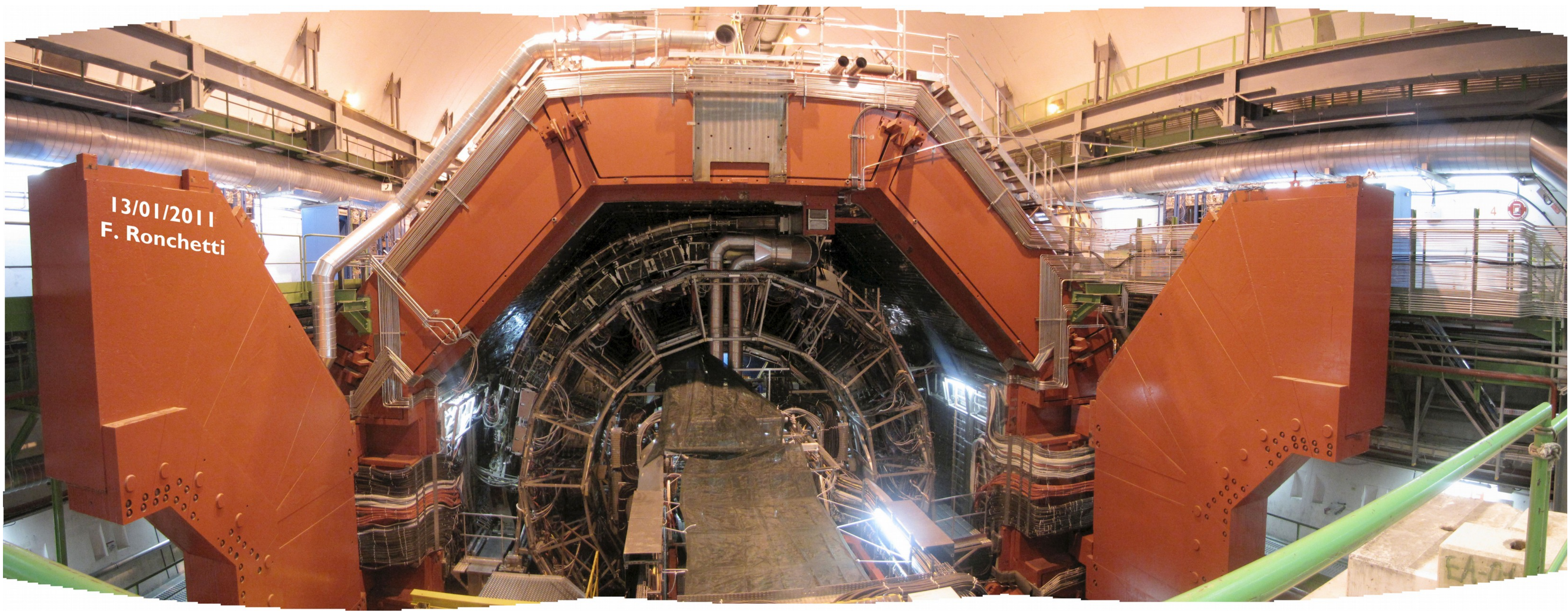



**Trigger detectors:** When do we have a collision?

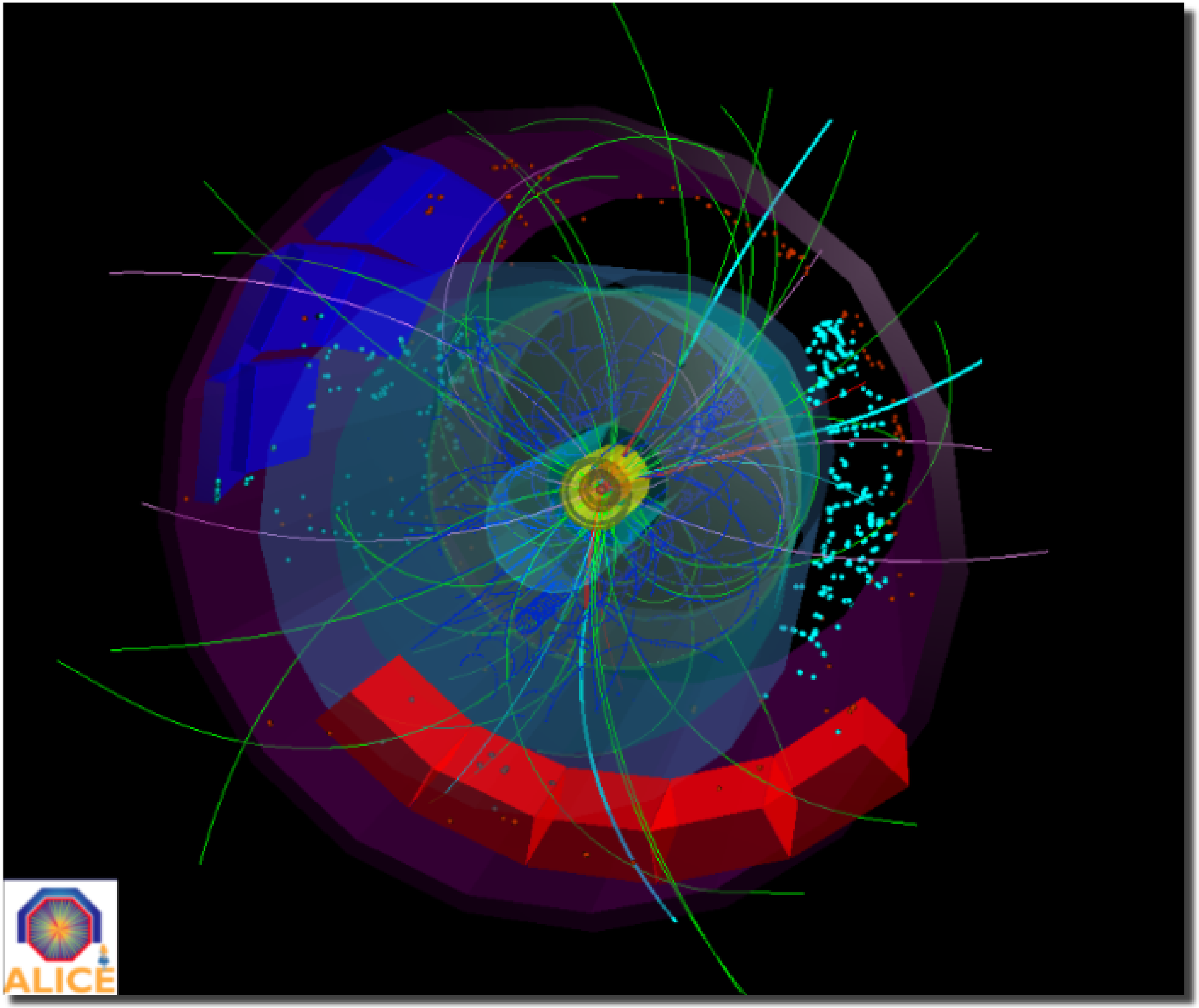
**Tracking detectors:** Where did the particle go?

**Identification detectors:** What kind of particle is it?

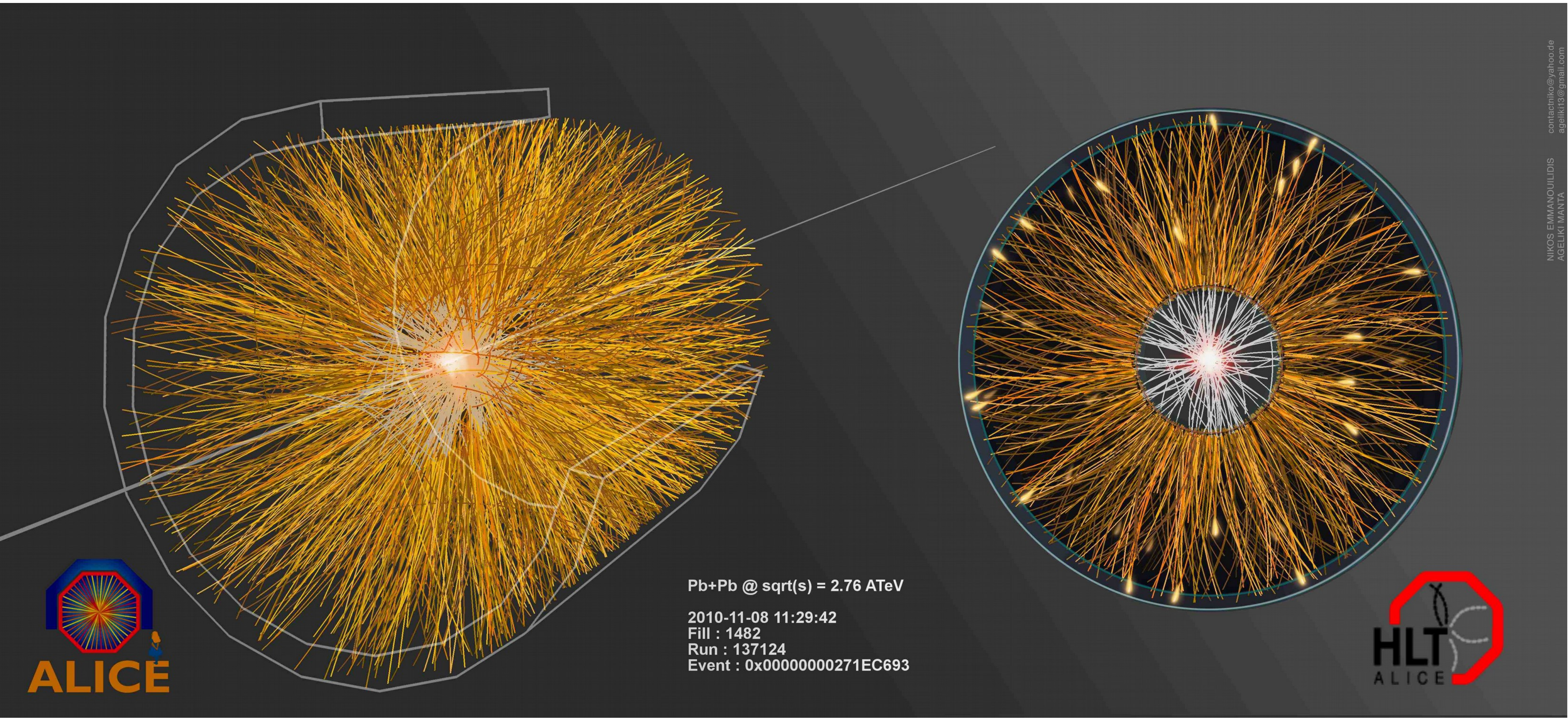
**Calorimeters:** How much energy does the particle have?


13/01/2011
F. Ronchetti

# p+p collisions

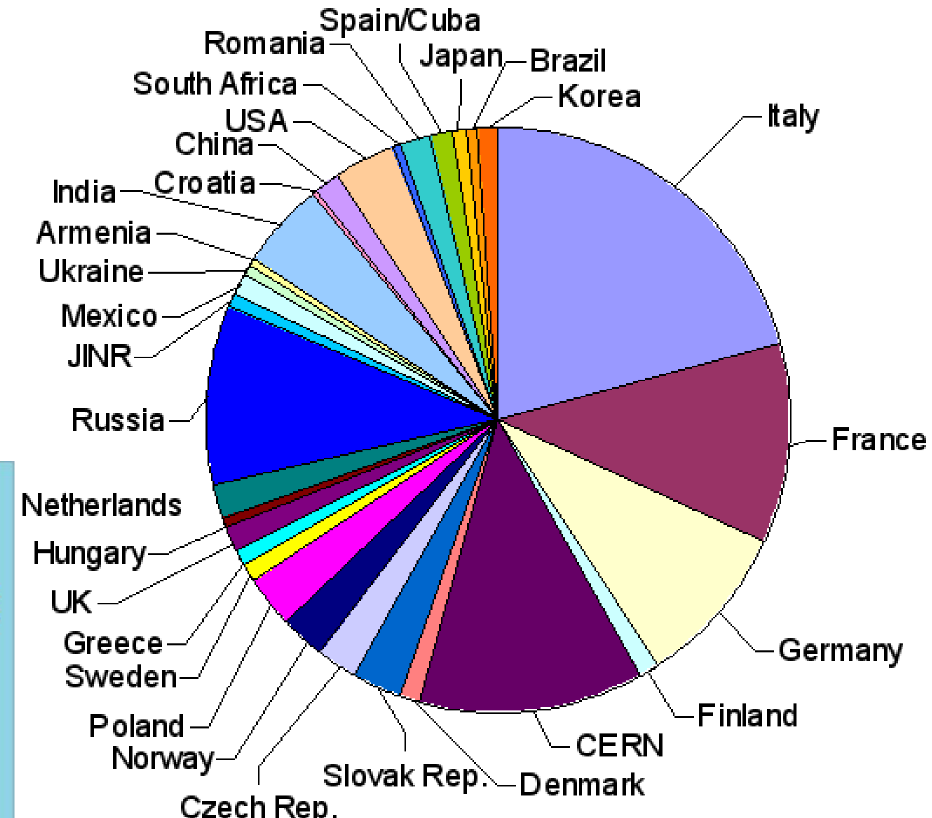


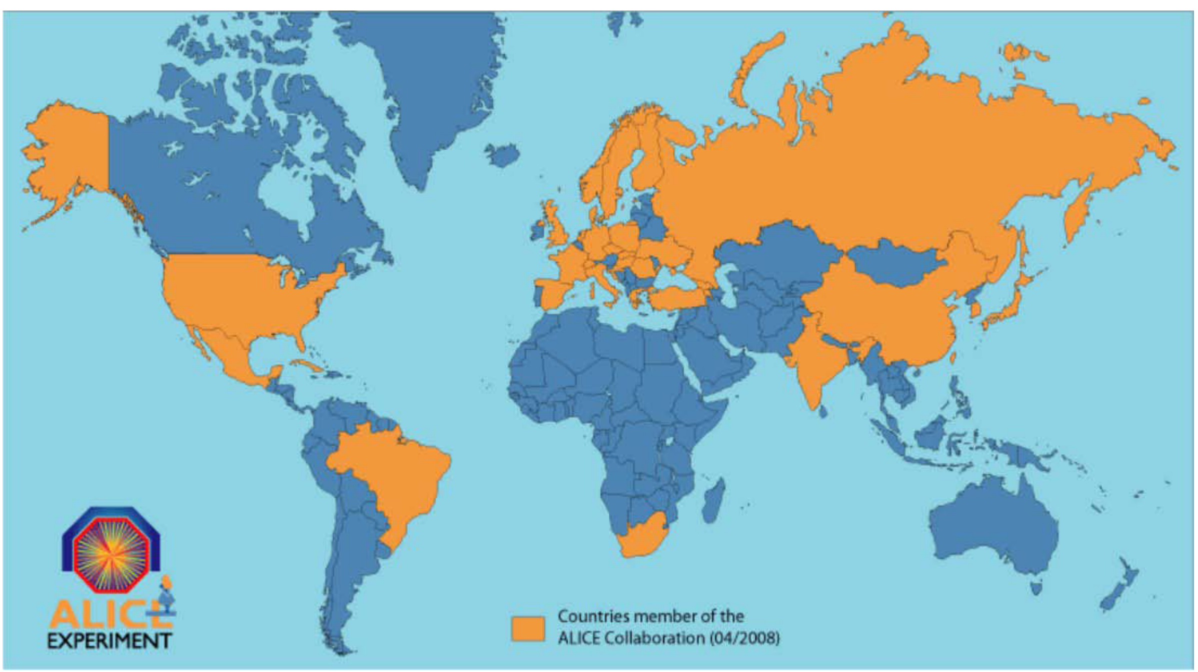
# Pb+Pb collisions



# The ALICE Collaboration

~1000 Members
63% from CERN member states
~30 Countries
~100 Institutes
~$150 million Capital cost (+magnet)



# Scales

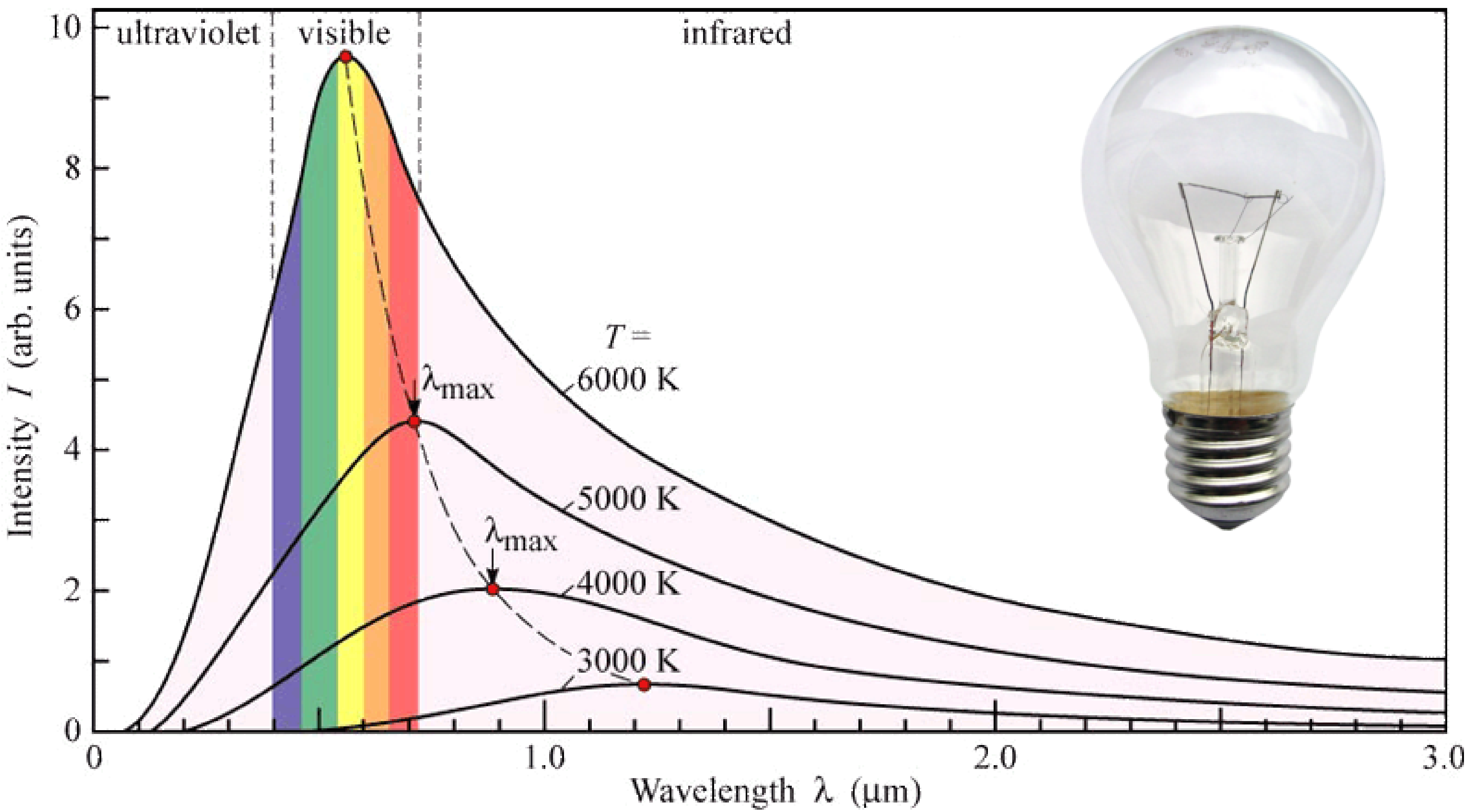
- Time: ~$10^{-23}$ seconds
  - 1 minute for us ~ 1,000,000 lifetimes of the universe for QGP
- Energy: 1 TeV ~ 10 trillionths ($10^{-11}$) of a Calorie
  - About the amount of energy if two mosquitoes collide
  - About 1 trillionth of a candy bar
- Energy density: ~6-8 GeV/fm$^3$
  - $10^{35}$ times that of a candy bar (~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: ~2000-3000
  - Same number as in 1 $\mu m^3$ = 1/16 $in^3$ of air
- Size of QGP: 1 $fm^3 = 10^{-45}$ $m^3$
  - If this room were the size of the solar system, the QGP could fit in 1 $cm^3$
- Data volume: PB ~ 1,000,000 GB
- Data rates: ~1 PB/month written to disk, a few GB/second

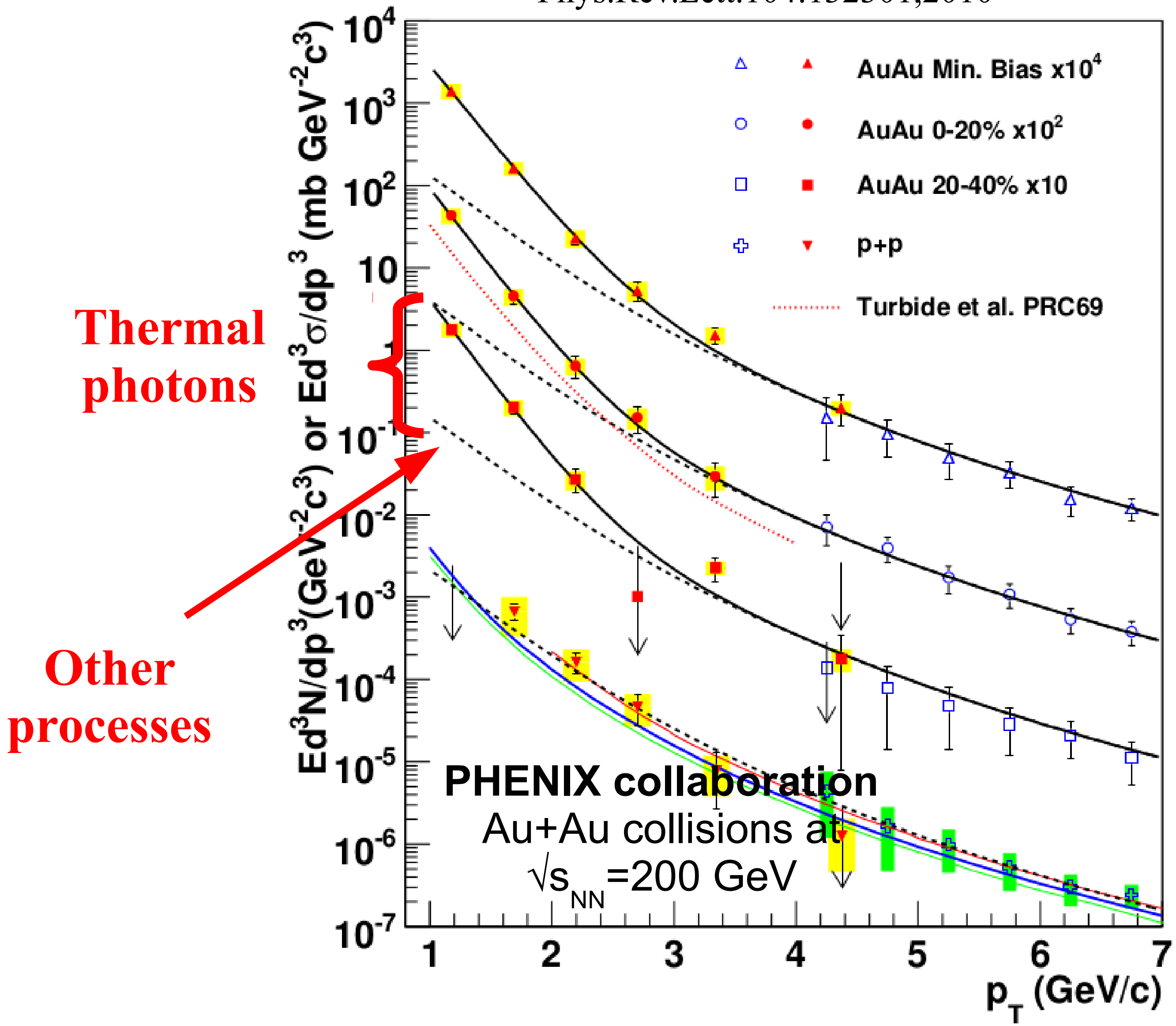
# Measuring temperature

# Thermal photons



# Thermal photons

Phys.Rev.Lett.104:132301,2010

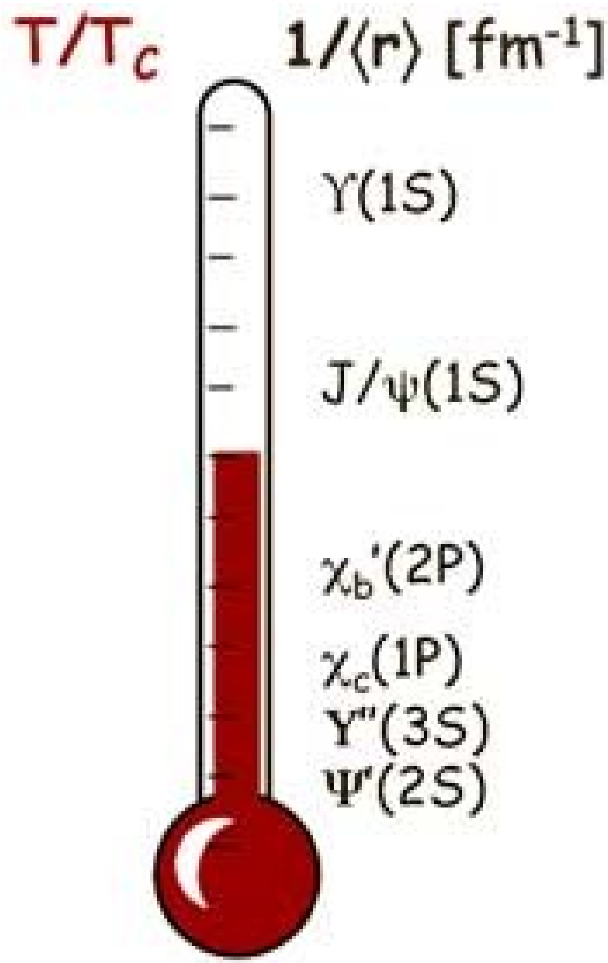


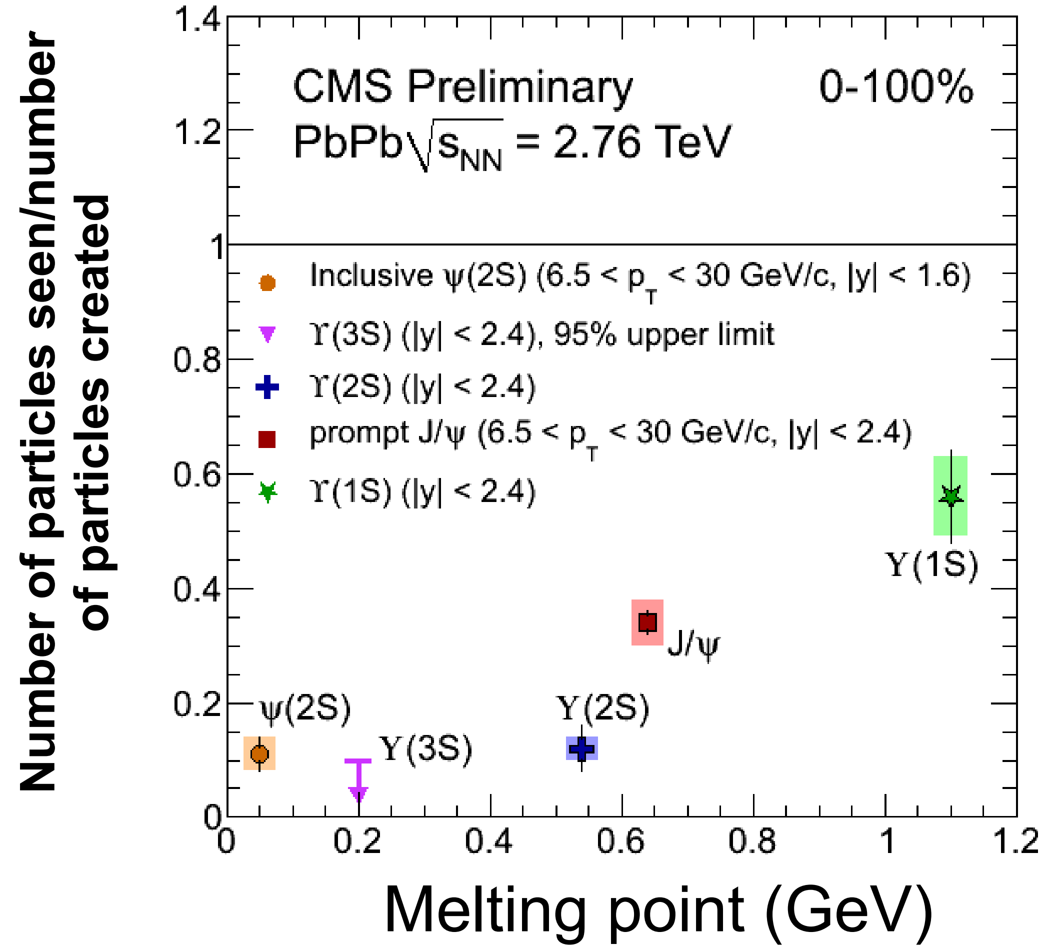

**Inverse slope:**
**T = 221 +/- 19 (stat) +/- 19 (syst) MeV**

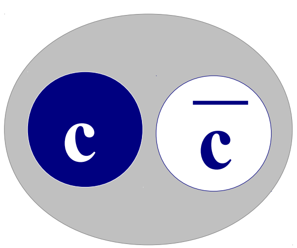
**Consistent with models with T=300-600 MeV**

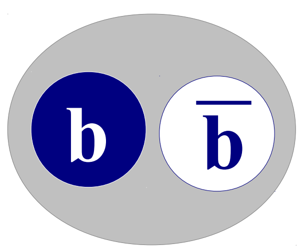
**$T_c \sim 170$ MeV**

# Quarkonium-thermometer



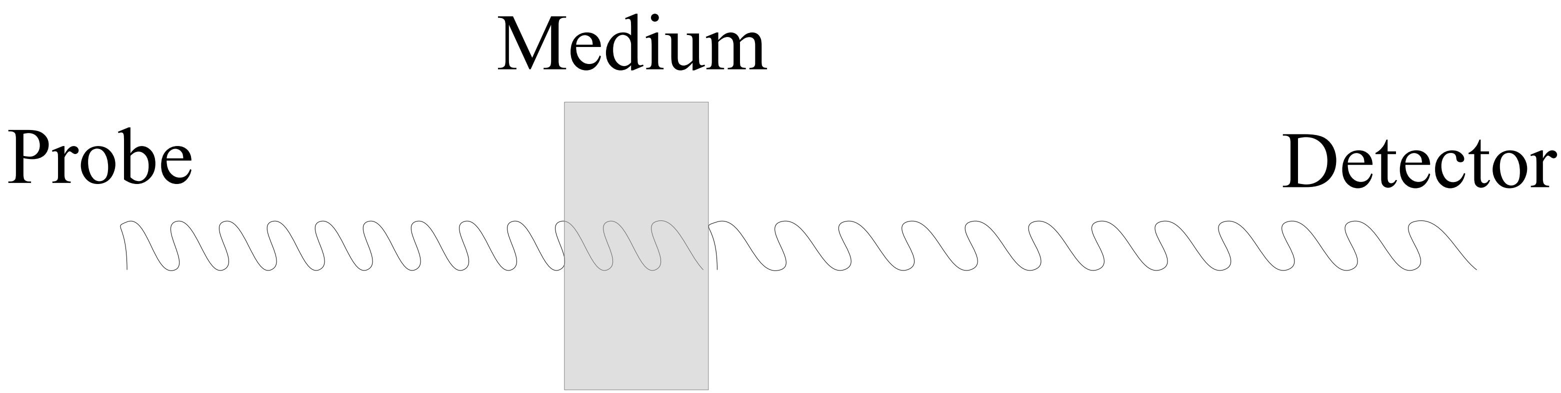




CMS-PAS HIN-12-014, HIN-12-007

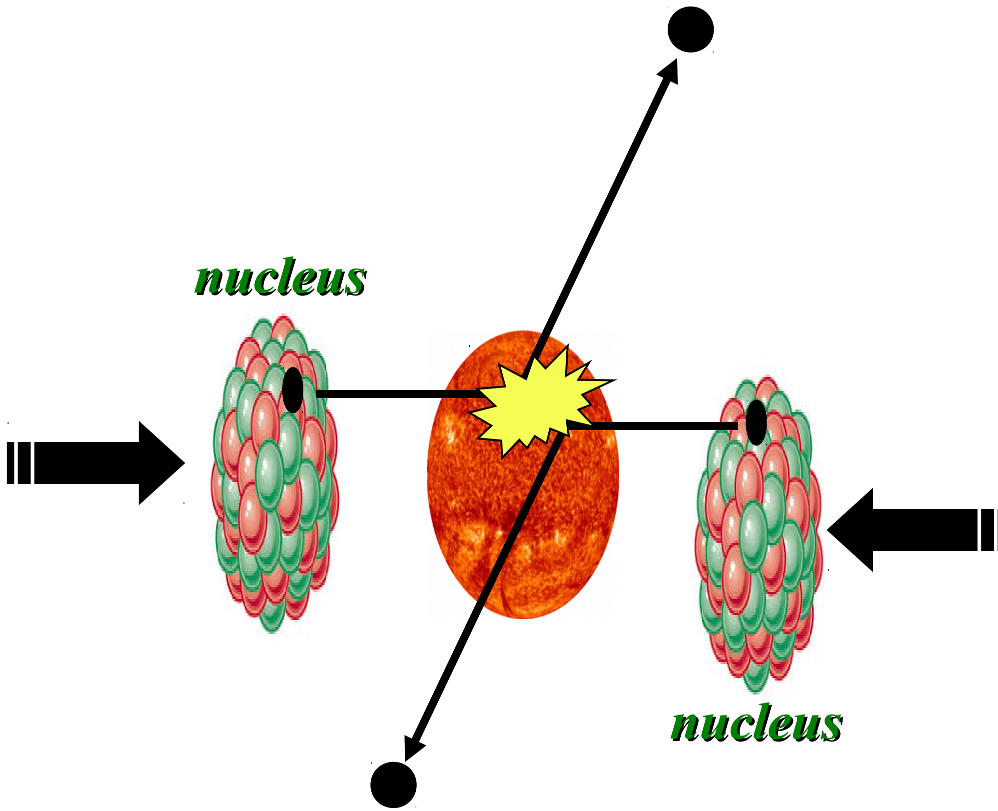
# Imaging the Quark Gluon Plasma

# Probing the Quark Gluon Plasma



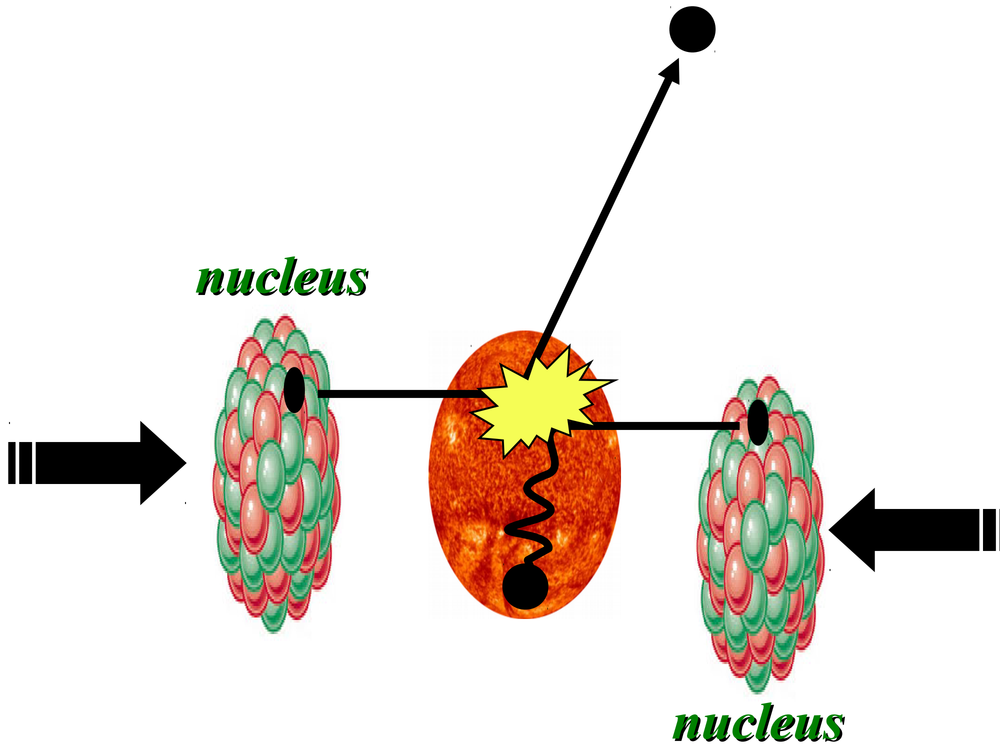

Want a probe which traveled through the collision
QGP is very short-lived (~1-10 fm/c) →
cannot use an external probe

# Probes of the Quark Gluon Plasma



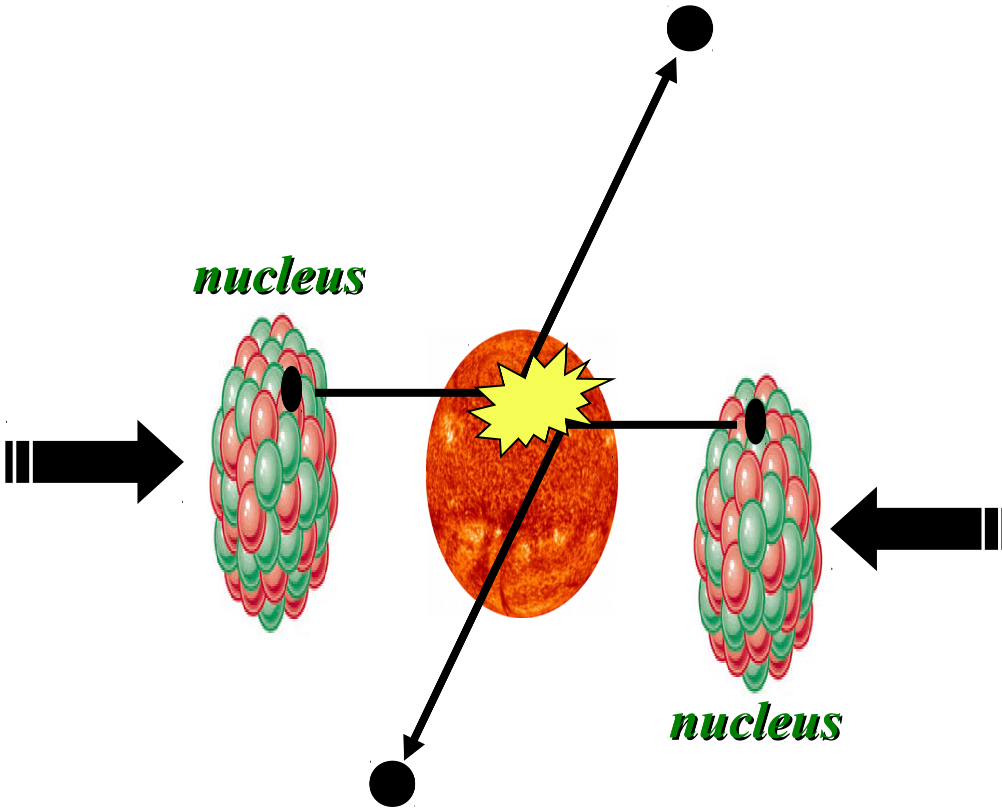

Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision

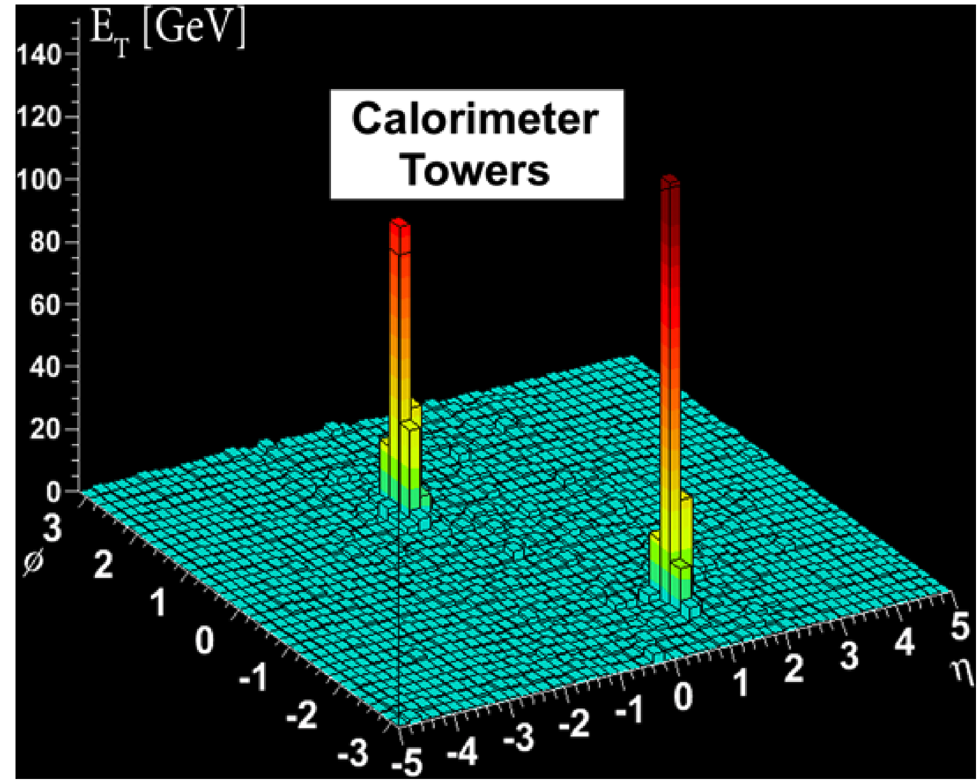
# Probes of the Quark Gluon Plasma




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

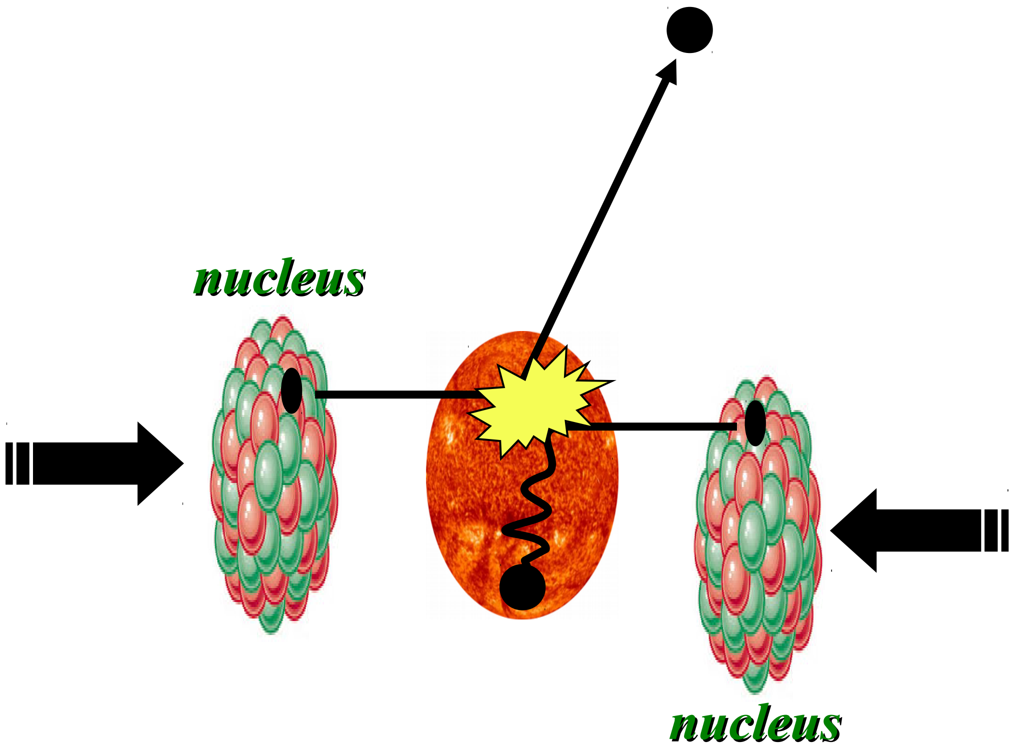
# Jets

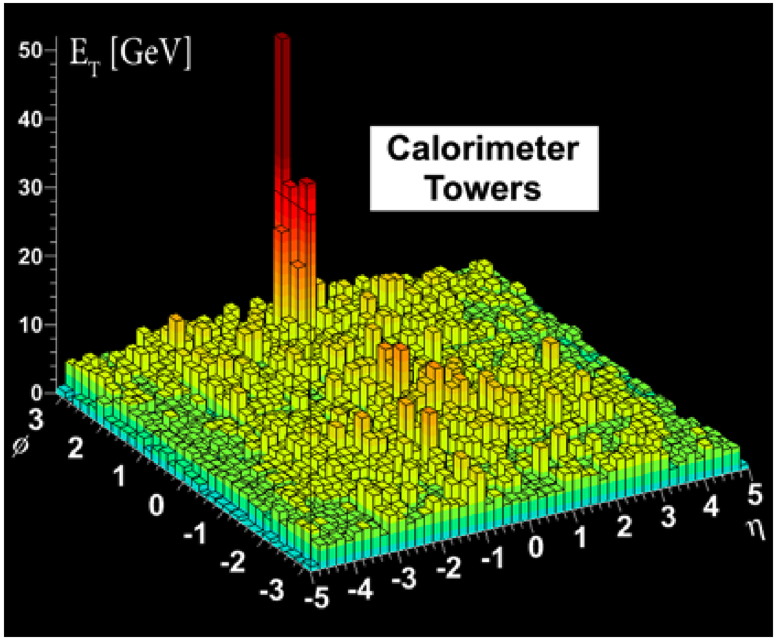



- Quarks and gluons are confined – we don't see them outside of mesons and baryons
- Instead we see a cone of particles around the outgoing quark or gluon
- Looking at jets analogous to spectroscopy

# 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

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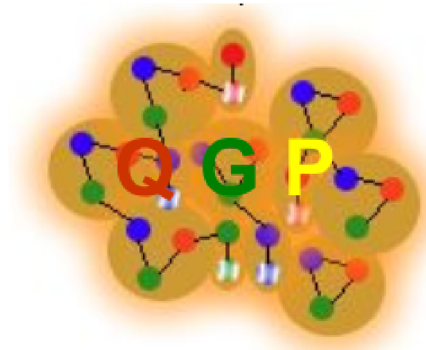
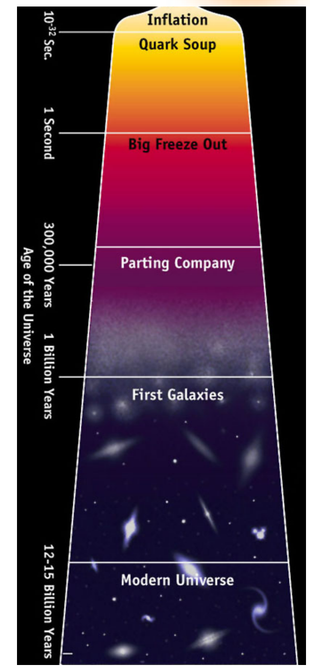
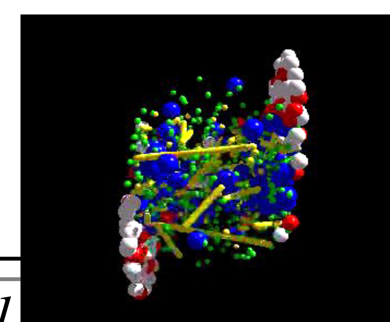
- This quark gluon plasma is similar to what was present in the early universe
- We can produce a QGP in high energy heavy ion collisions



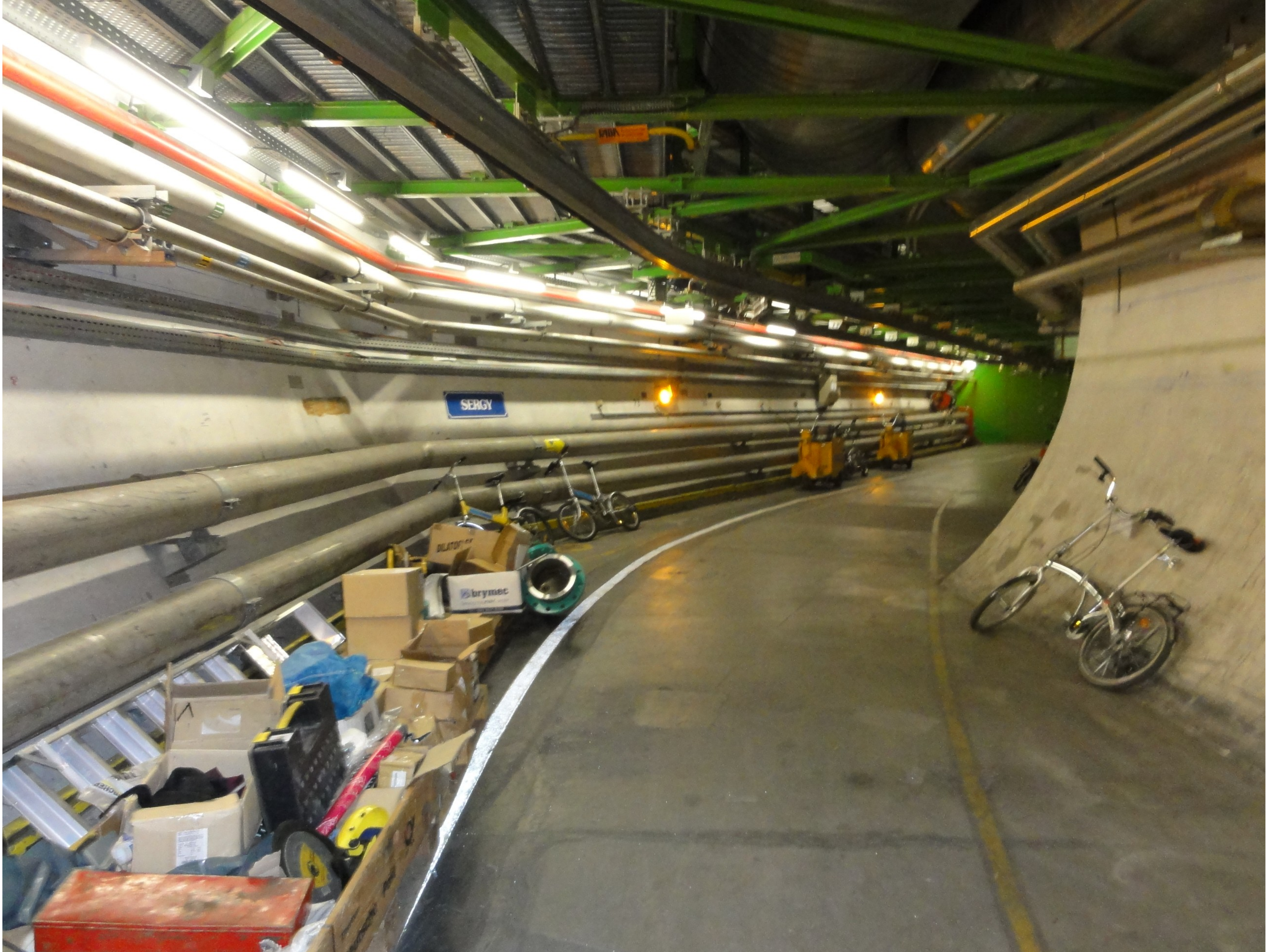



# What I spend my time doing

- 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
- Teaching
- Advising undergraduate students
- Supervising/mentoring students & post docs on research
- Reviewing papers, proposals


TREE FRIENDS


SERGY
brymec


PETZL
PETZL



Entrance Forbidden

# 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