

The primordial Universe: the Quark Gluon Plasma production at ALICE-LHC

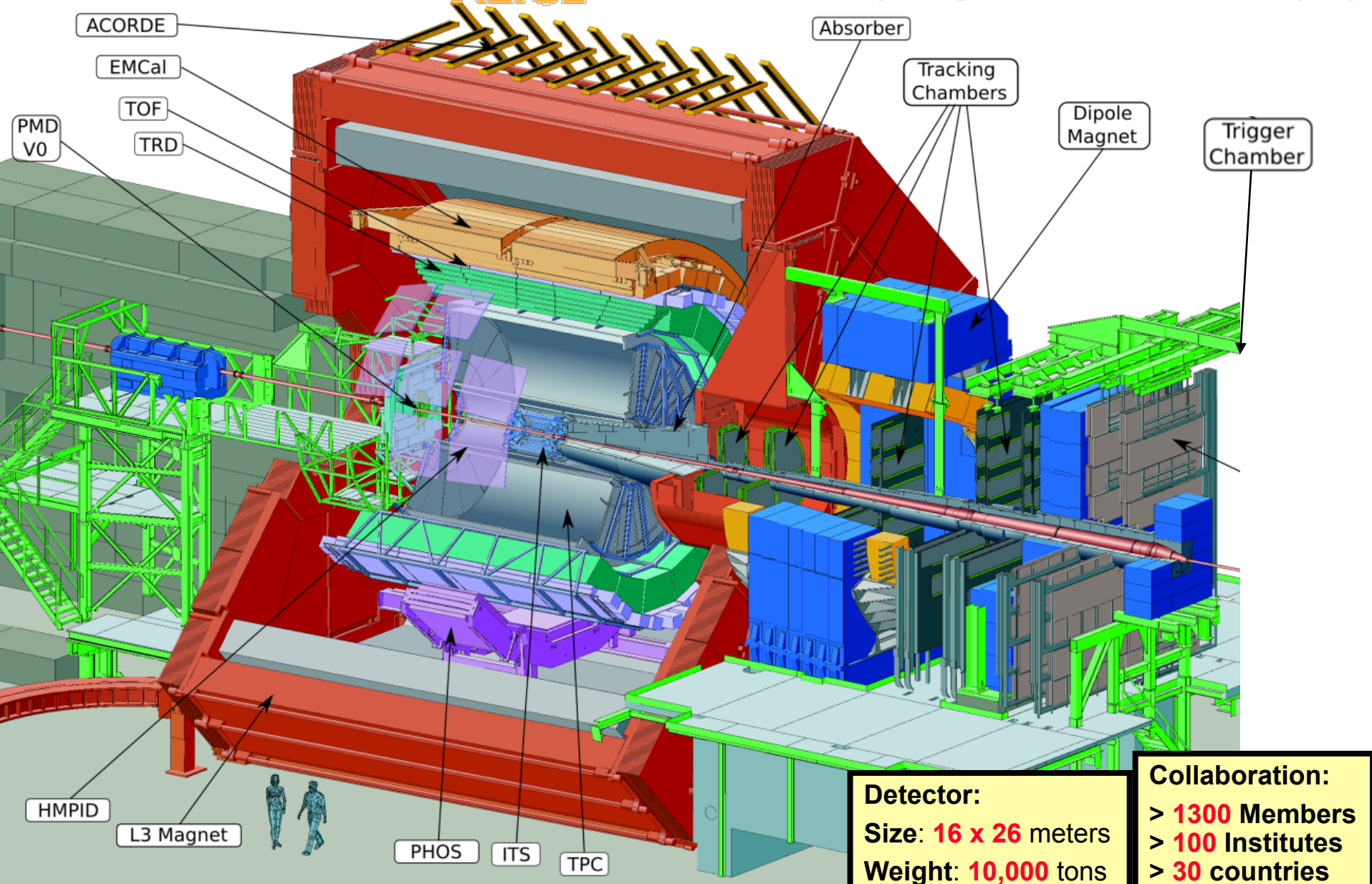
Pasquale Di Nezza



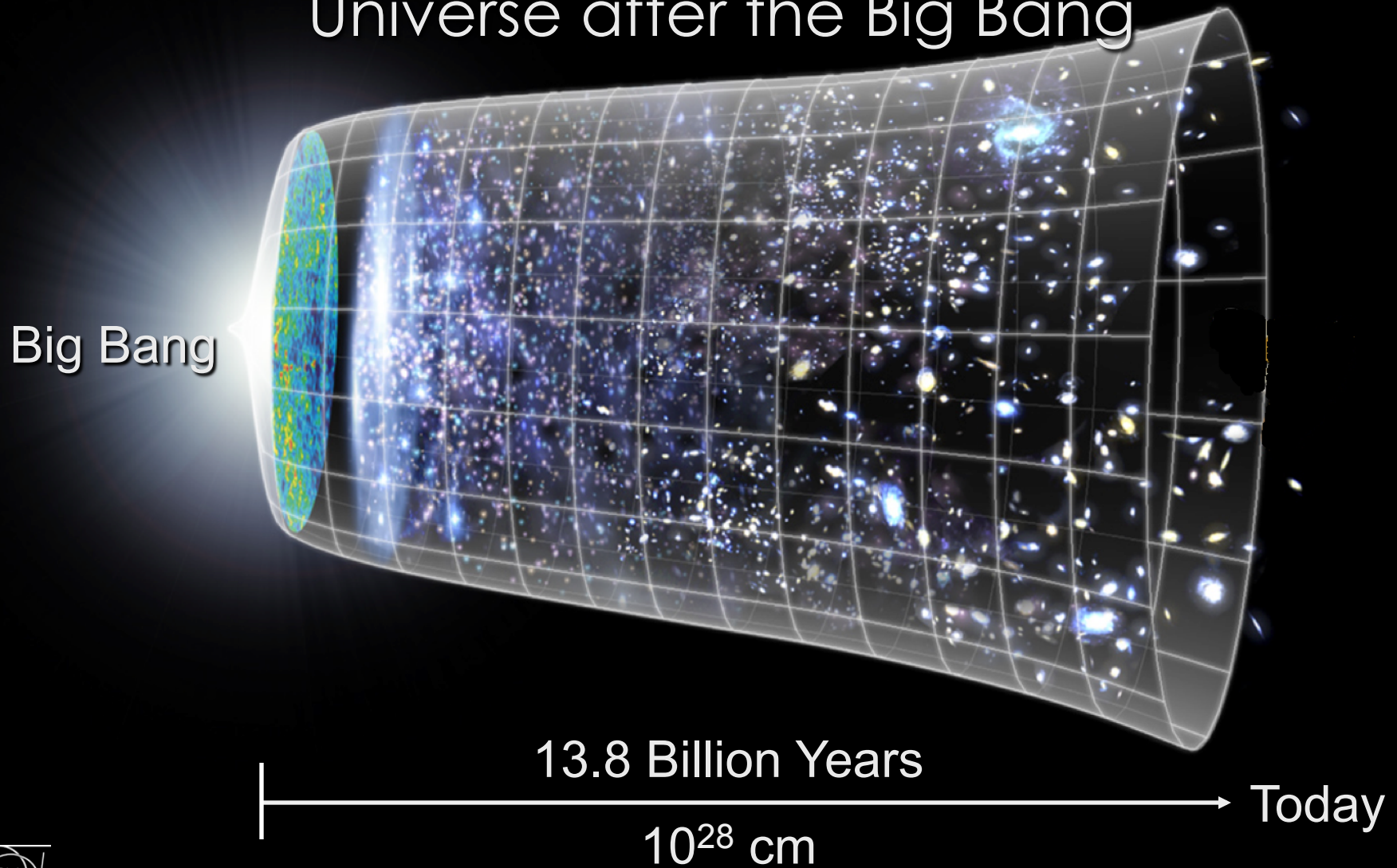


A Large Ion Collider Experiment

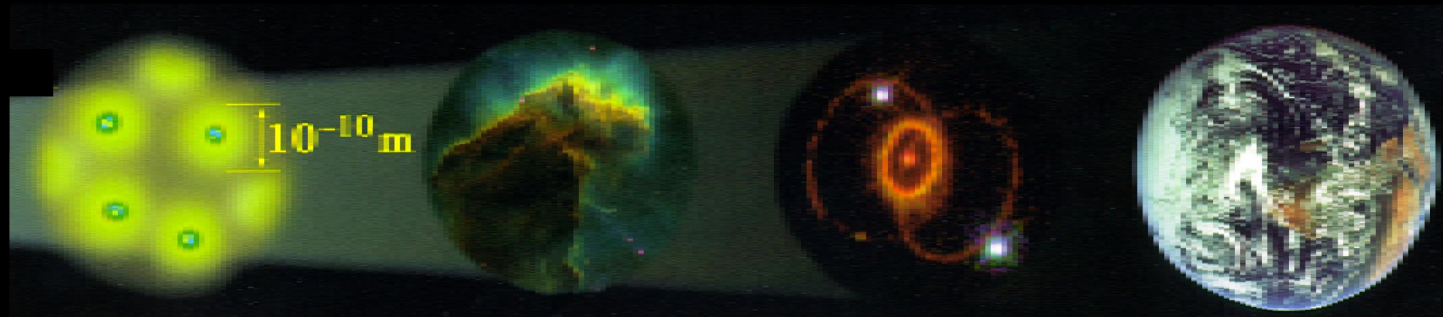
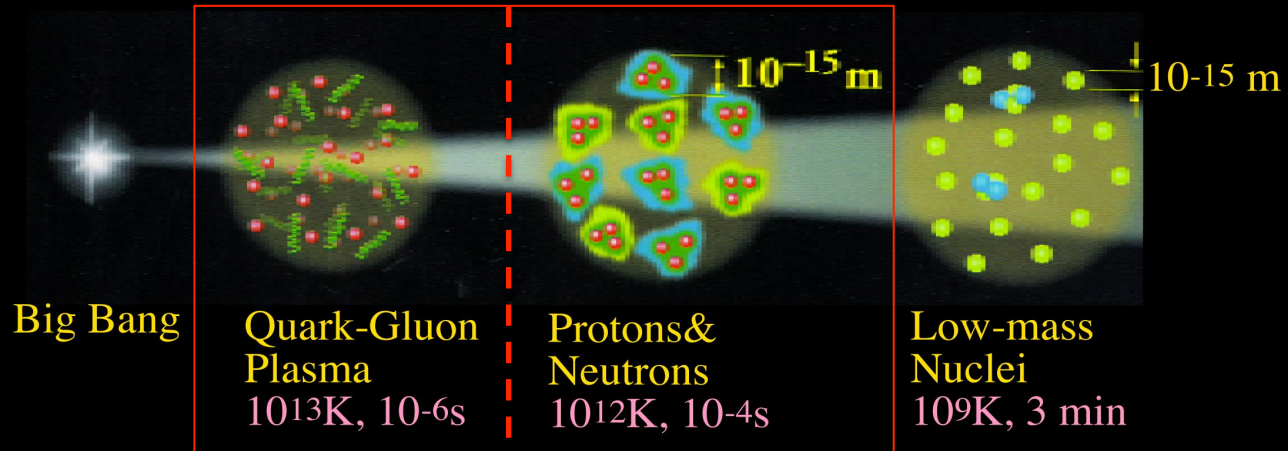
European Organisation for Nuclear Research



An Important Scientific Challenge: to understand the very first moments of our Universe after the Big Bang



History of the Universe



Neutral
Atoms
 4000K , 10^5y

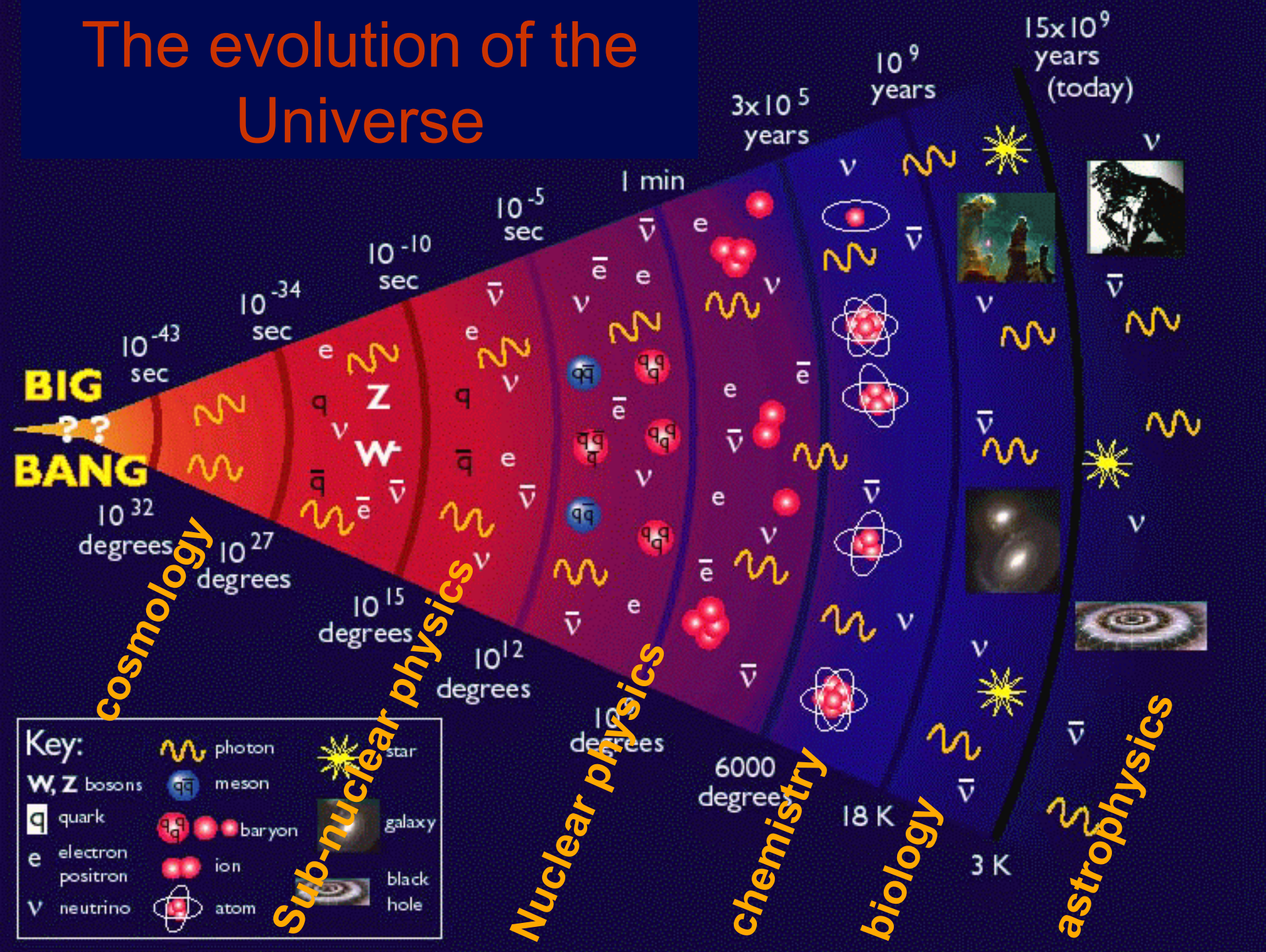
Star
Formation
 10^9y

Heavy
Elements
 $>10^9\text{y}$

Today

Source: Nuclear Science
Wall Chart

The evolution of the Universe





In order to understand the deepest nature of the matter we have to:

create the initial conditions of the Universe

create who is carrying the information

create the relevant particles

Particle Factories: the accelerators



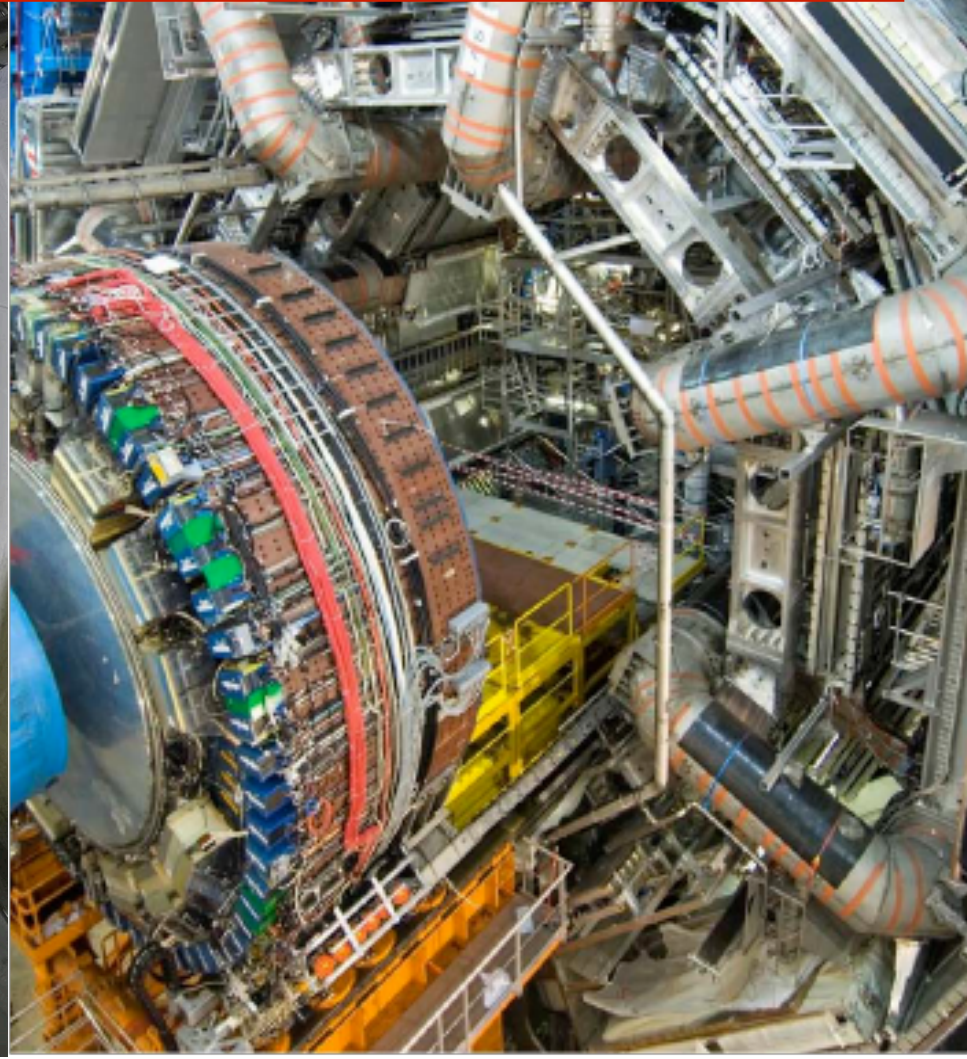
Colliders



LHC at CERN, Geneva 2009

The global adventure

Everything started more than 20 years ago

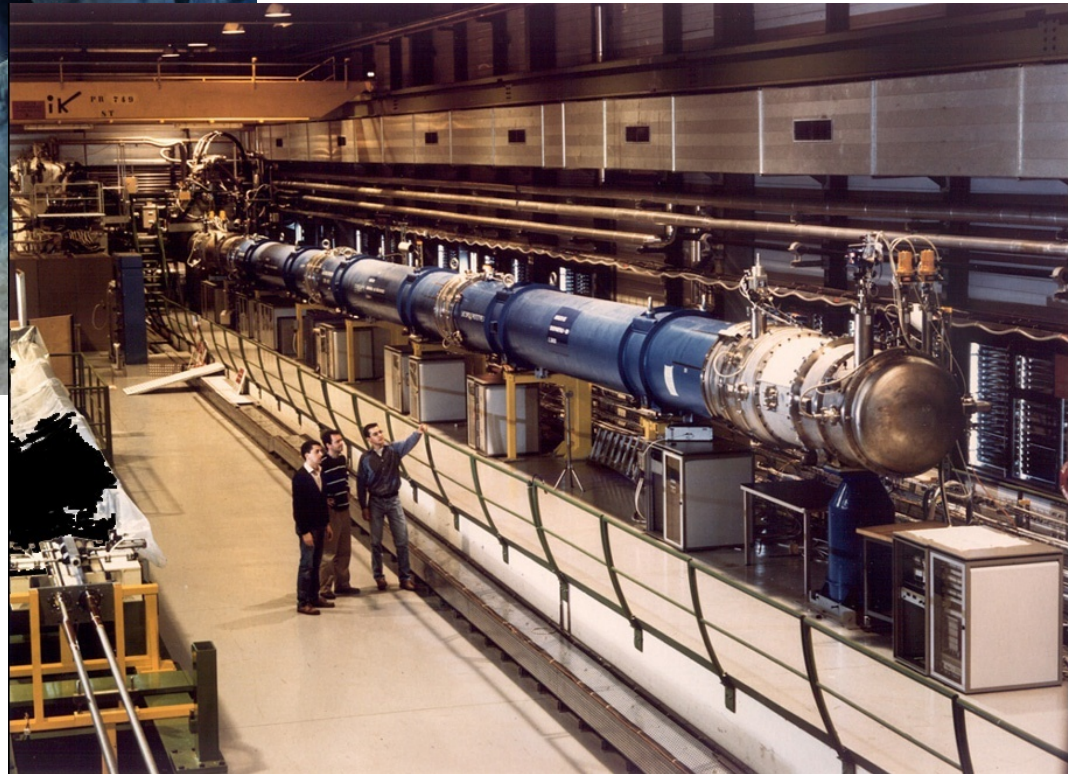


LHC needed years of R&D



Construction of one
of the cavern hosting
the experiments

Dipole magnets
string test





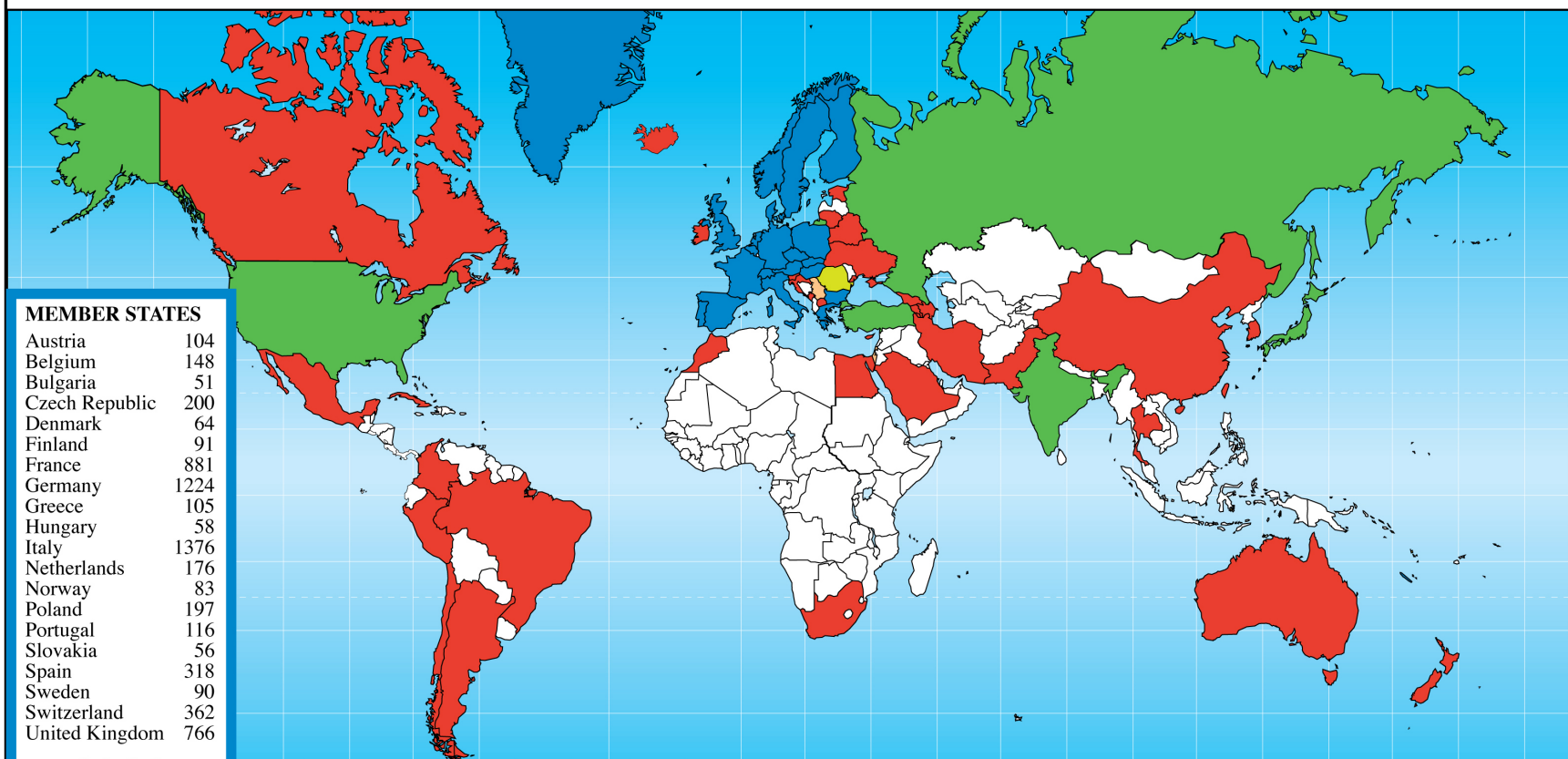
CAUTION
Helium Release Point
No stop zone
Point de rejet d'hélium
Stationnement interdit

Accelerator Control Room



Science is getting more and more global

Distribution of All CERN Users by Location of Institute on 2 September 2013



6466

OBSERVERS

India	154
Japan	224
Russia	899
Turkey	106
USA	1787

3170

CANDIDATE FOR ACCESSION

Romania	82
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ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	57
Serbia	30

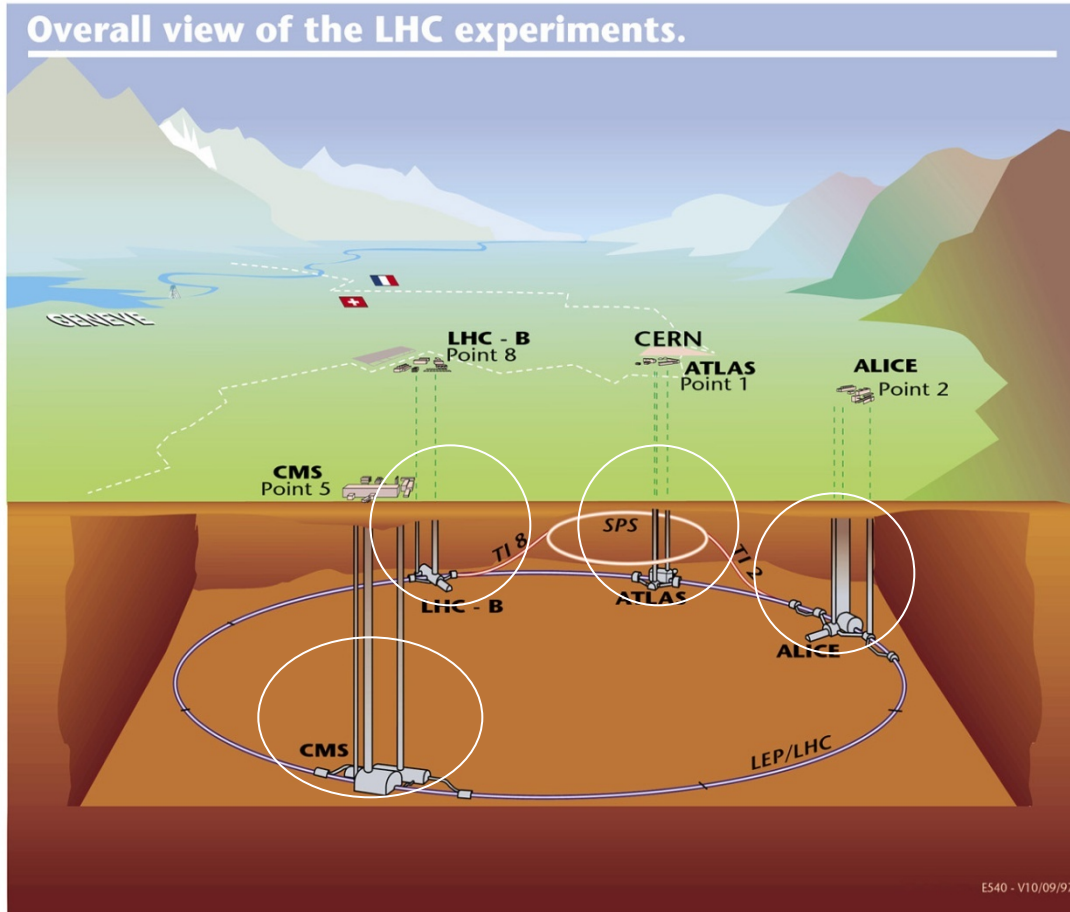
OTHERS

Chile	7	Georgia	10	New Zealand	6
China	130	Iceland	4	Pakistan	21
China (Taipei)	70	Iran	22	Peru	2
Colombia	11	Ireland	7	Saudi Arabia	3
Croatia	25	Korea	103	Slovenia	25
Azerbaijan	2	Lithuania	16	South Africa	31
Cuba	3	Mexico	40	Thailand	6
Belarus	23	Montenegro	1	T.F.Y.R.O.M.	1
Brazil	110	Morocco	9	Ukraine	26
Egypt	18				
Estonia	18				
Canada	154				

987

The LHC tunnel is at 100 m underground

Overall view of the LHC experiments.

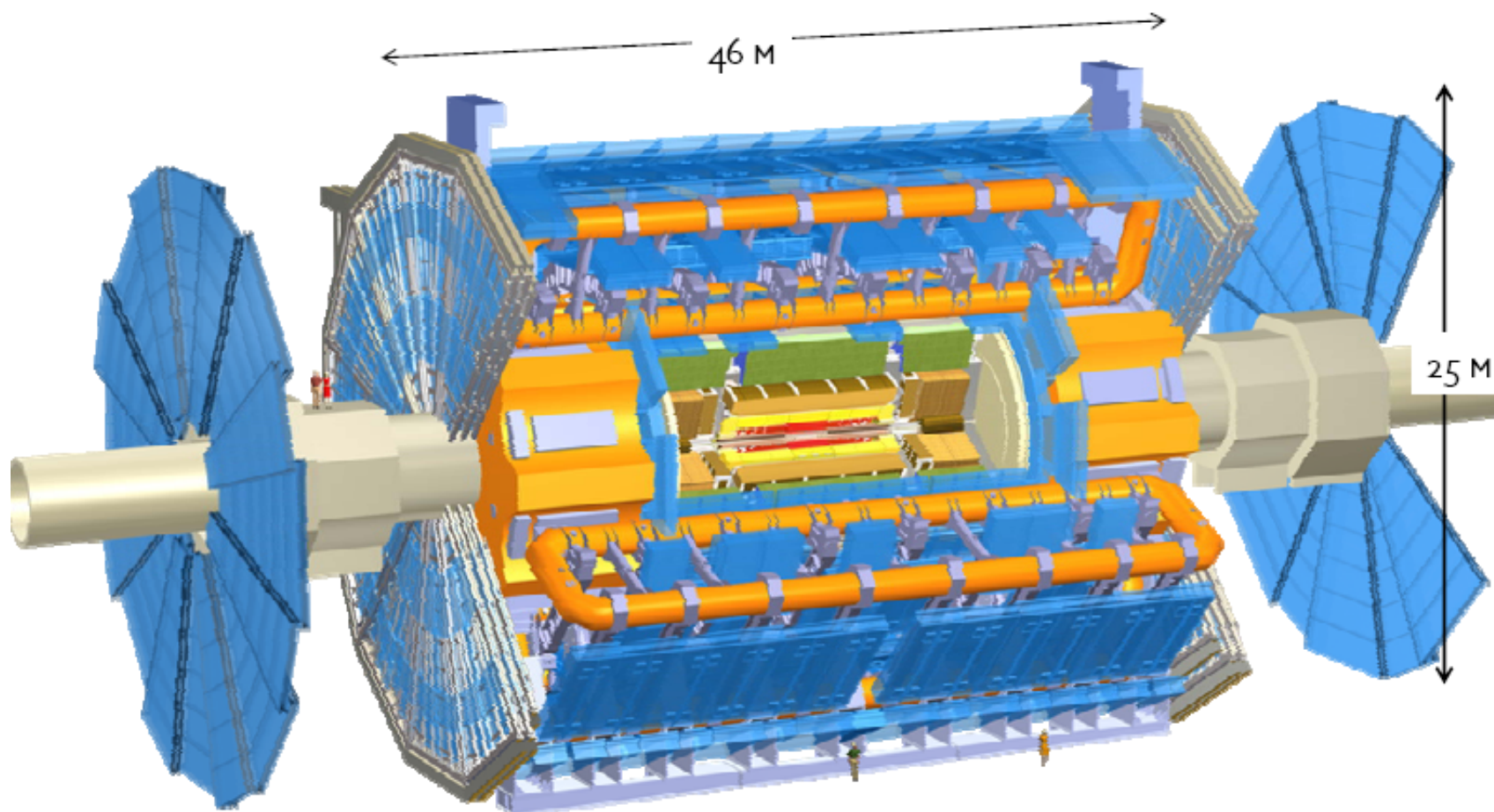


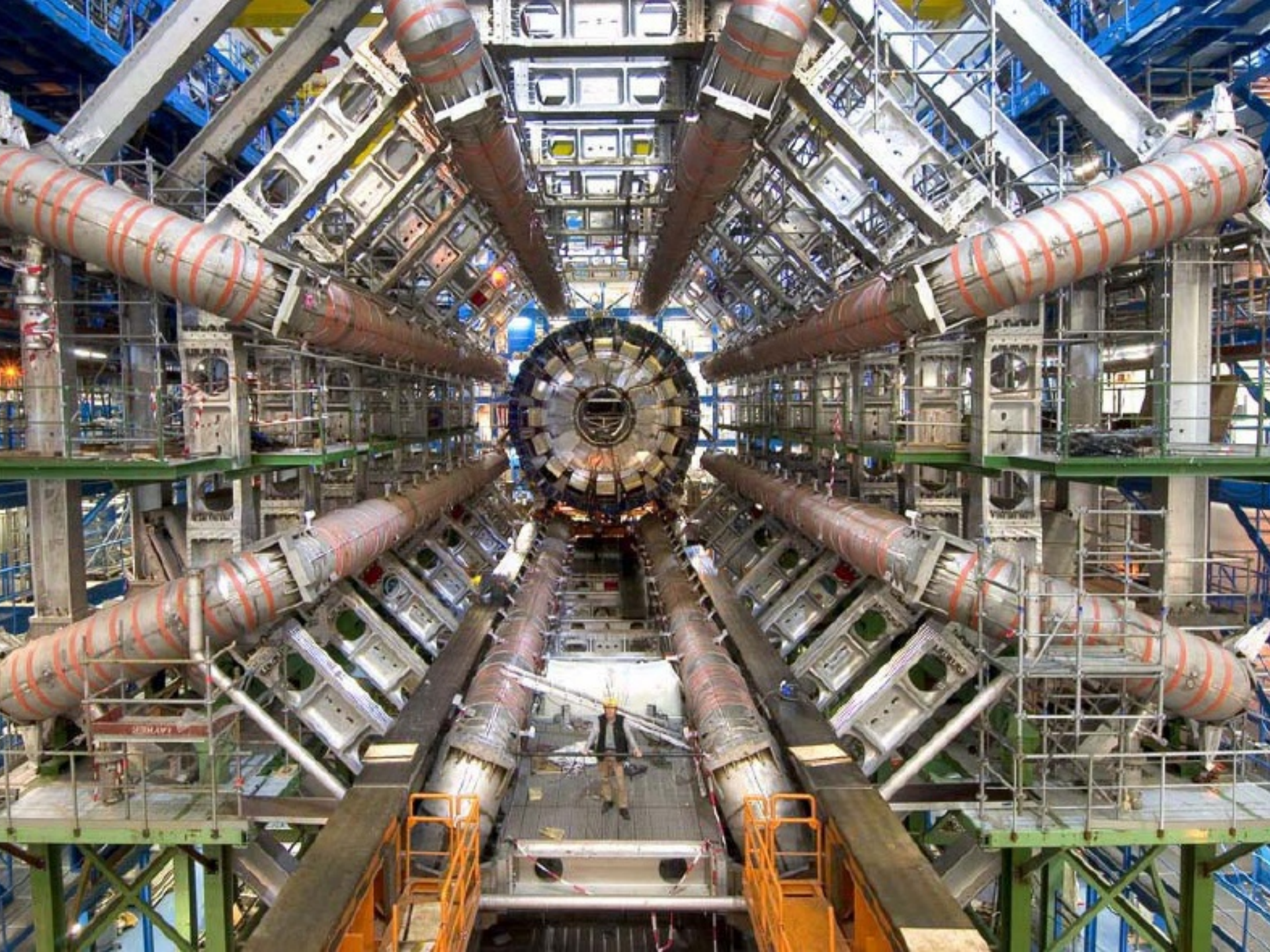
ES40 - V10/09/97

- 4 gigantic caverns host 4 huge detectors
- center of mass energy of 14 TeV, never reached before
- beam intensity orders of magnitude higher than before
- almost 40.000 ton of material at 1.9 K, a temperature lower than the cosmic background

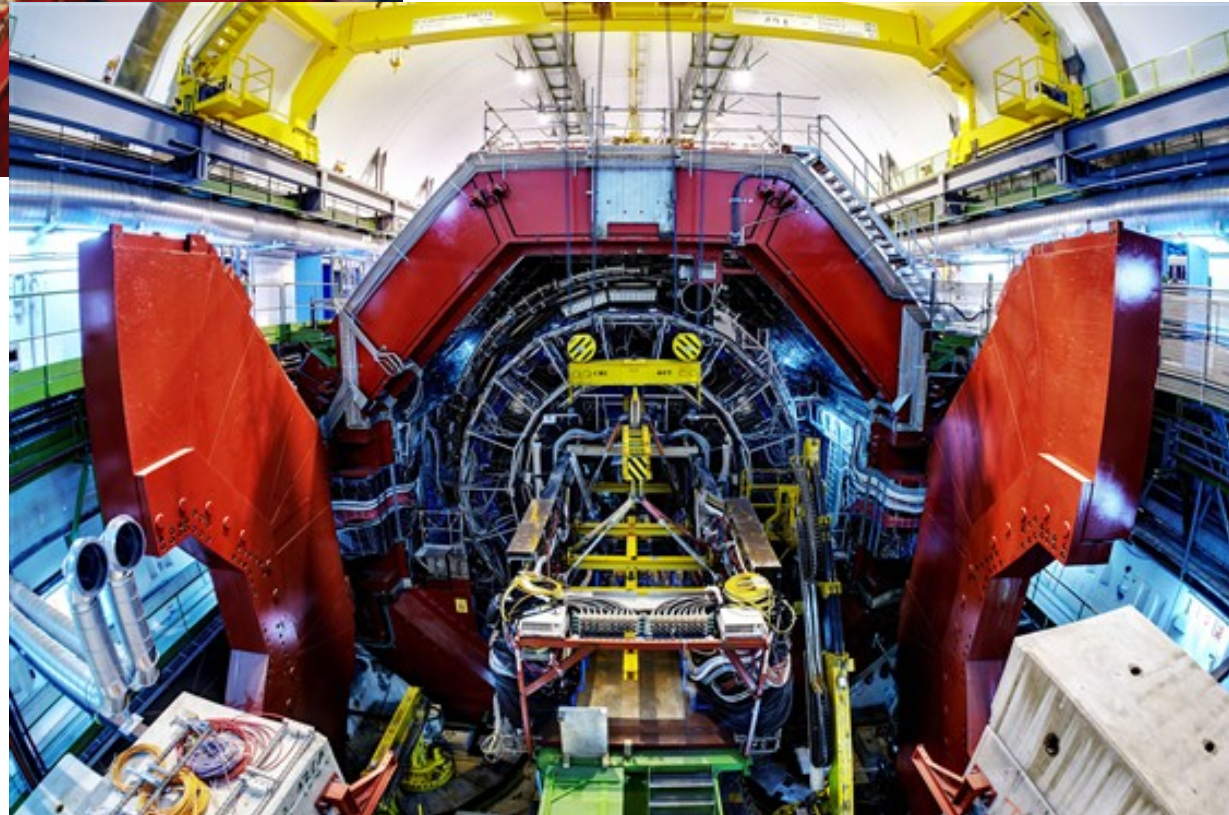
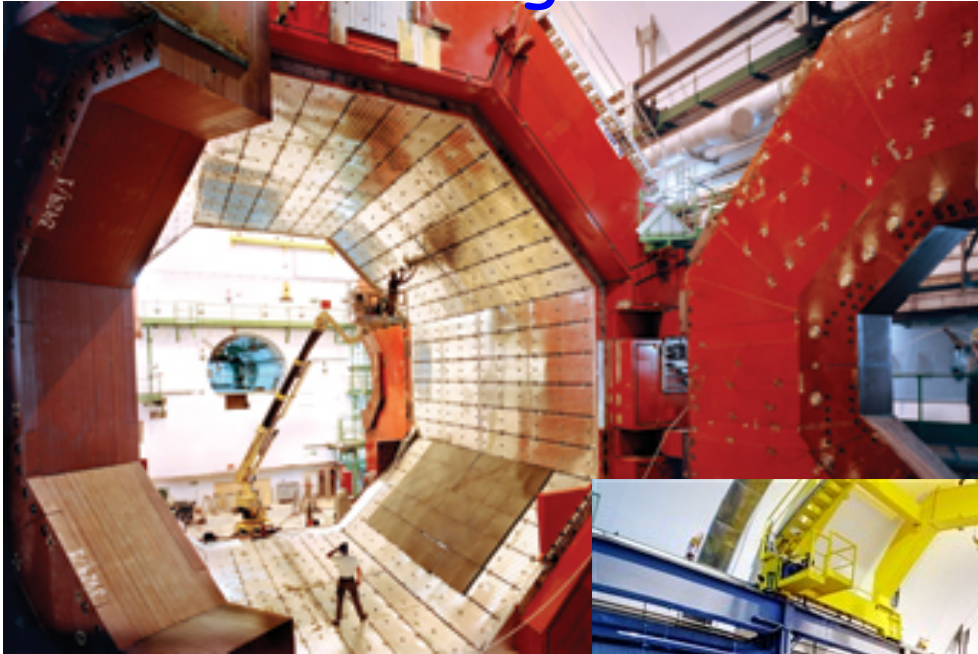
ATLAS → atlas.ch

7000 t – 100,000,000 canali di elettronica - 2100 scienziati, 37 nazioni, 167 istituti
Costo 400 M€





ALICE magnet

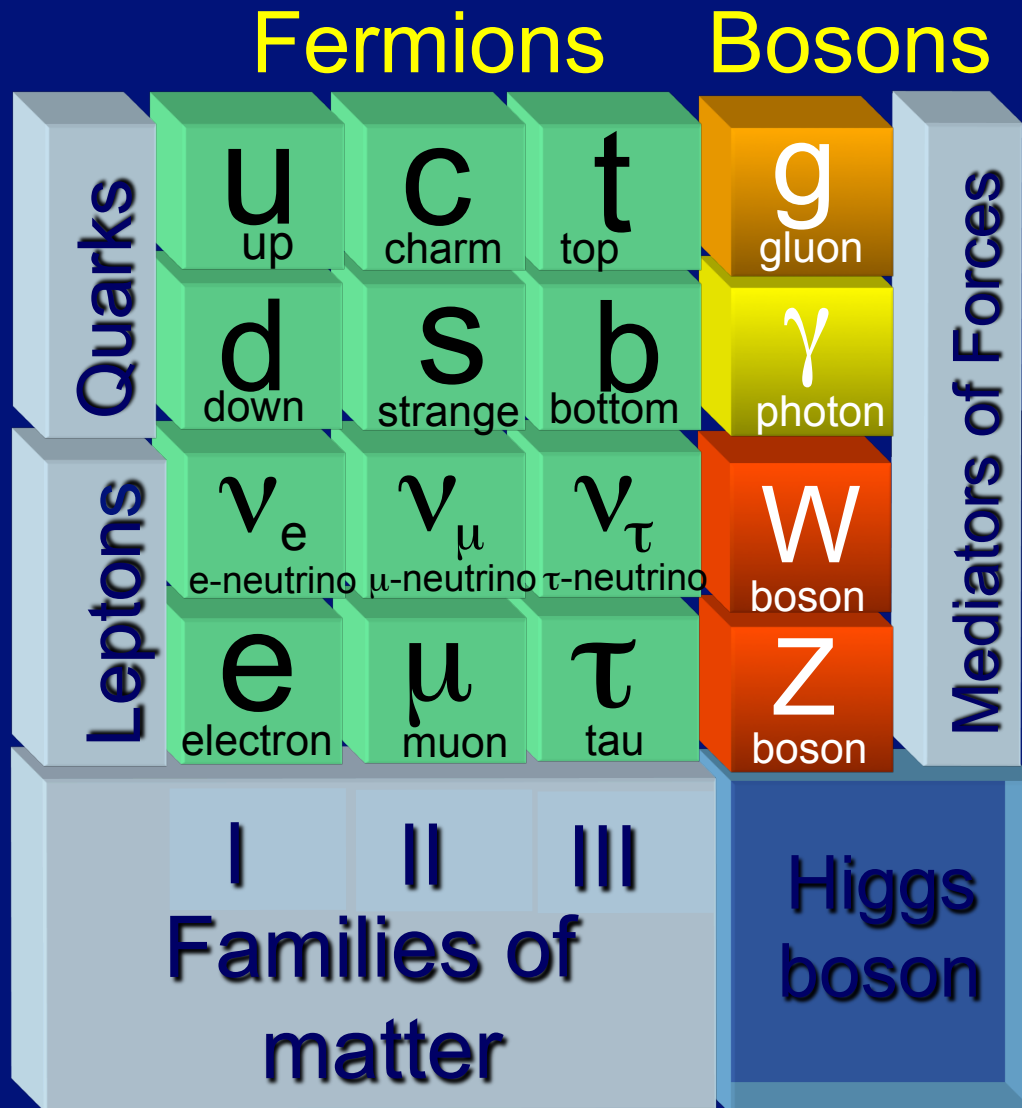




The first step: the bricks
of the Universe...

The Standard Model

The Standard Model



The fundamental interactions

Interaction

Strength

Effect

Gravitational

1

Keeps you on the ground



Weak

10^{29}

Decay:
 $n \rightarrow p + e^- + \bar{\nu}$



Electromagnetic

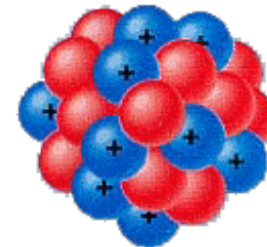
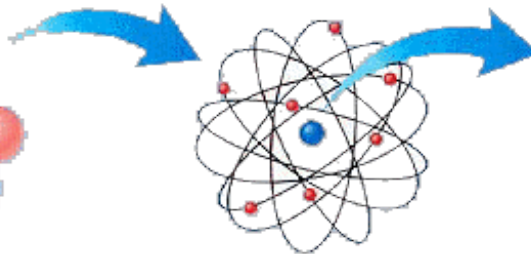
10^{40}

Keeps together the atoms

10^{-9} m

10^{-10} m

$10^{-15} - 10^{-14} \text{ m}$



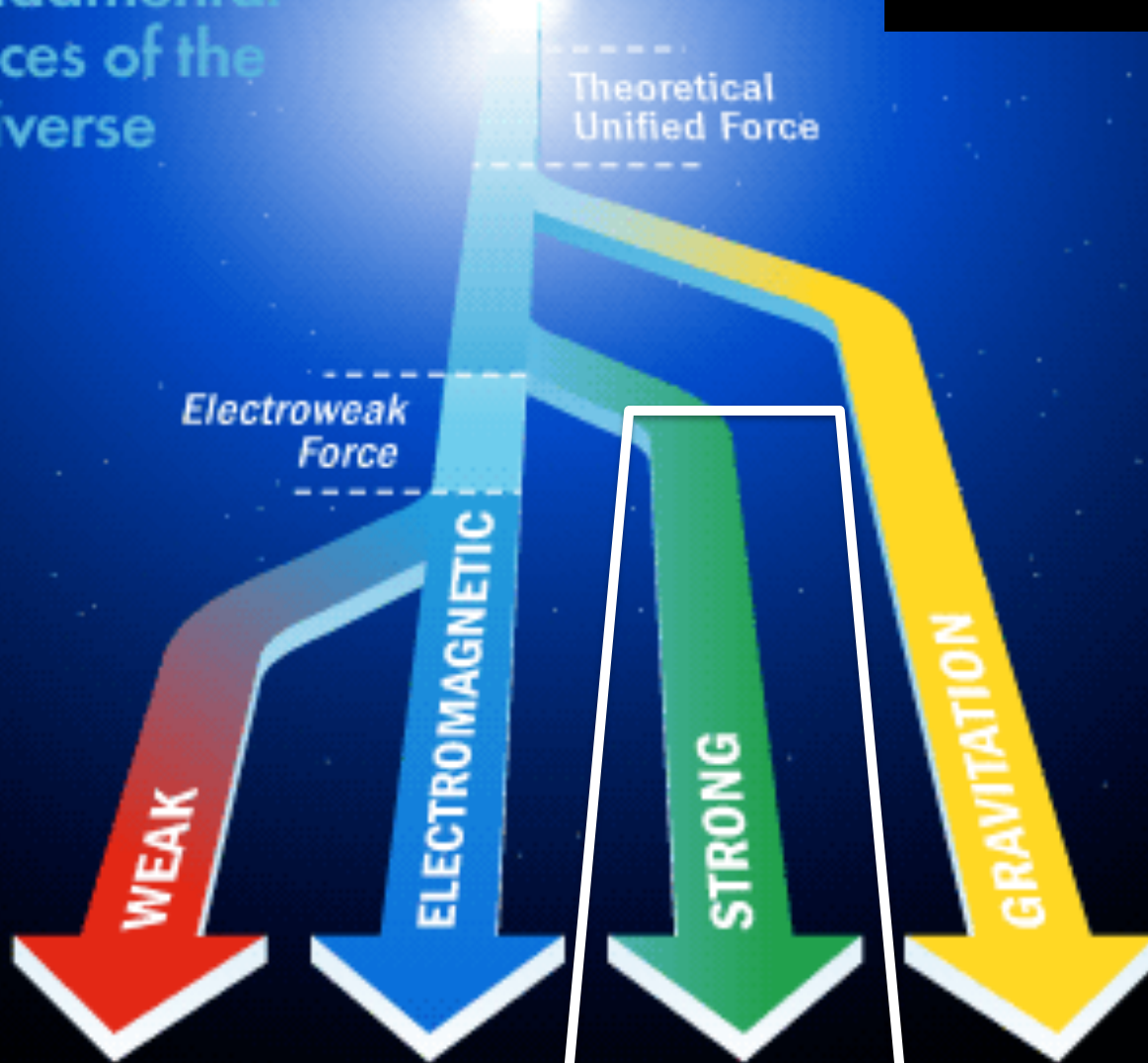
Strong

10^{43}

Keeps together the nuclei



Fundamental Forces of the Universe



THE BIG BANG THEORY

TIME
BEGINS

ONE
SECOND

PRESENT
DAY

Time 10^{-43} sec.
Temperature

10^{-32} sec.
 10^{27}°C

10^{-6} sec.
 10^{13}°C

3 min.
 10^8°C

300,000 yrs.
 $10,000^{\circ}\text{C}$

1 billion yrs.
 -200°C

15 billion yrs.
 -270°C

1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second

2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles

3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons

4 Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog

5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine

6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars

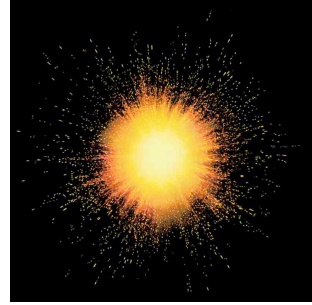
7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets

NOTE: The numbers in cosmology are so great and the numbers in subatomic physics are so small that it is often necessary to express them in exponential form. Ten multiplied by itself, or 100, is written as 10^2 . One thousand is written as 10^3 . Similarly, one-tenth is 10^{-1} , and one-hundredth is 10^{-2} .

Source: *The Birth of the Universe*; *The Kingfisher Young People's Book of Space*

TIME Graphic by Ed Gabel

A Mini-Bang in the lab




- We need a small system so that it can be accelerated to ultrarelativistic speed (99.9% c)
- That system (i.e. a chunk of matter and not just a single particle) must follow simple rules of thermodynamics and form a new state of matter in a particular phase
- We can use heavy ions (e.g. Pb). They are tiny ($\sim 10^{-14}$ m) but have a finite volume that can be exposed to pressure and temperature

We will try to force matter, through a phase transition, to a new state of matter called “Quark Gluon Plasma”

We need Heavy Ions

2 nuclei
colliding at
very high
energy



Pb+Pb $E_{\text{cm}}=5.5$ TeV

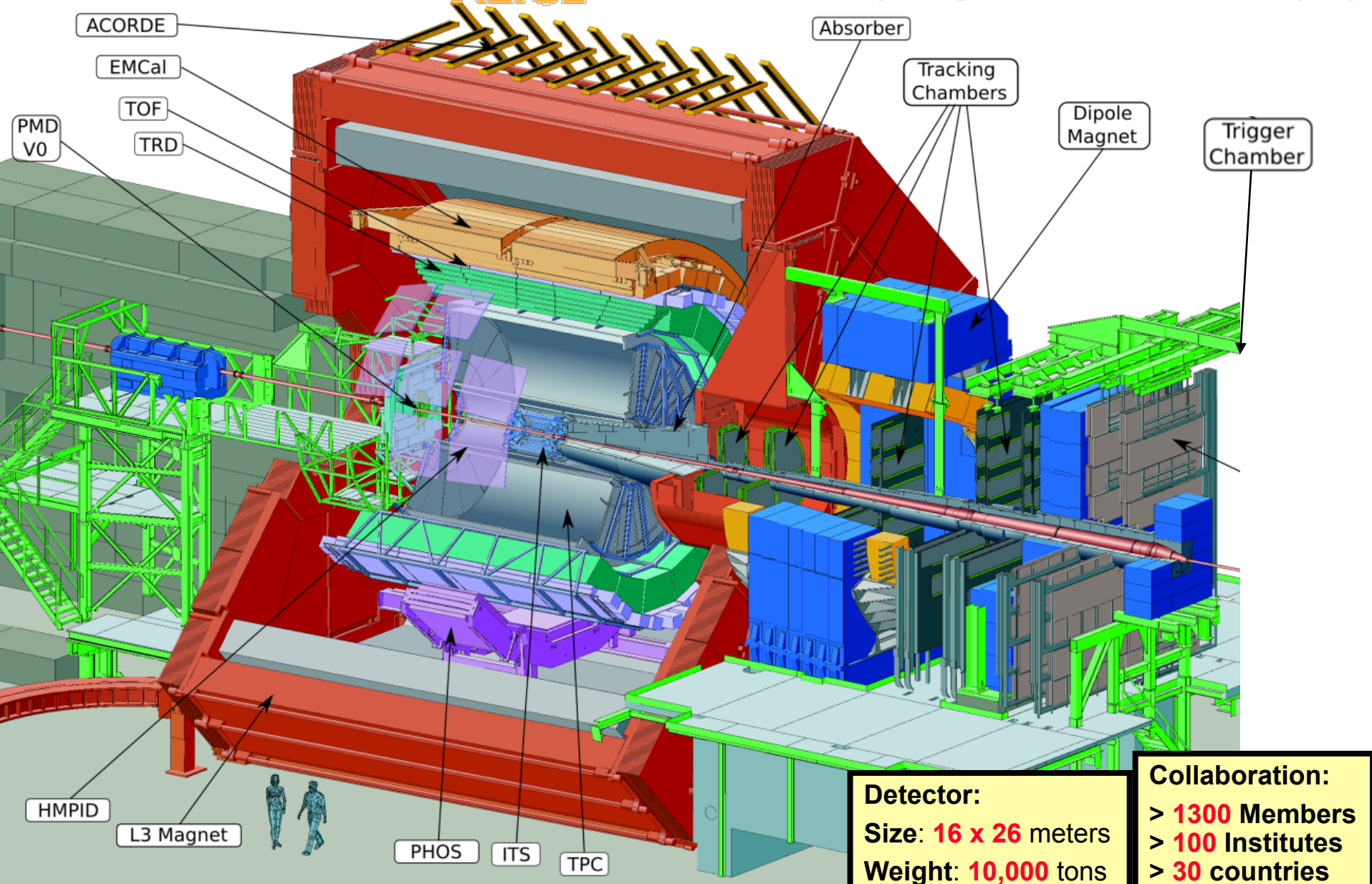
$t=-19.00$ fm/c





A Large Ion Collider Experiment

European Organisation for Nuclear Research



Detector:

Size: 16 x 26 meters

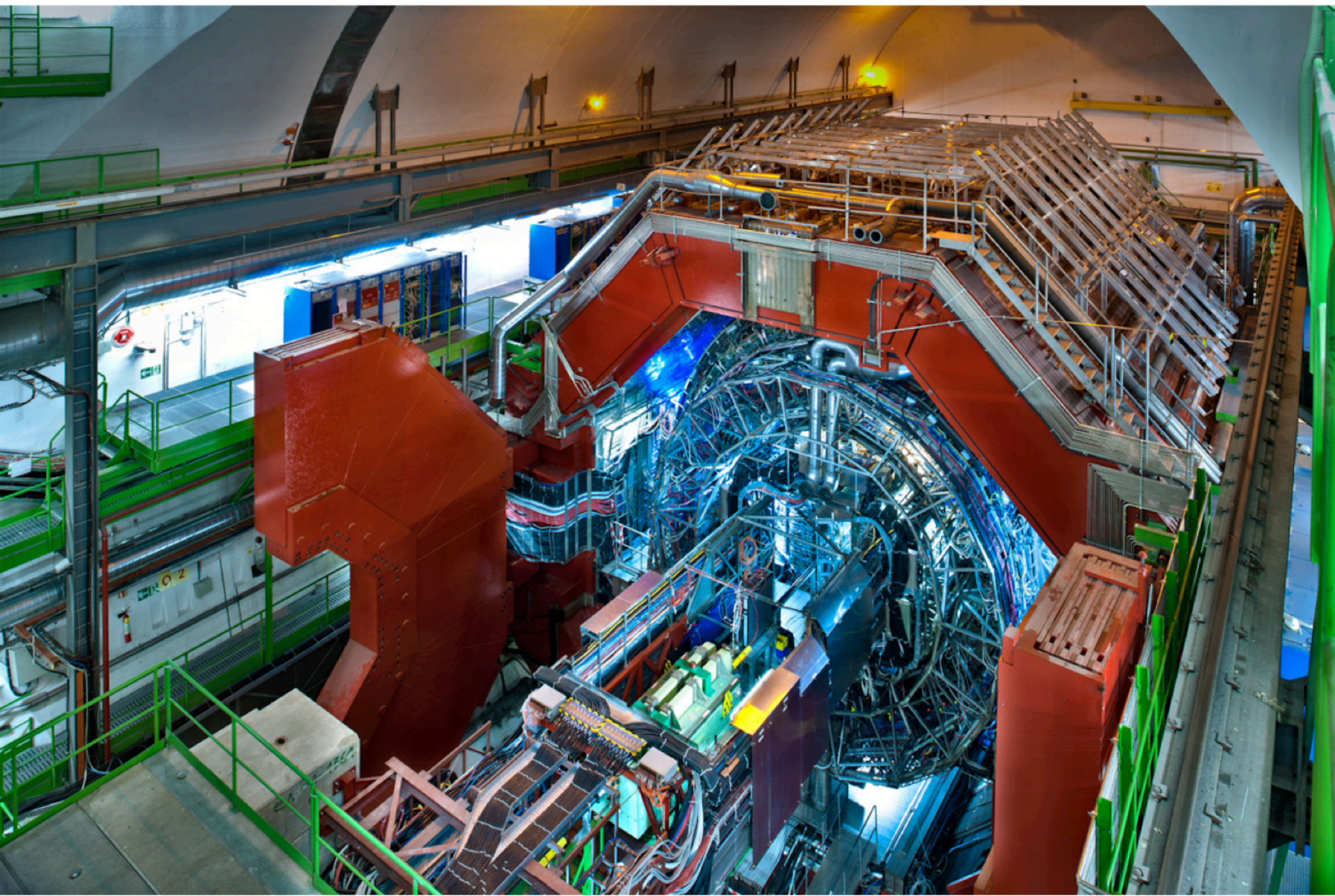
Weight: 10,000 tons

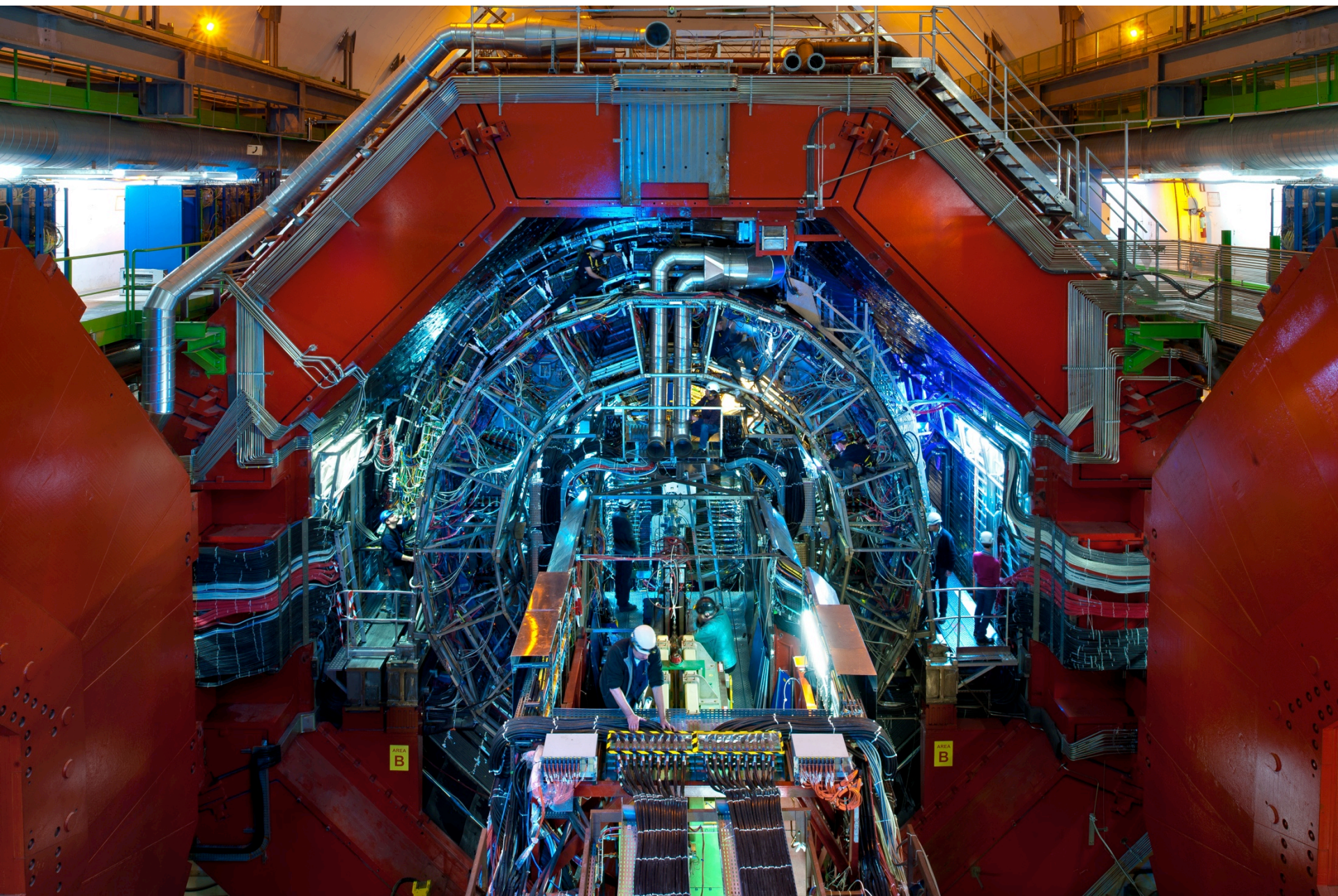
Collaboration:

> 1300 Members

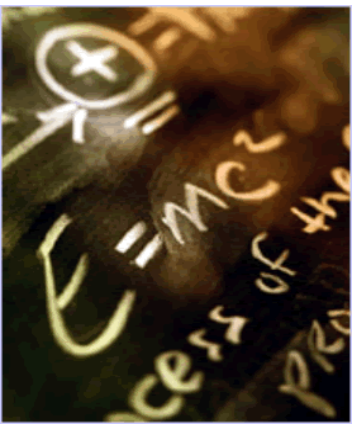
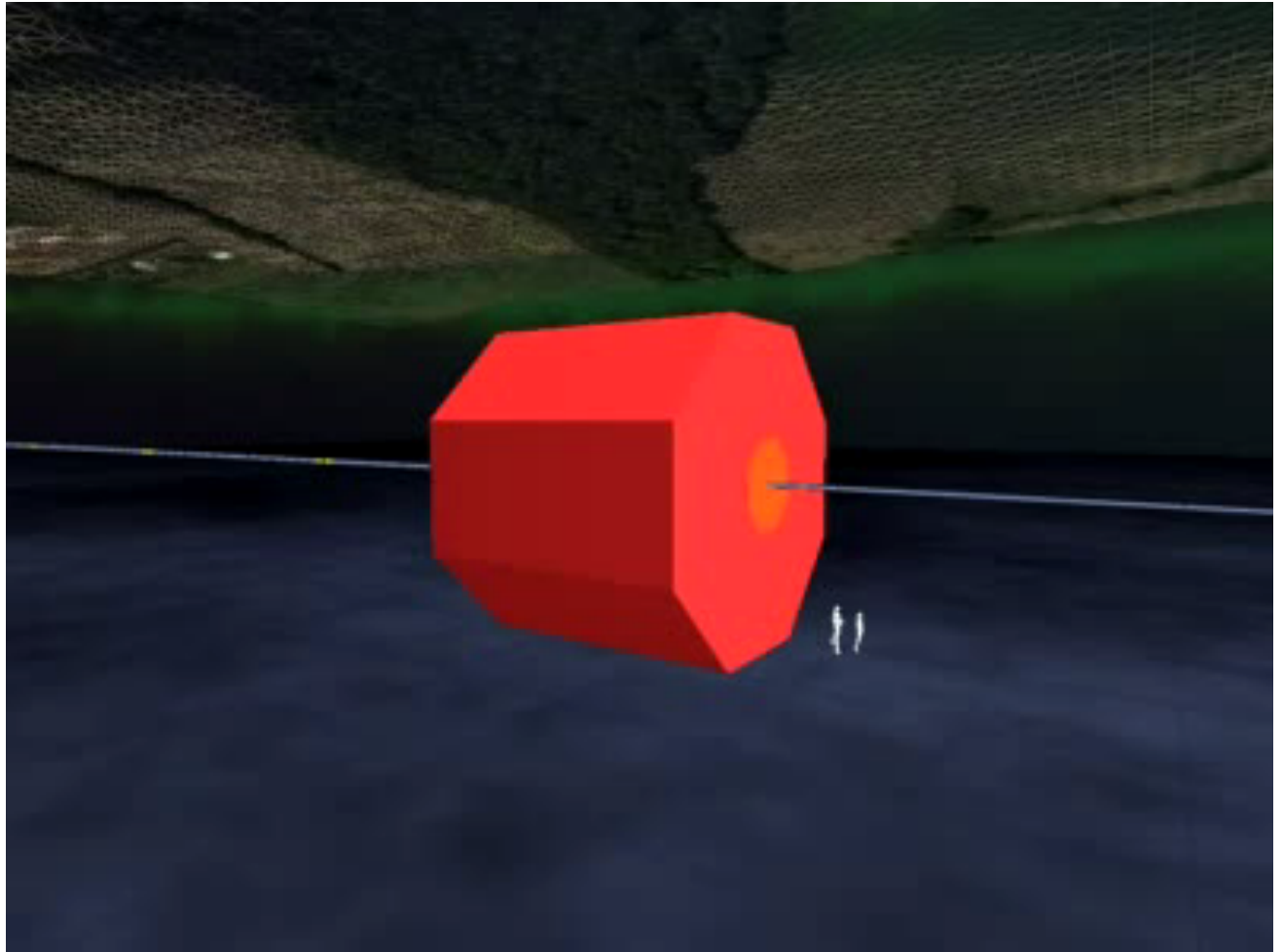
> 100 Institutes

> 30 countries





A simulated collision in Alice

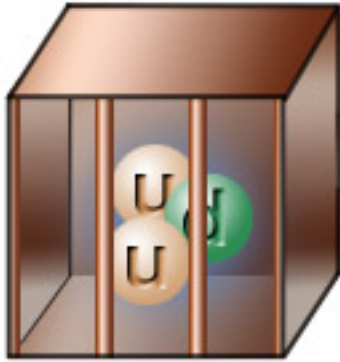


Up to 10^{-37} - 10^{-5} s from the Big Bang the Universe was formed by a “soup” of quarks and gluons ... the Quark Gluon Plasma (QGP)

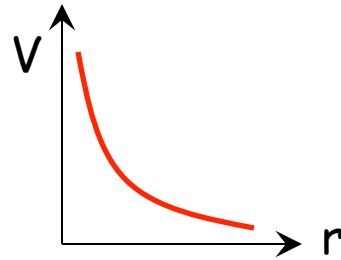


- Why to study the QGP?
- Which are the main features of the QGP?
- Is it possible to have such a system in laboratory?
 - $T_{\text{QGP}} = 2000$ billions K
 - $T_{\text{SUN}} = 15$ millions K

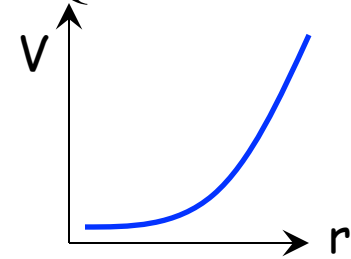
Asymptotic freedom \rightarrow Confinement



$$V_{\text{Coulomb}} \propto \frac{q_1 q_2}{r}$$

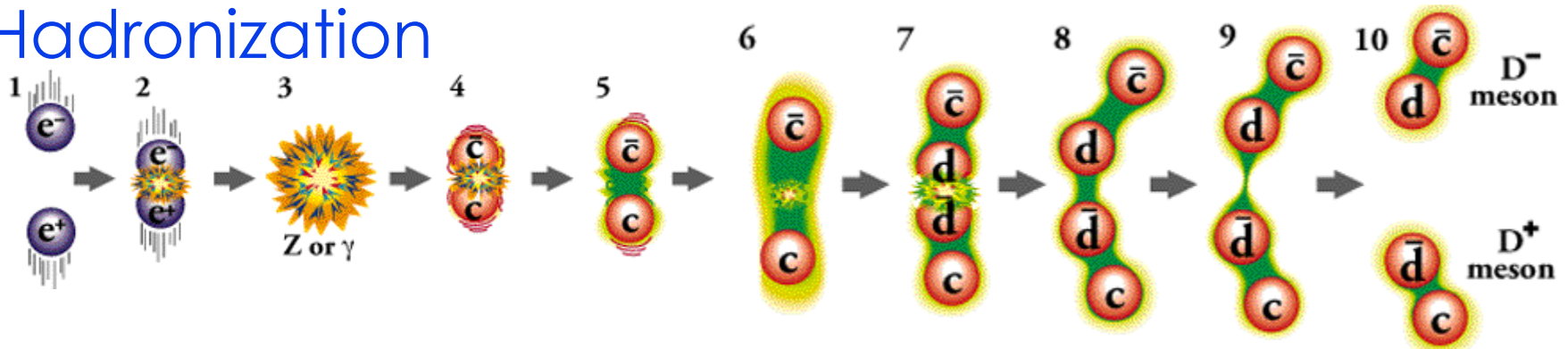


$$V_{\text{QCD}} \propto e^{k \cdot r}$$

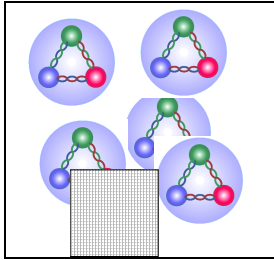


Separating interacting quark, a tension (energy) able to create new particles is formed (1000 MeV / fm)

Hadronization



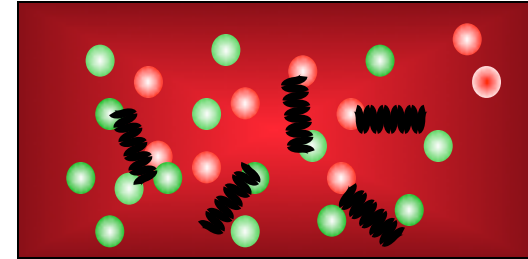
We need to create a system with high energy density (particles at infinitesimal distance) in order to have negligible strong interactions



Hadrons



ENERGY



Quark Gluon Plasma

Nobel Prize 2005

D. Gross
H.D. Politzer
F. Wilczek

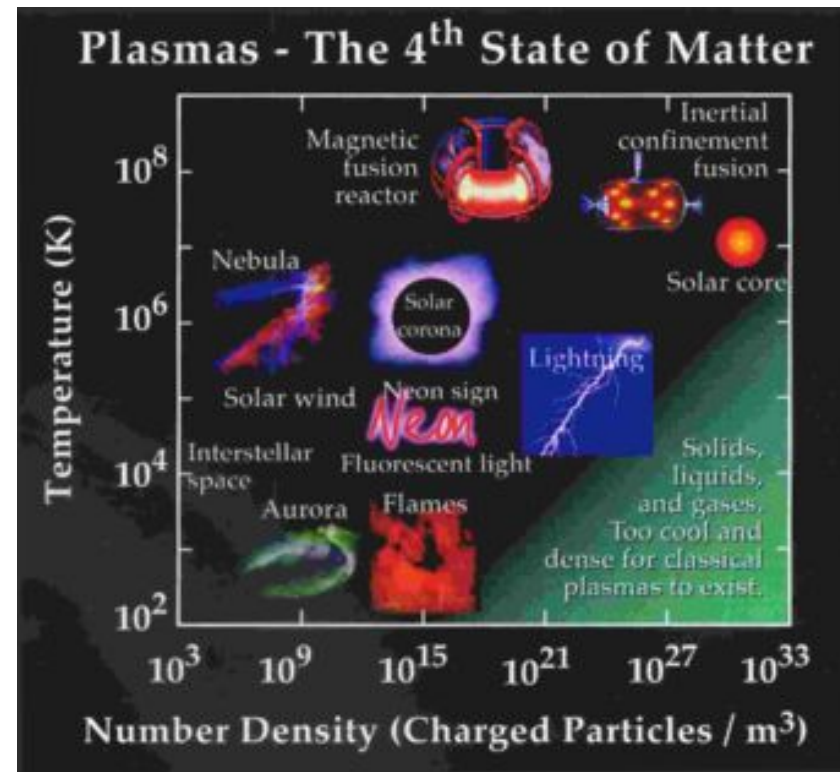
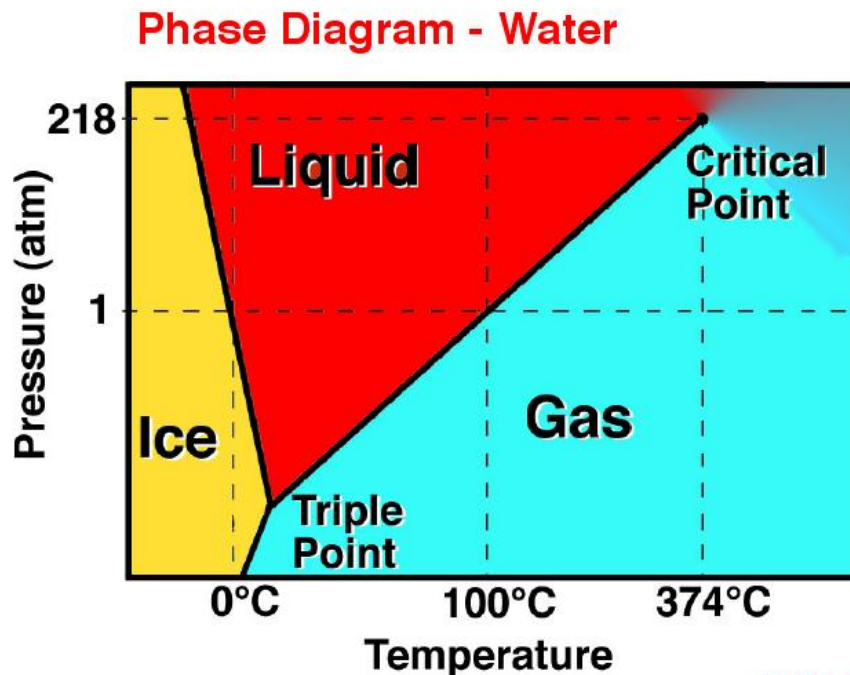
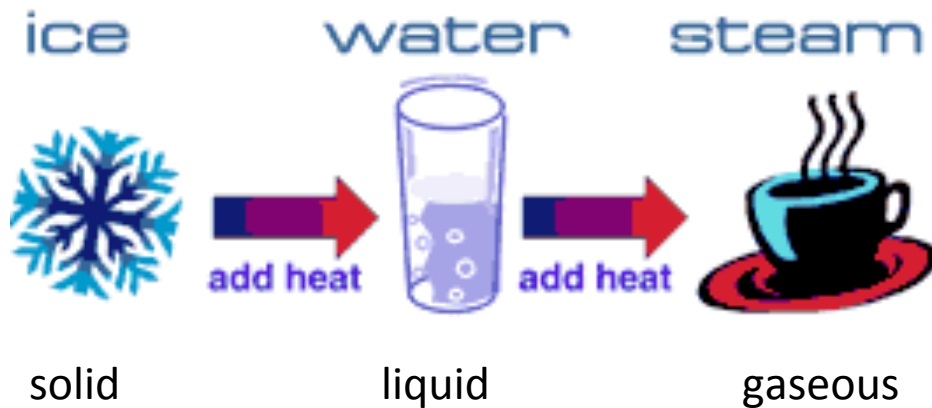
QCD Asymptotic Freedom (1973)



"Before [QCD] we could not go back further than 200,000 years after the Big Bang. Today...since QCD simplifies at high energy, we can extrapolate to very early times when nucleons melted...to form a quark-gluon plasma."

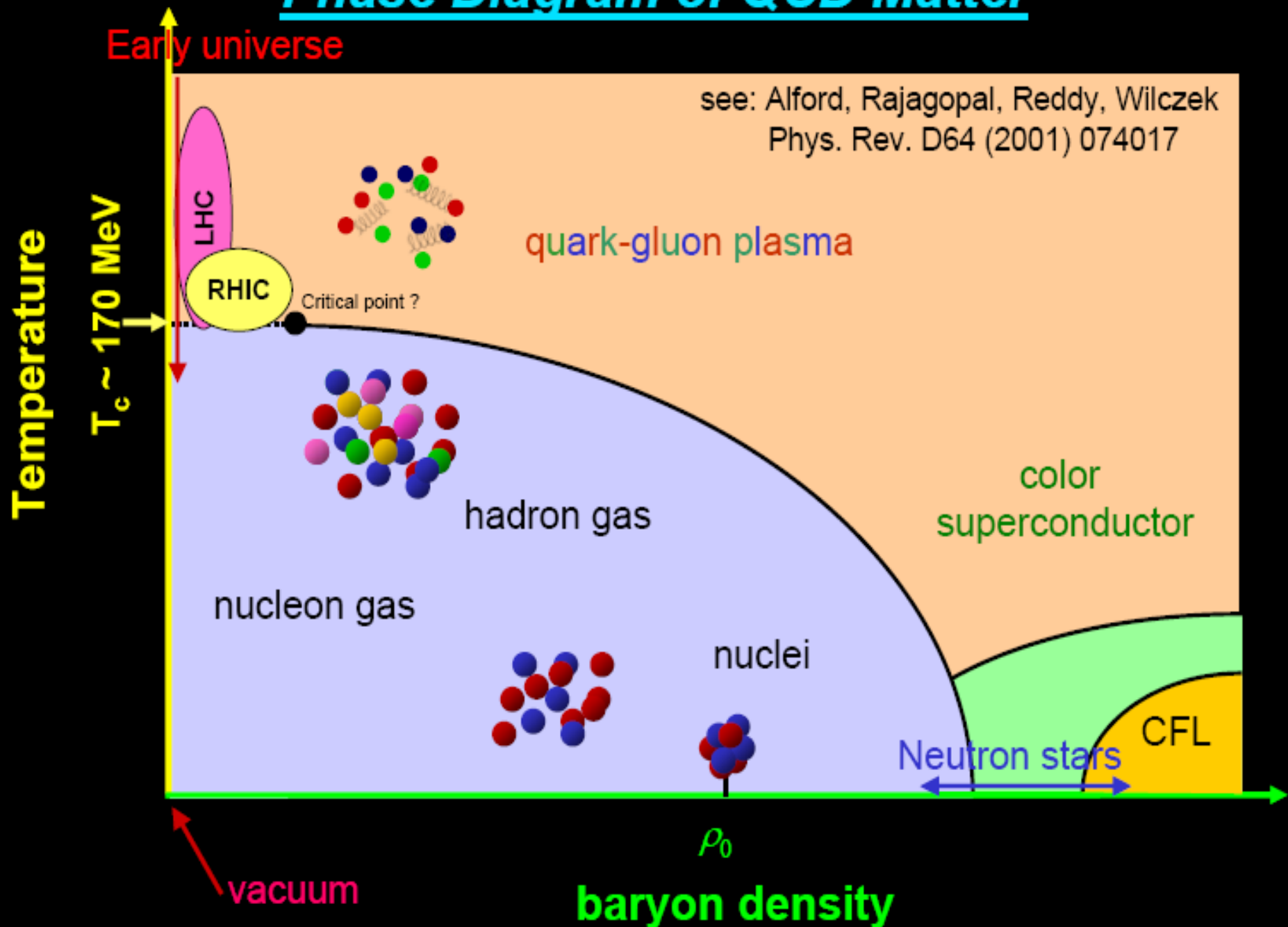
David Gross, Nobel Lecture (RMP 05)

Phases of the "normal" matter

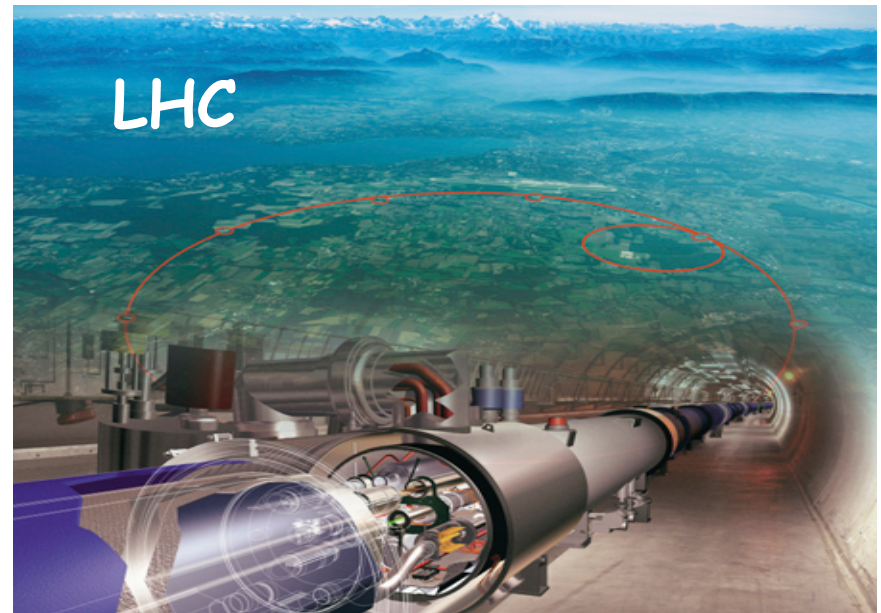
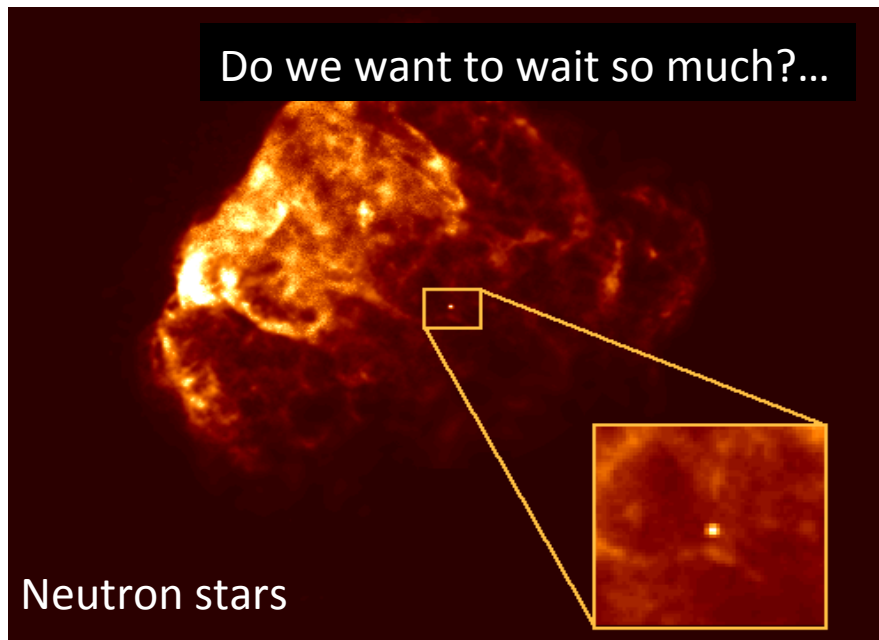
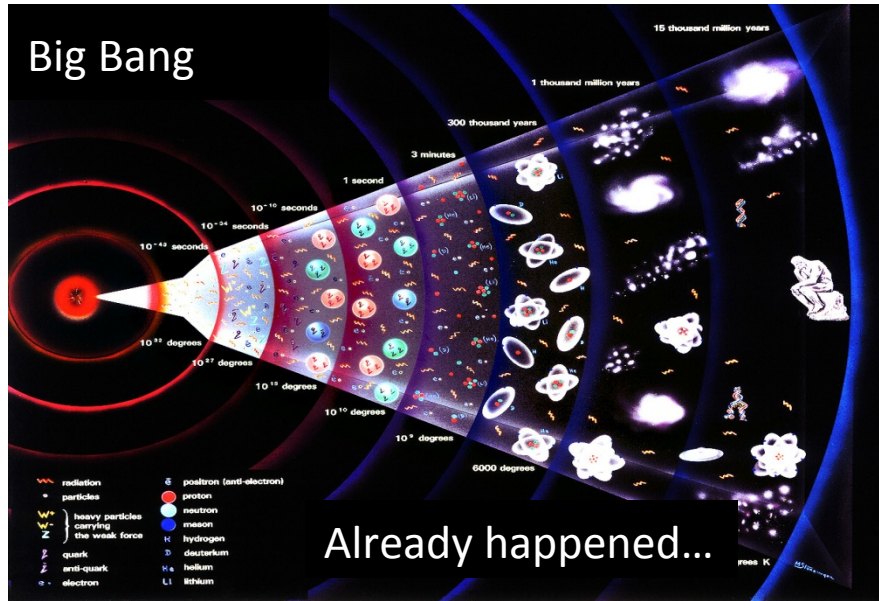


Classic Plasma

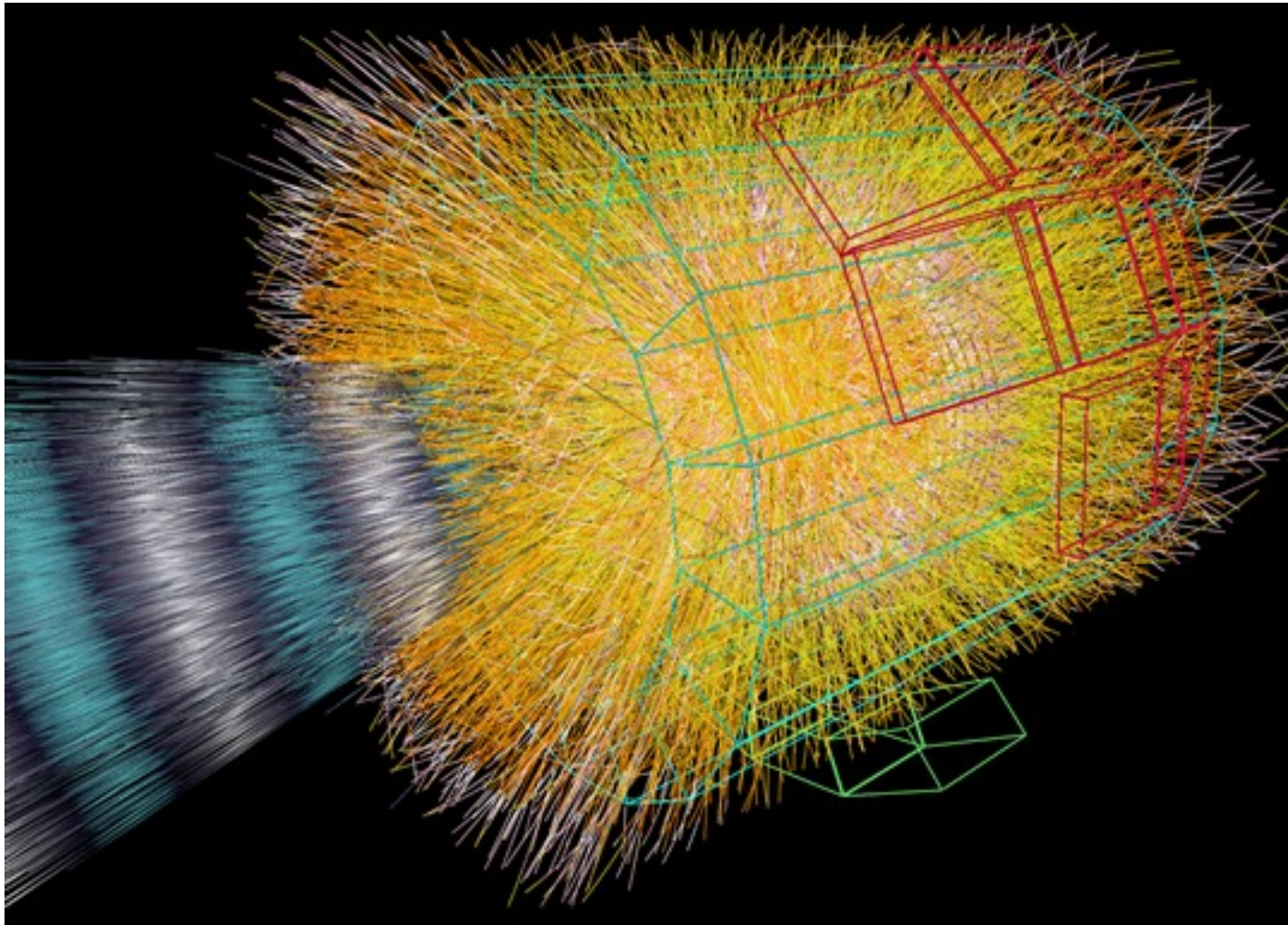
Phase Diagram of QCD Matter



Where can we produce the QGP?



Pb+Pb event in Alice



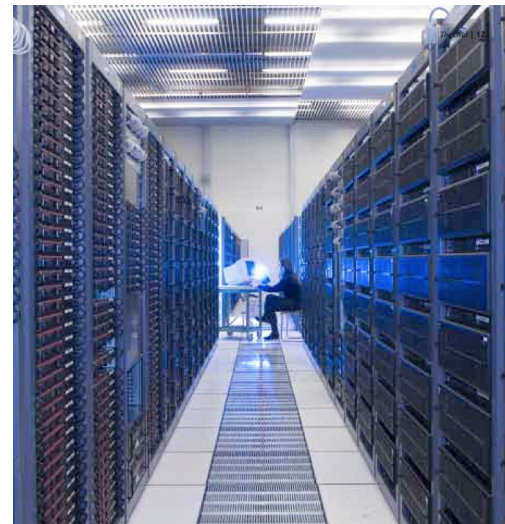
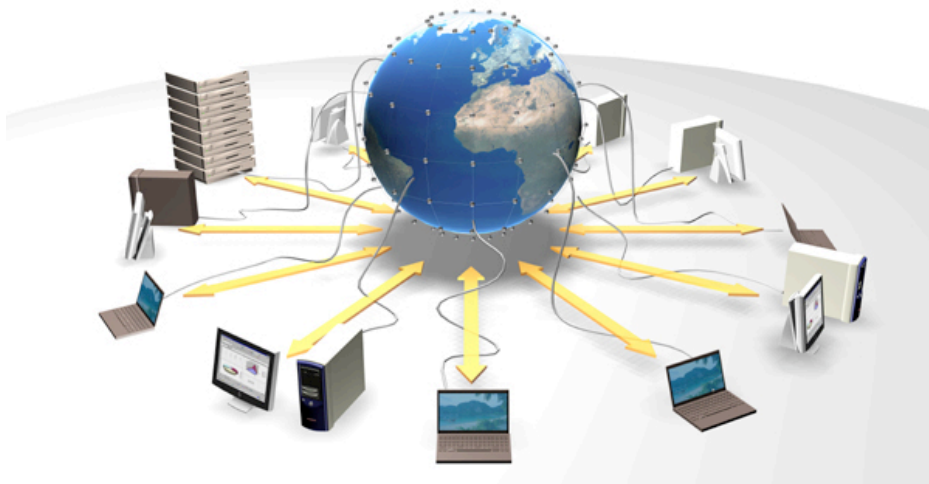
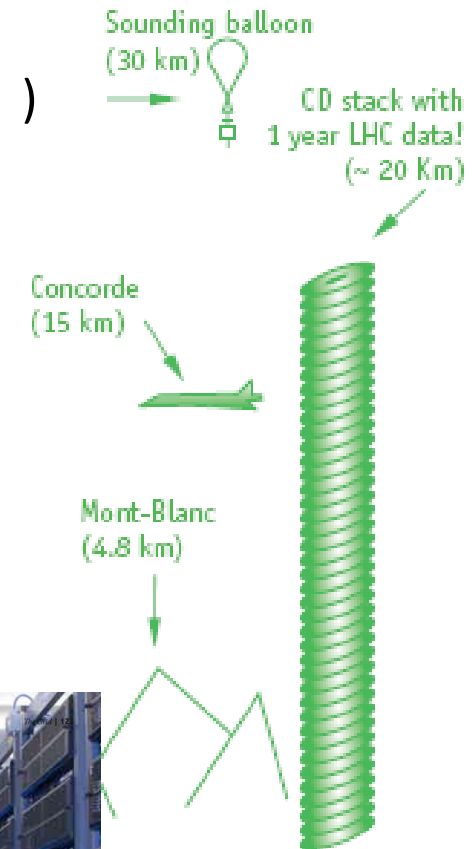
Thousands of particles produced per collision (25 ns)

Data Acquisition and Analysis

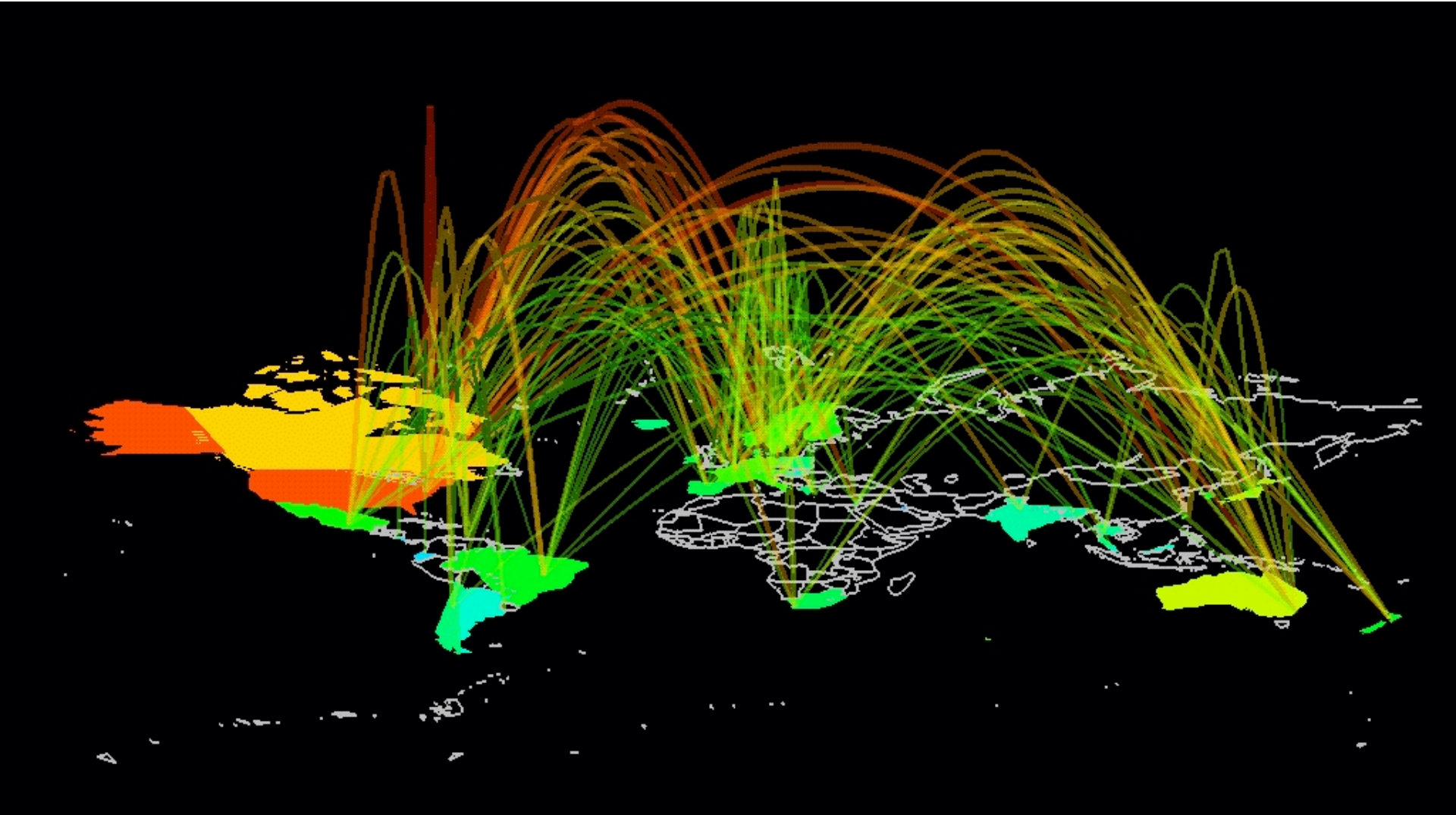


Experimental data at the LHC

- The quantity of produced data is enormous!
 $\sim 1.3 \text{ GB/s} \rightarrow 6 \text{ times the Britannic Encyclopedia}$
- If we had to store those data on CD we should need a stack of disks 20 km tall ... each year!
- New computing solutions developed: GRID



GRID architecture

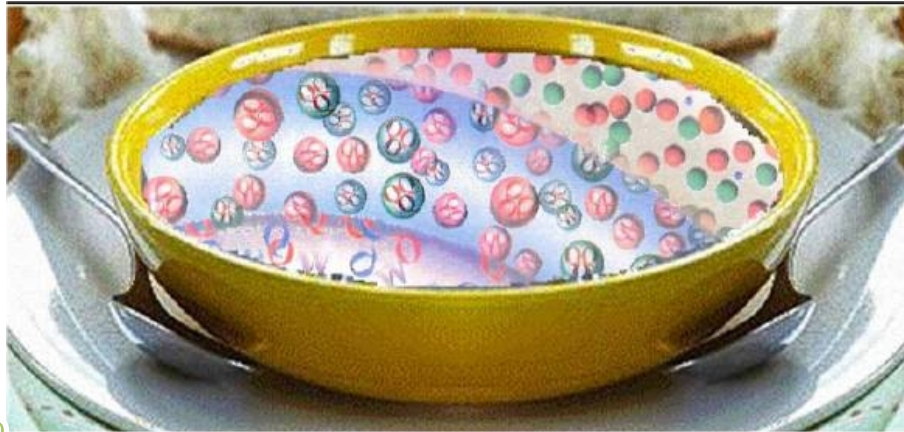


A “soup” reach of information

Space-time evolution of
the birth of a hadron

Properties of QCD at high
temperature: degrees of
freedom, viscosity, conductivity, ...

Restauration of
chiral symmetry



Elliptic Flow

Plasma and color
caos instability

Freezout
Puzzle barionico

Phase transition in cosmological theories
of the primordial Universe

Equation state of
QCD

Partonic energy loss

Chemical composition

Global observables summary

The Early Universe behaved as a perfect fluid

Something less interesting ... at least for you

- Energy density $> 50 \text{ GeV/fm}^3$
- Freeze-out volume $\sim 300 \text{ fm}^3$
- Time scale until decoupling 10 fm/c
- Elliptic flow as expected from hydro-dynamical calculations
- Initial state saturation effects smaller than expected

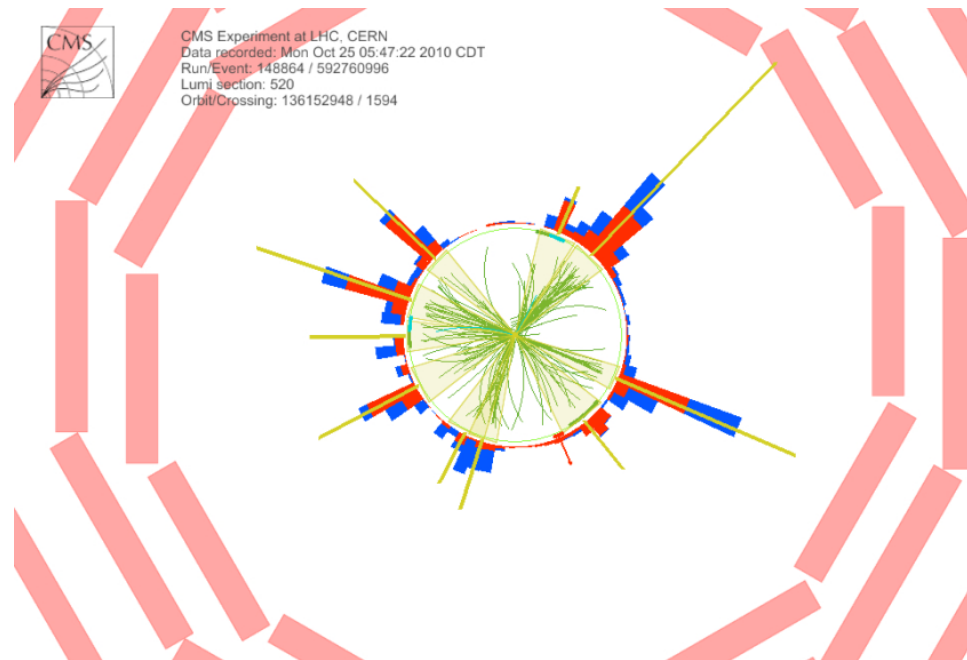
Can a Black Hole be produced at the LHC?



Black Holes evolution and decay

- Mini black holes produced at LHC would be light and tiny compared to cosmic black holes ($\sim \text{TeV}$ versus ~ 3 Solar masses)
- This means they would be extremely hot ($T \sim 100 \text{ GeV}$) and evaporate almost instantaneously, mainly via Hawking radiation
- \rightarrow cosmic BH 10^{19} GeV \rightarrow LHC energy $\sim 10^4 \text{ GeV}$
- Typical decay signature:
 - ~ 6 ptc for each decay emitted spherically
 - 75% quarks and gluons
 - 10% charged leptons
 - 5% neutrinos
 - 5% of photons or W/Z boson
 - new ptc around 100 GeV

*BH event
simulated by CMS*



Conclusions

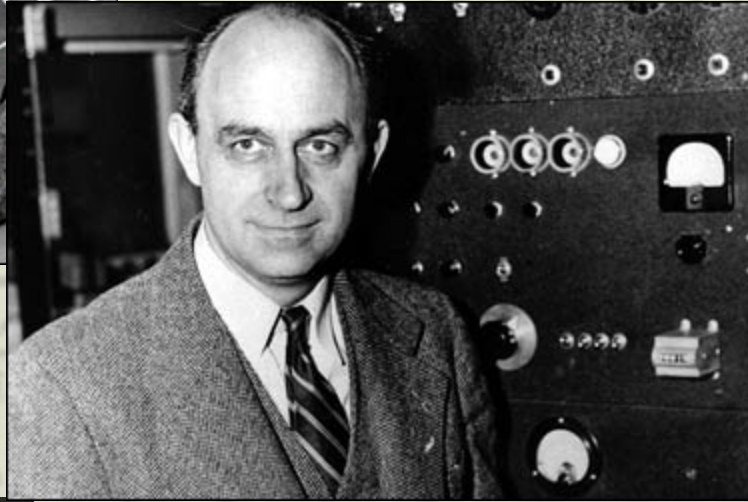


Alice and the LHC are operating wonderfully unveiling the first secrets of the Early Universe

A new and unique era for the exploration of the matter just started. The connections with other branches of physics are incredibly high and intriguing

Video: Inside the ALICE experiment

<https://www.youtube.com/watch?v=NFRSX00qeIU>



I'm still confused ...
... but at high level !

E.Fermi, Chicago 1951