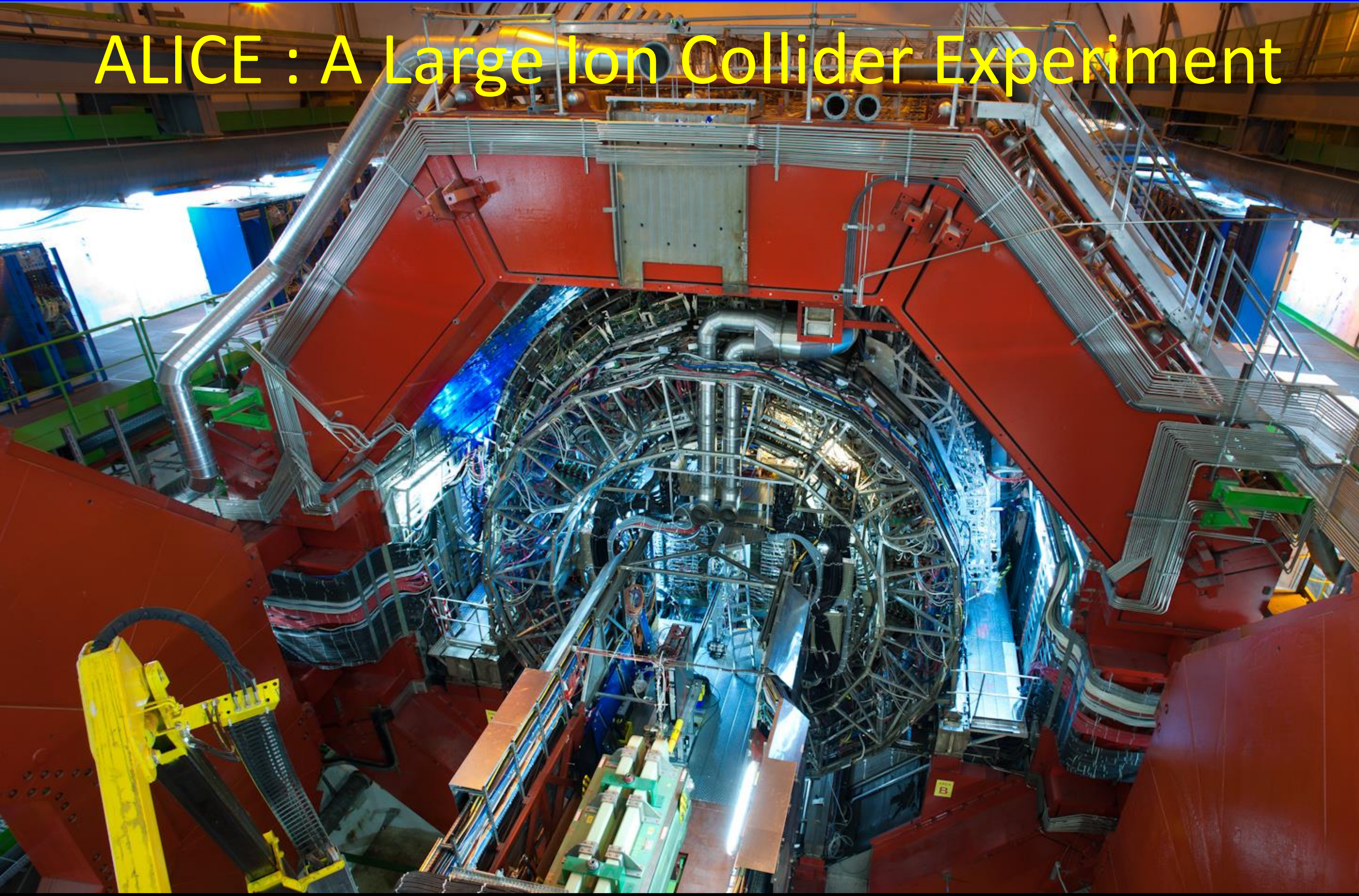
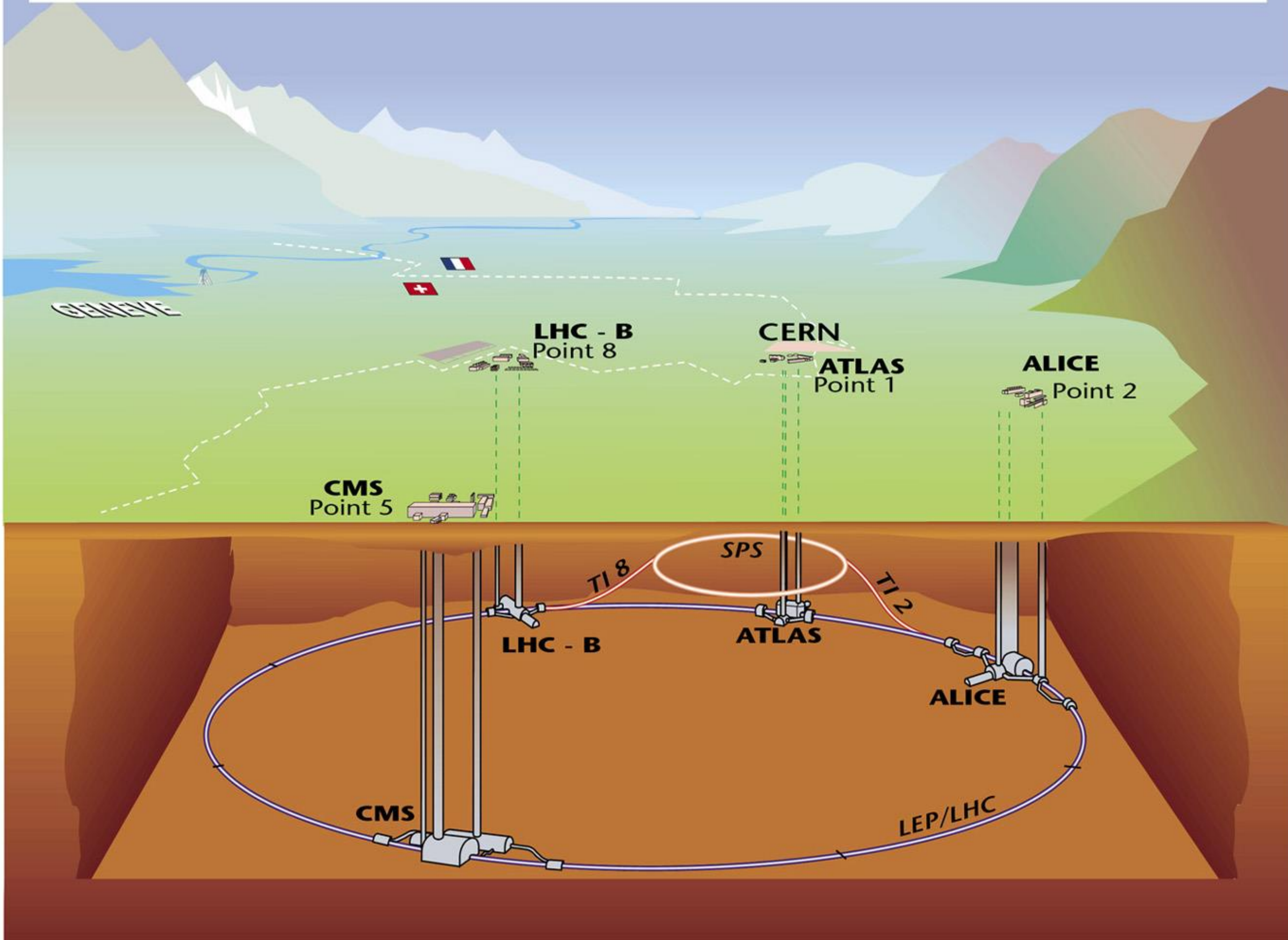
ALICE : A Large Ion Collider Experiment



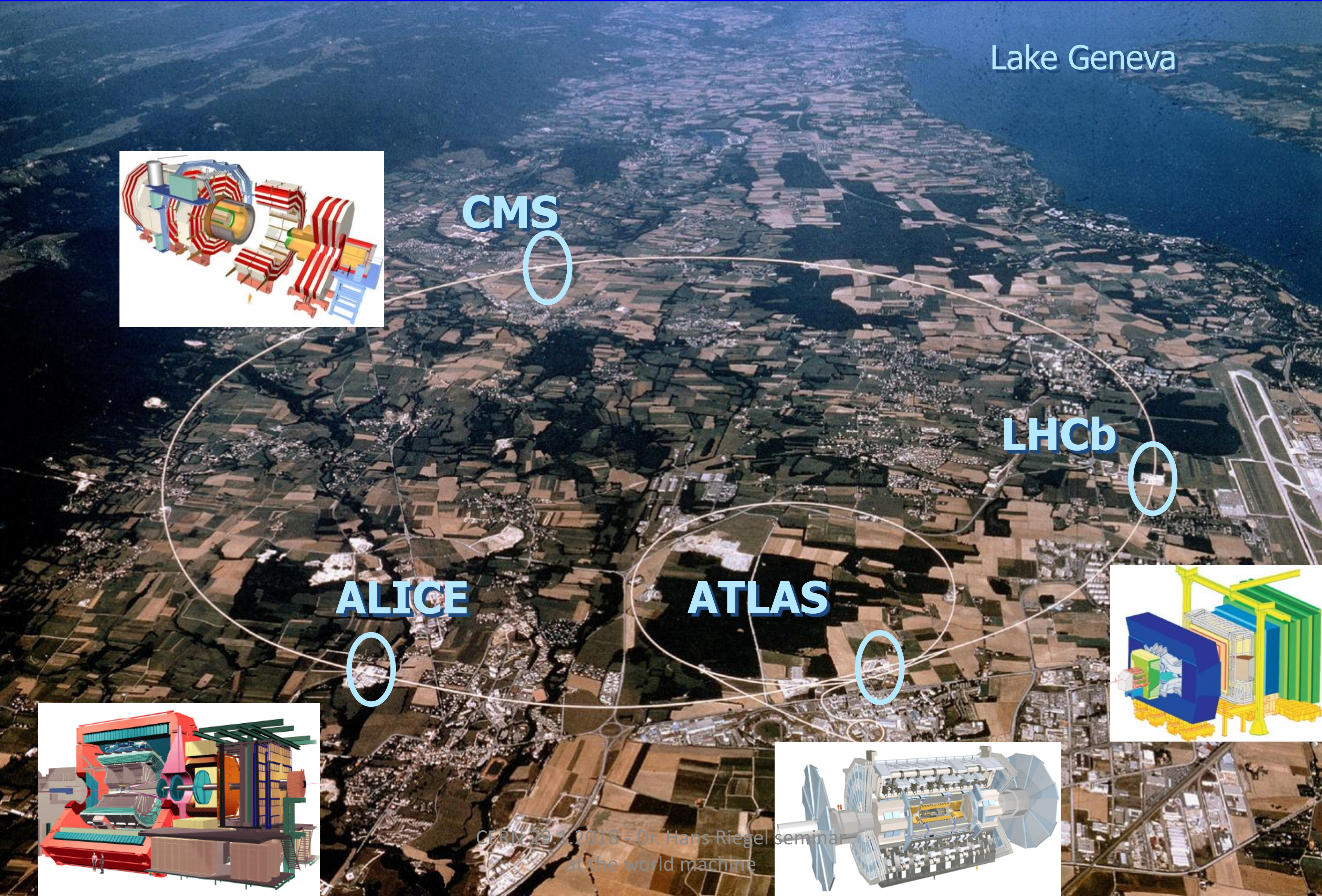
CERN, 29.1.2018

Despina Hatzifotiadou

Overall view of the LHC experiments.

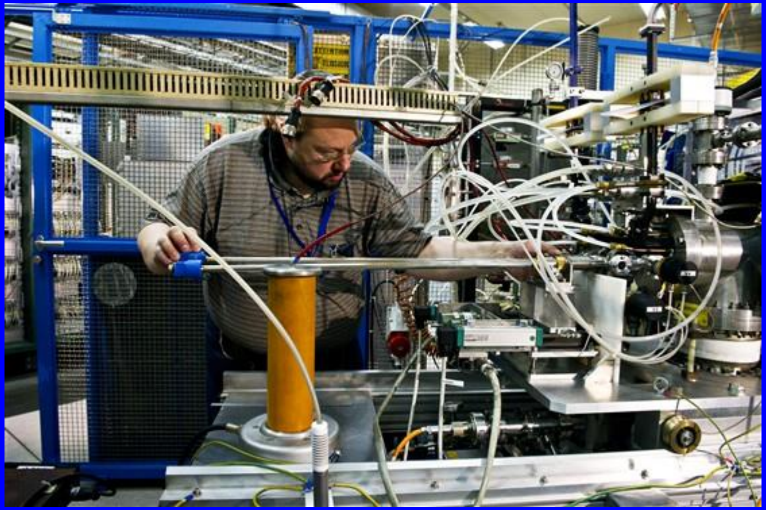


Large Hadron Collider



Heavy ions at LHC

isotope : Pb^{208}
82 protons
126 neutrons

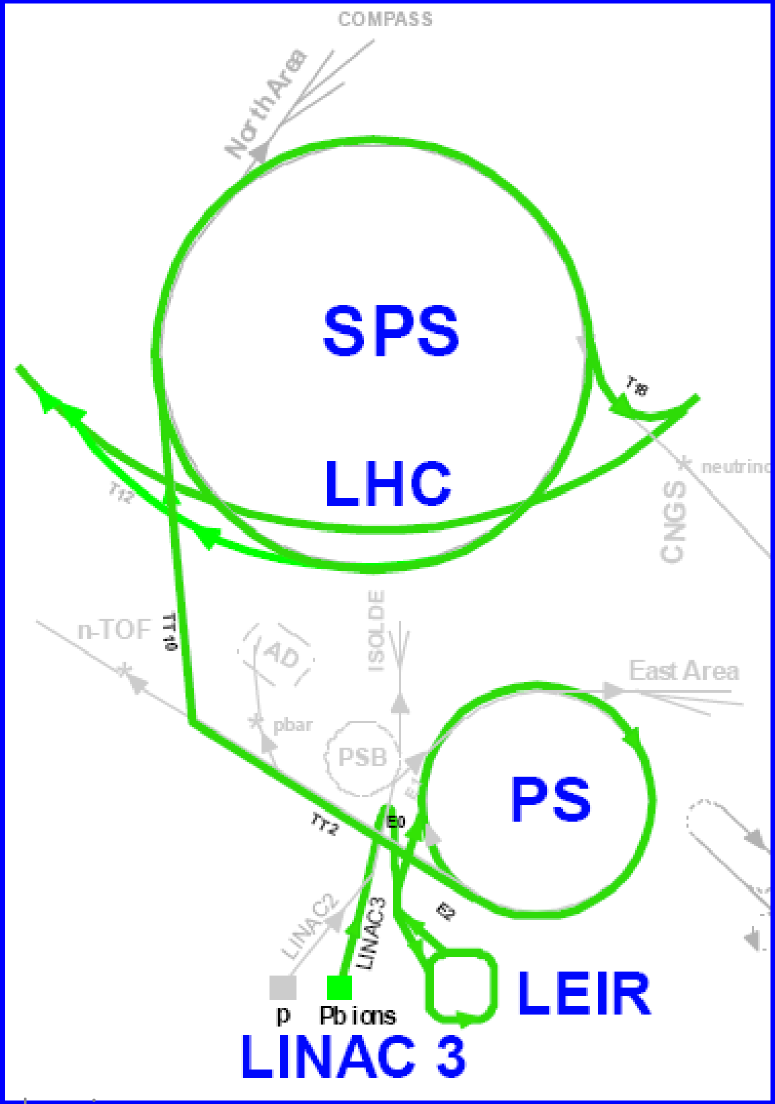


A small bar of lead, Pb^{208} (2 cm, 500 mg) is heated at 500°C and evaporates. An electric current ionises the atoms.

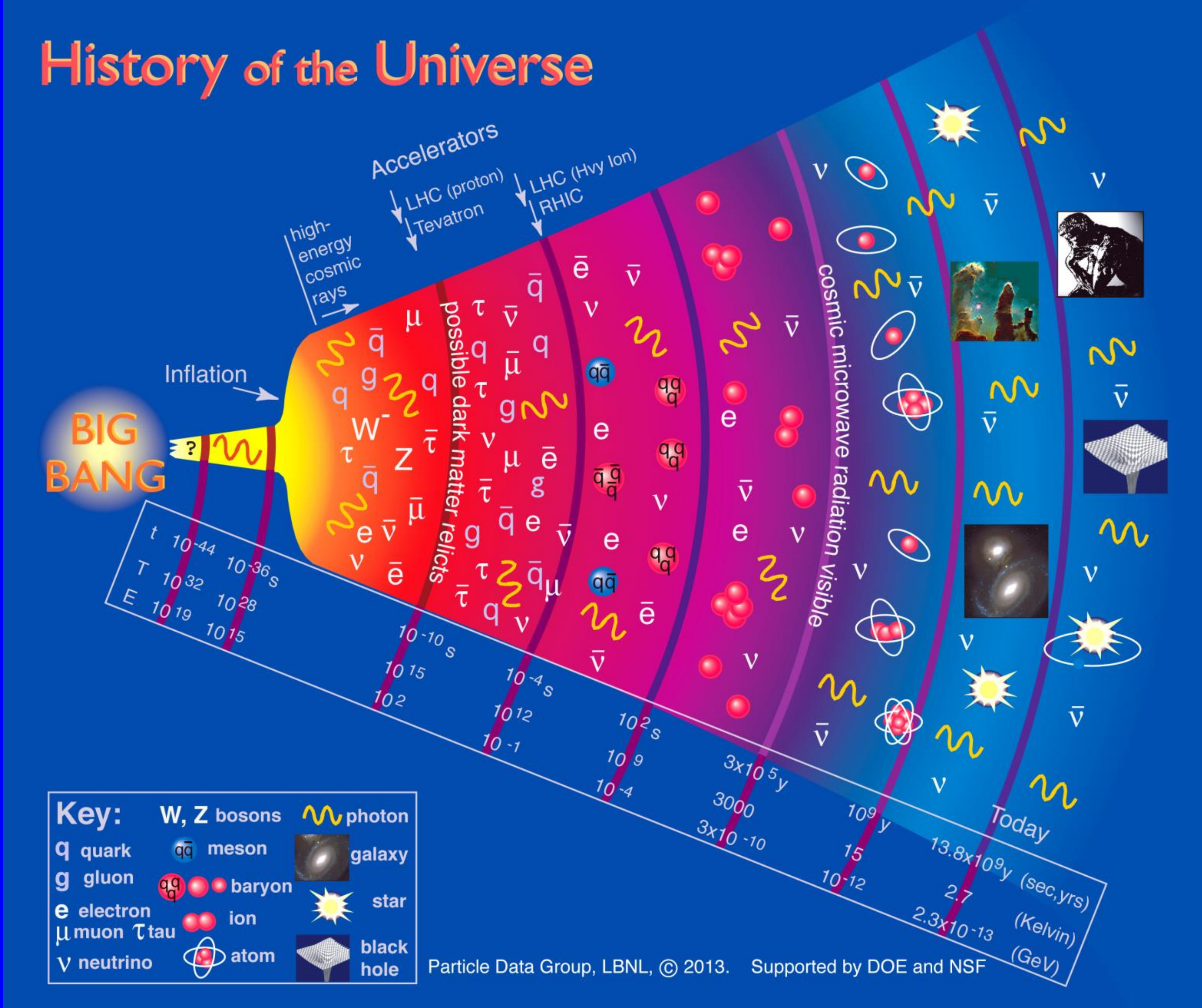
Pb atom -> Pb^{27+} -> Pb^{54+} -> Pb^{82+}

Heavy Ions at CERN

- Acceleration of Pb ions:
  - ECR source: Pb^{27+} (80 mA)
  - RFQ: Pb^{27+} to 250 A keV
  - Linac3: Pb^{27+} to 4.2 A MeV
  - Stripper: Pb^{53+}
  - LEIR: Pb^{53+} to 72 A MeV
  - PS: Pb^{53+} to 4.25 A GeV
  - Stripper: Pb^{82+} (full ionisation)
  - SPS: Pb^{82+} to 158 A GeV
  - LHC: Pb^{82+} to 2.76 A TeV
  - LHC: Pb^{82+} to 5.02 A TeV



What is the particular interest of lead ion collisions at high energies ?



13.7 billion years ago the universe was born from a Big Bang

Millionths of a second after the big bang, all matter is made of free quarks and gluons,

THE QUARK GLUON PLASMA

As the universe cools and expands, the quarks and gluons are "imprisoned" for ever inside hadrons: from these, only protons and neutrons remain today

Little Bang

By colliding lead nuclei at very high energies we recreate the conditions of density and temperature which existed fractions of a second after the Big Bang

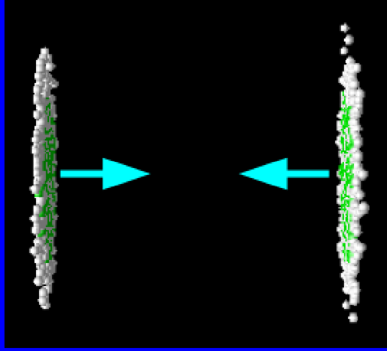
The protons and neutrons which constitute the lead nuclei melt liberating the quarks and gluons which are bound inside them

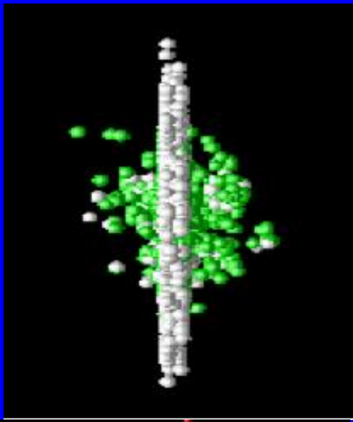
A new state of matter is created : the QUARK GLUON PLASMA

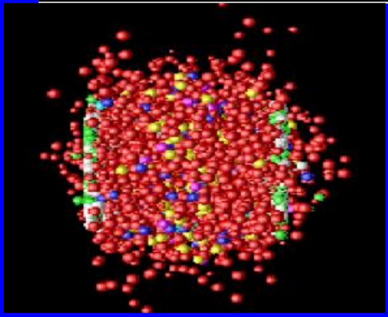
By studying its properties

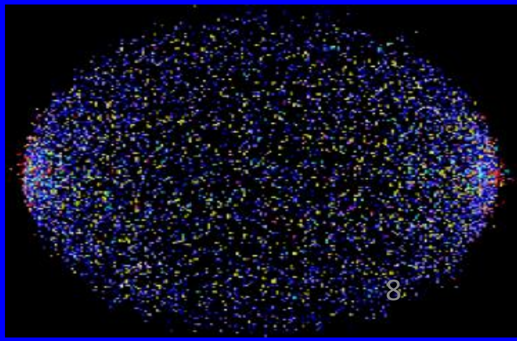
- We will understand better the processes which took place during the first fractions of a second in the life of the universe

- We will understand better the strong interaction and how the protons and neutrons acquire their mass

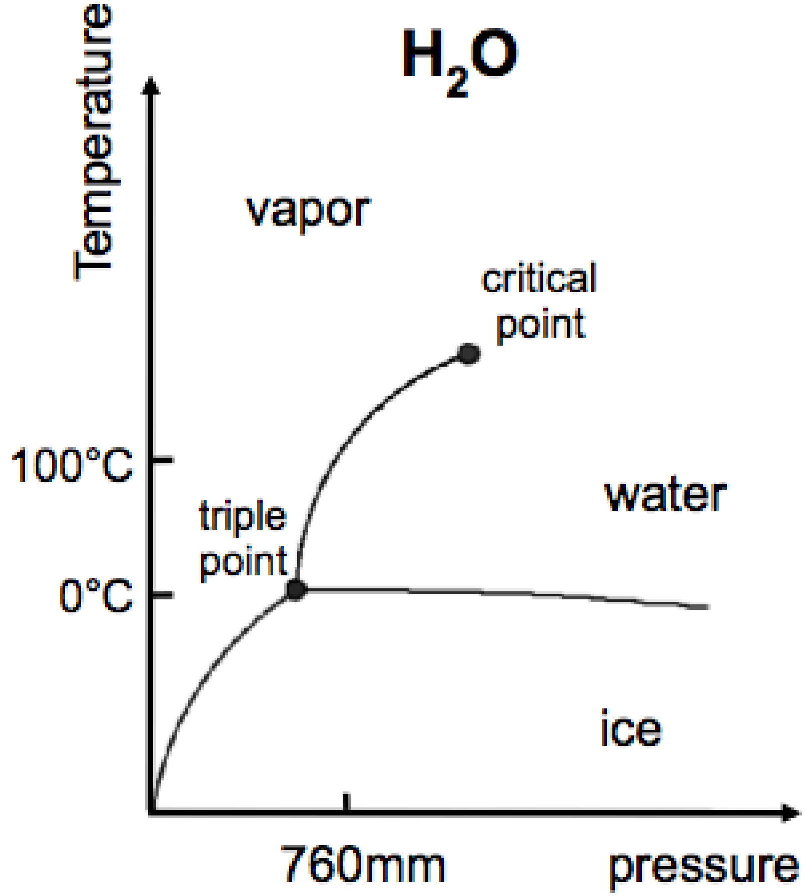




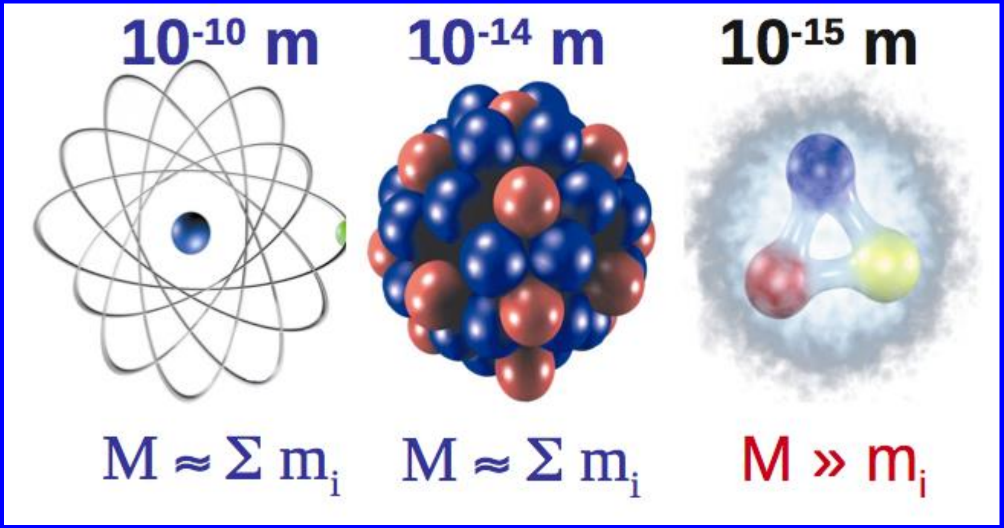




Reminder: Phase diagram



atom nucleus nucleon



In nucleons (protons and neutrons) the mass is not defined by the sum of masses of their constituents but mainly from the energy due to the movement of quarks and the energy of the gluons

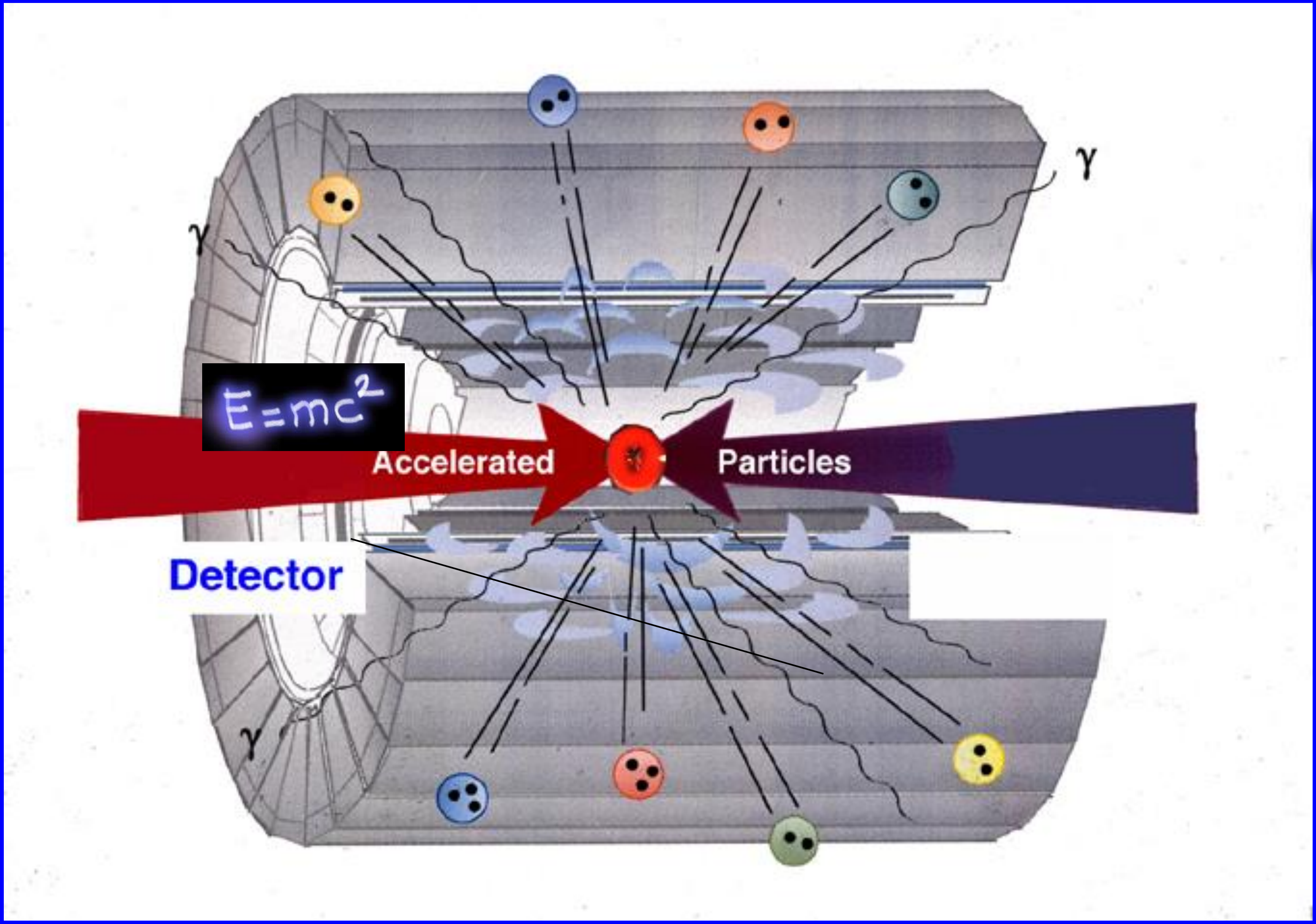
Example

the proton (uud) mass : 938 MeV/c^2

up quark mass : 1.7 – 3.3 Mev/c^2

down quark mass : 4.1 – 5.8 MeV/c^2

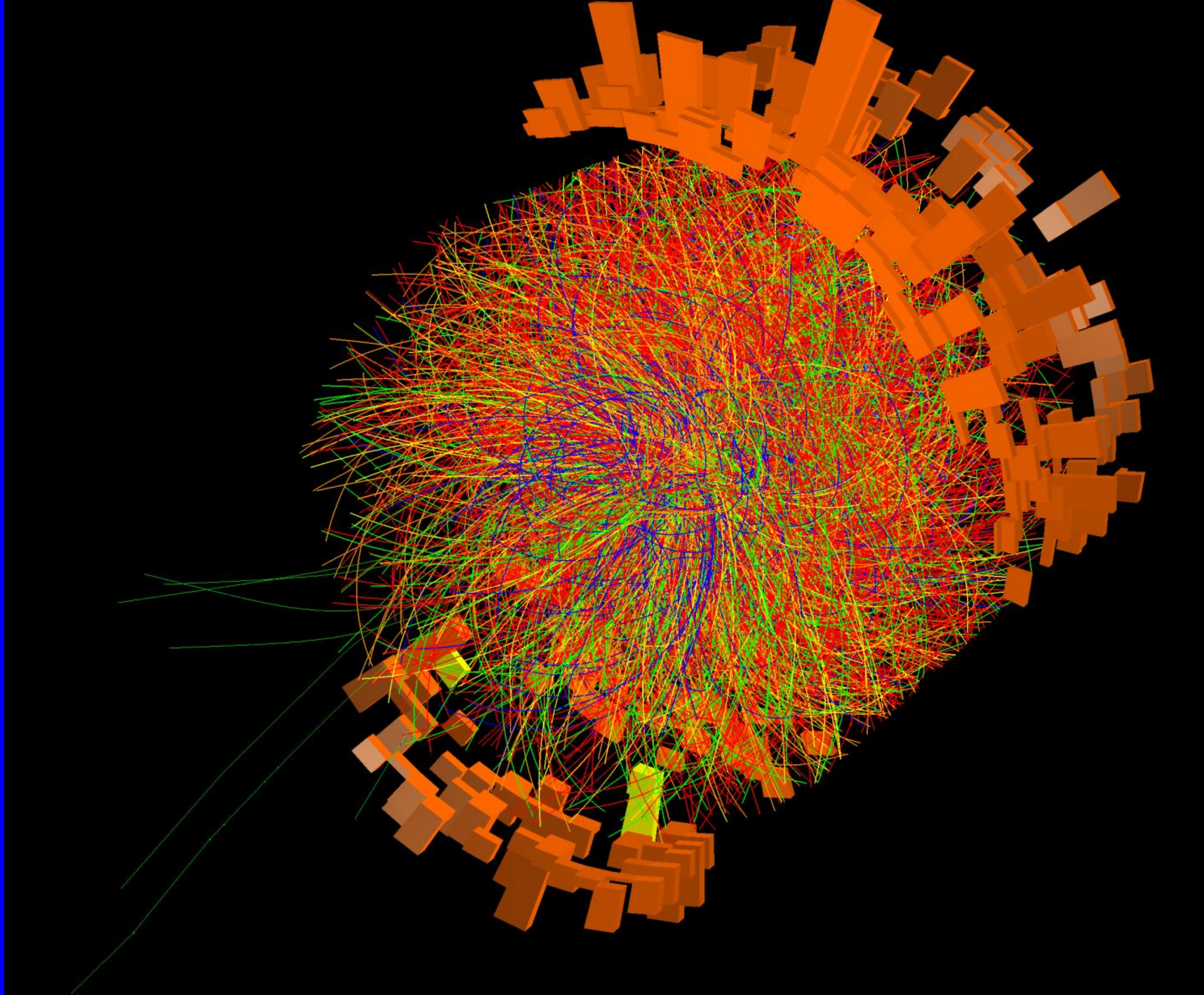
Sum : 7.5 -12.4 MeV/c^2

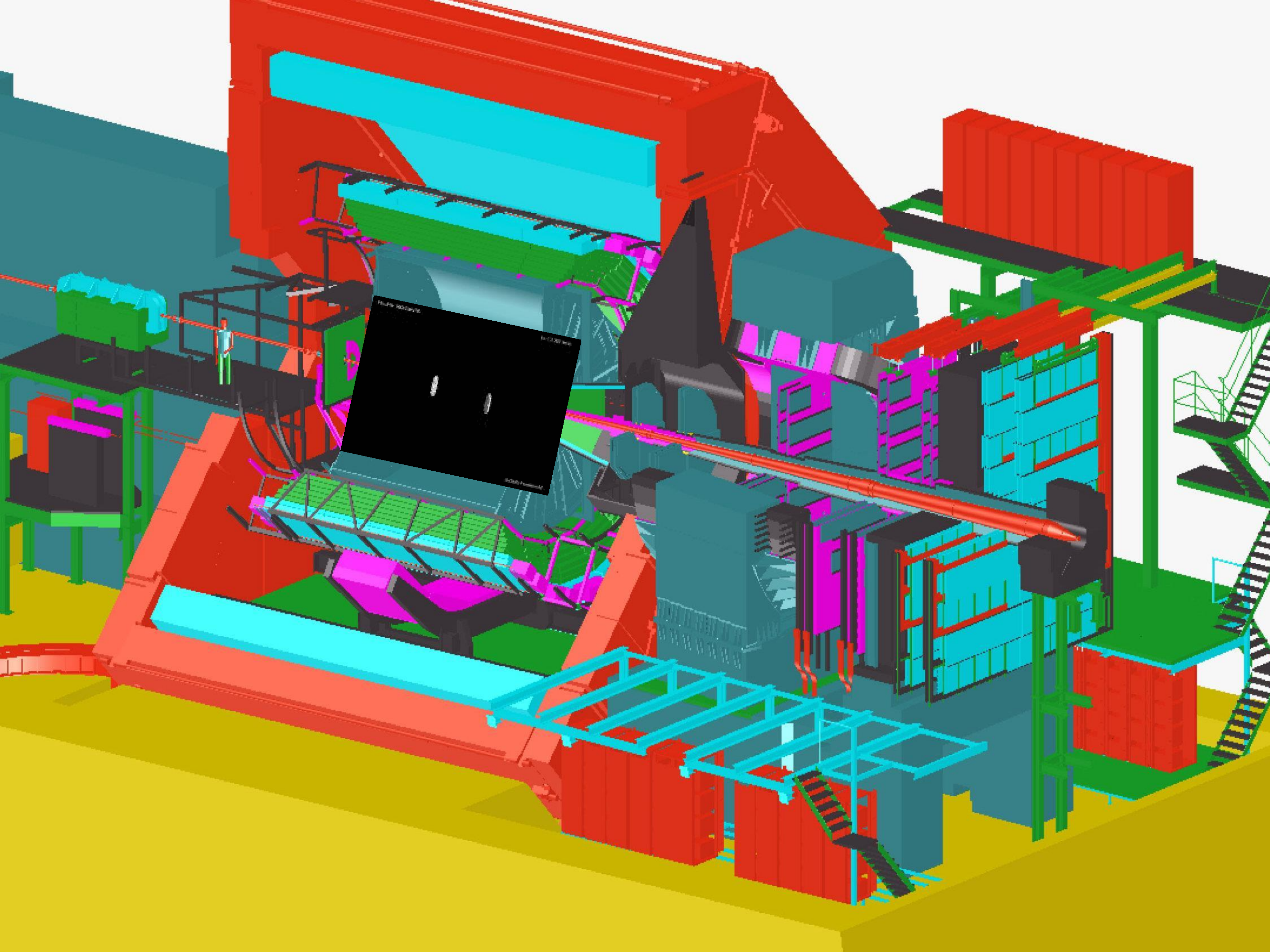


1) Concentrate energy on particles (**accelerator**)

2) **Collide** particles (recreate conditions after Big Bang)

3) Create new particles and identify with **Detectors**





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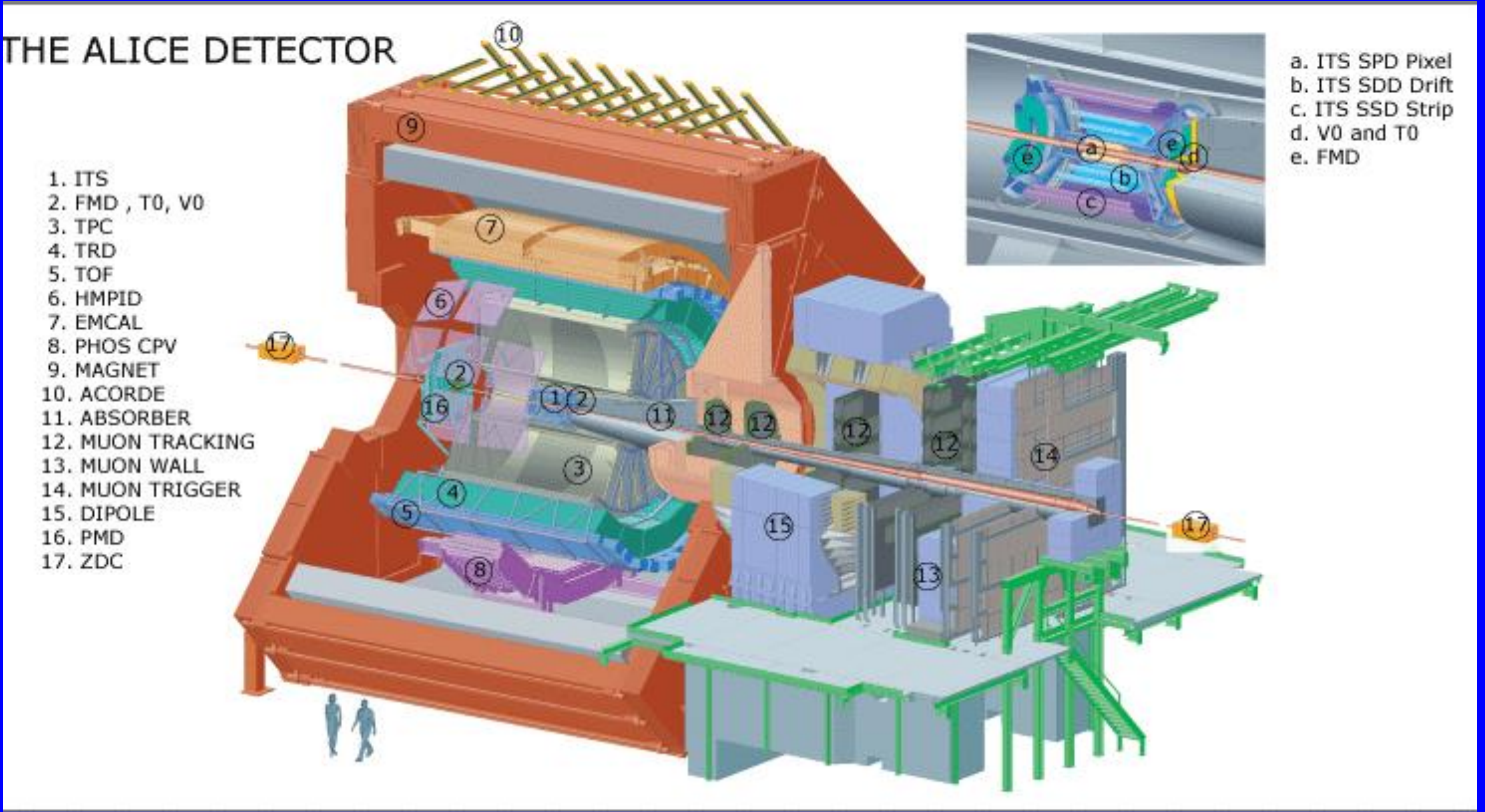


16 m x 16 m x 26 m 10 0000 tons installed at point 2 of LHC, 56 m underground

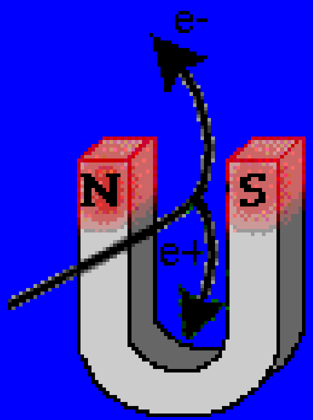
Particle Detectors

- They "see" the particles produced from beam-beam collisions
- The detection is based on interaction of the particles with matter and eventually production of an electrical signal

- Various types of detectors :
  Solid state detectors (semiconductors),
  Gaseous detectors,
  Scintillators …

- They convey information about :
  The particle trajectory (tracking devices)
  The particle type (particle identification)
  The particle energy (calorimeteres)

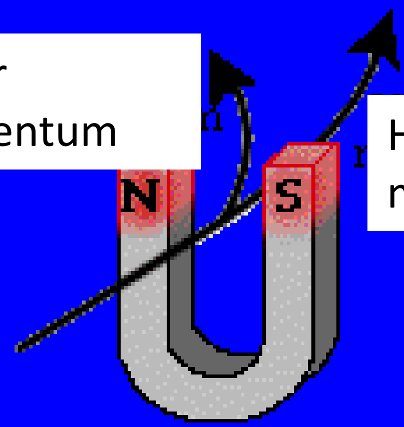
The magnetic field



Identifies the charge

Lower momentum

Higher momentum



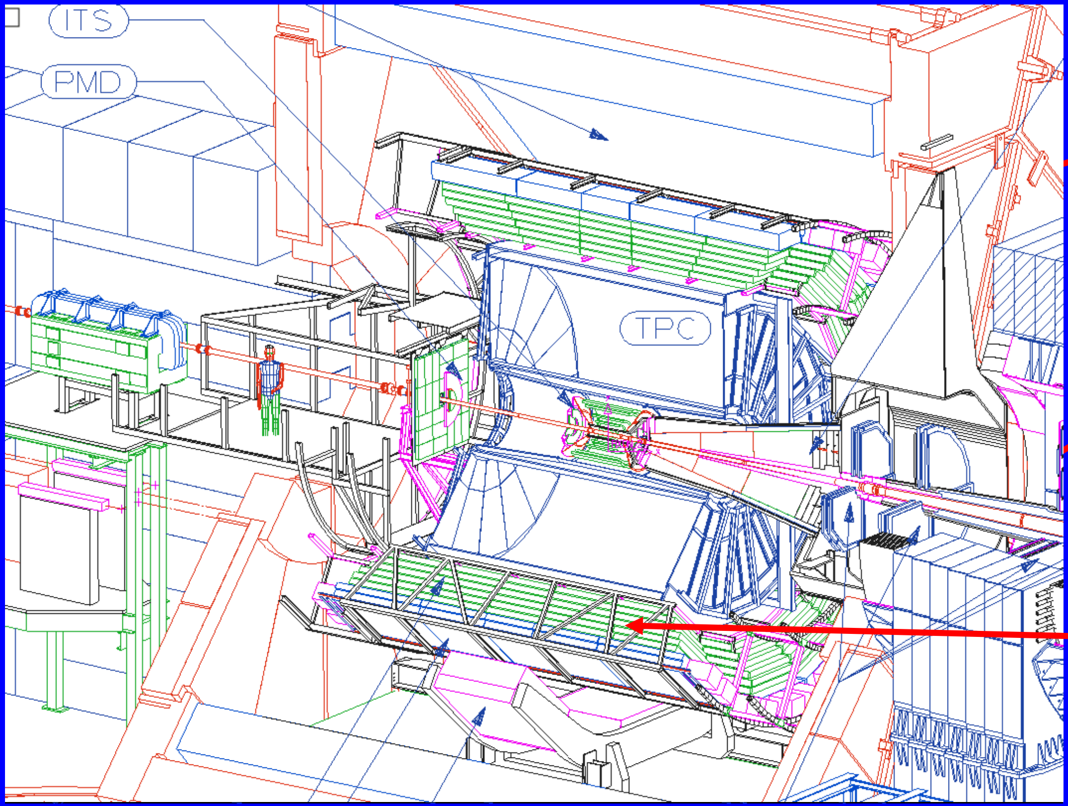
Measures momentum

p = momentum
R = radius of curvature
B = magnetic field
q = charge

$$R=p/qB$$

ALICE : 18 different detection systems

- Around the interaction point, we have installed detectors such as ...

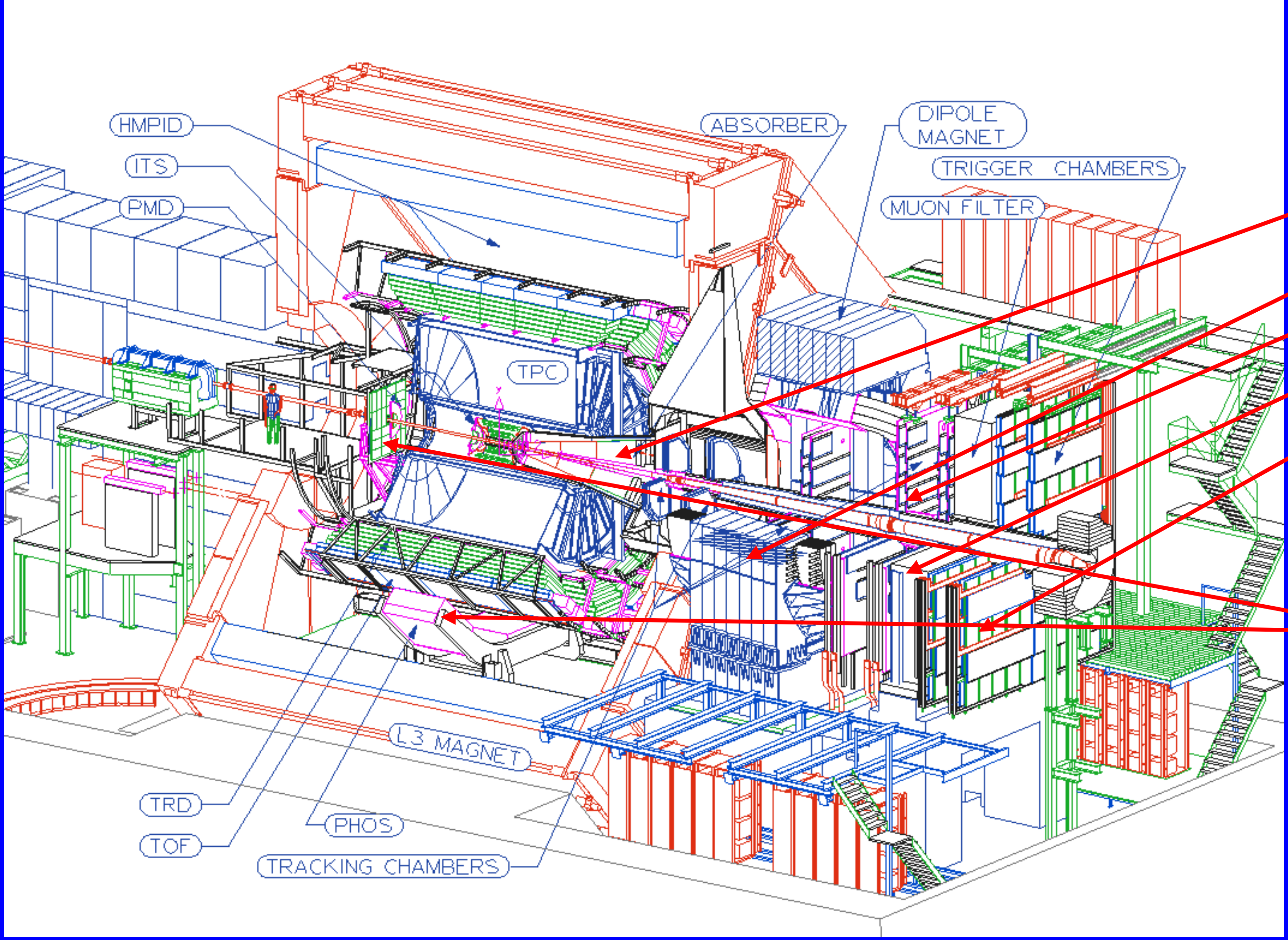


Inner Tracking System (ITS): p, pid

Time projection chamber (TPC) : p, pid

Transition radiation detector (TRD) : e^-
Time Of Flight (TOF): pid

… and some more specialised detectors



Muon spectrometer:
- Absorber
- Dipole magnet
- μ tracking chambers
- Filter
- Trigger

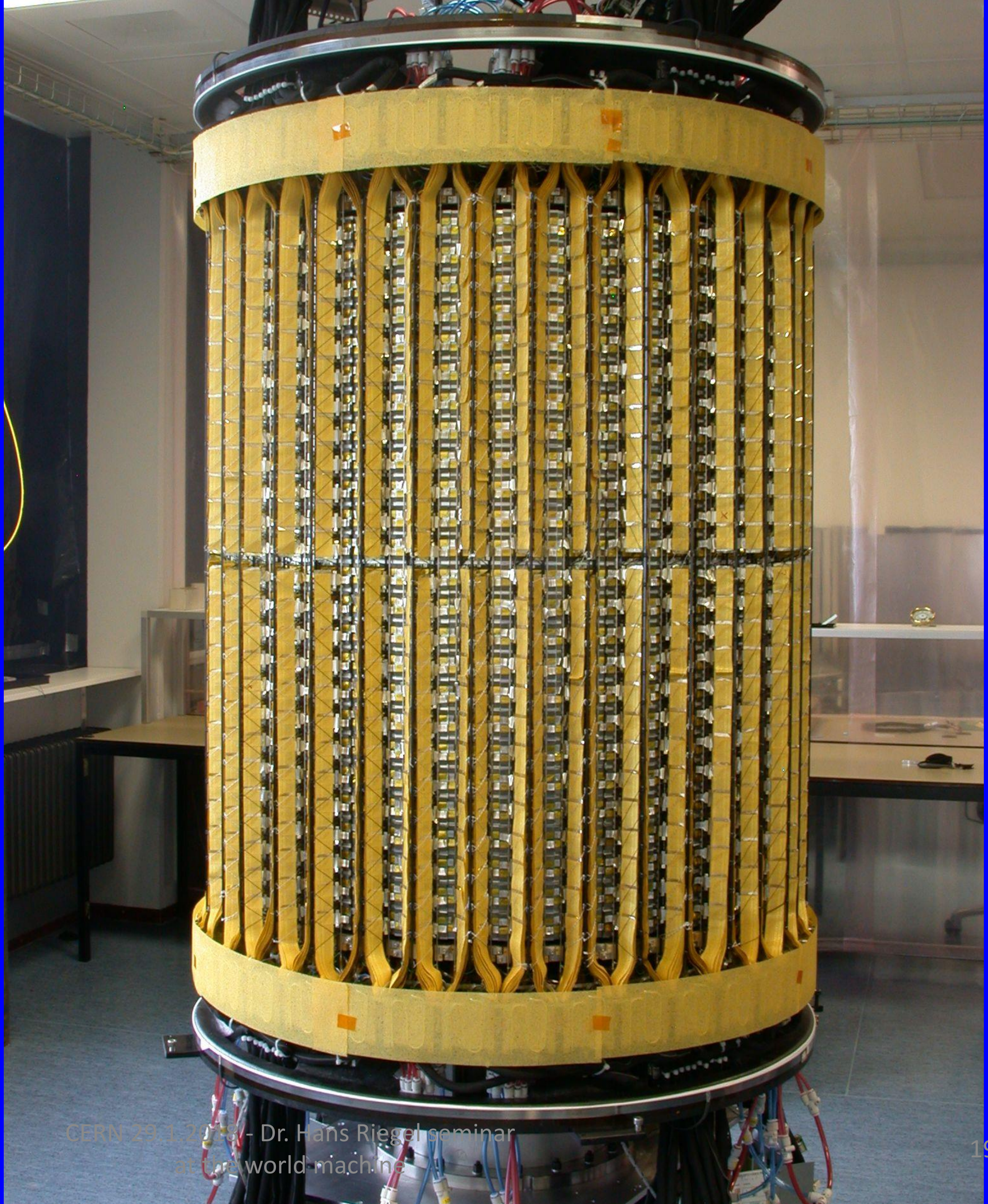
Photon detectors

ITS : Inner Traking System

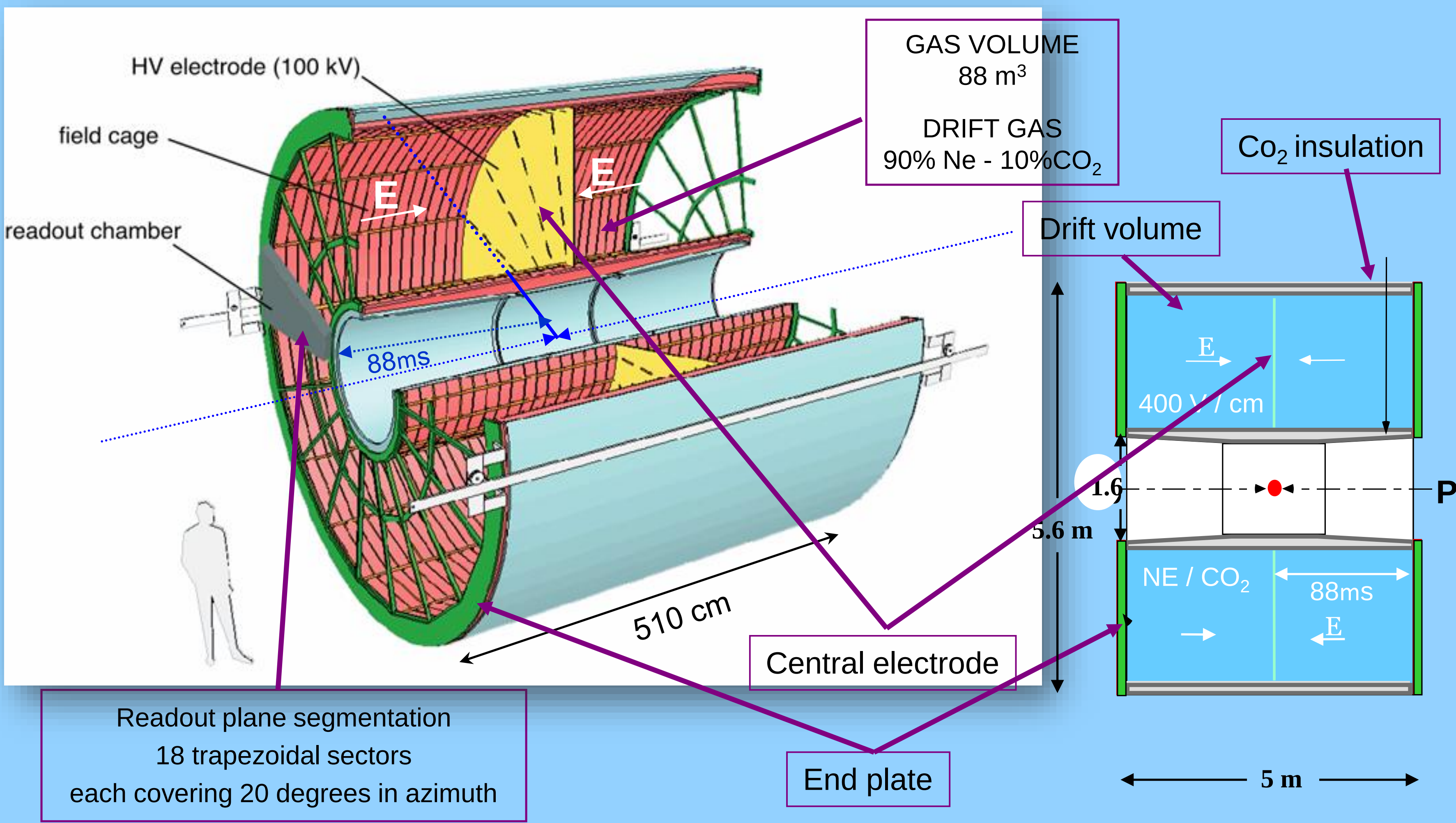
6 layers of silicon detectors

Silicon pixels
Silicon drift detectors
Silicon strips

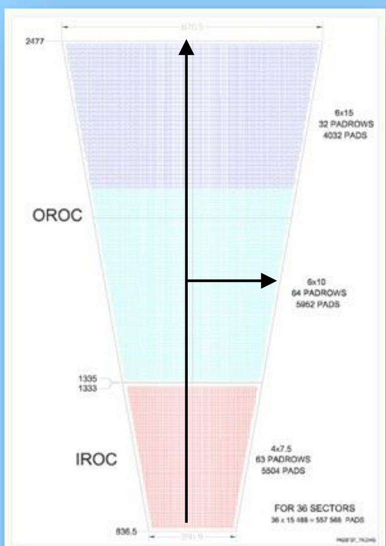
> 10 million channels

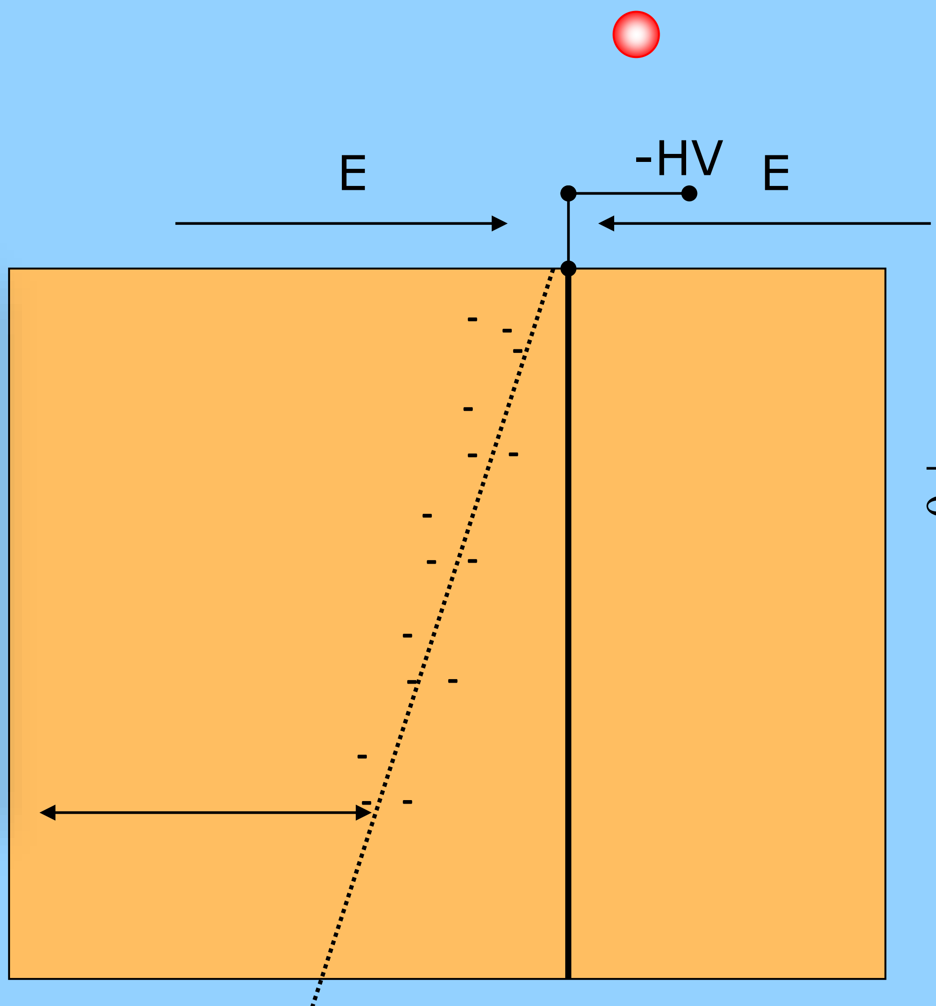


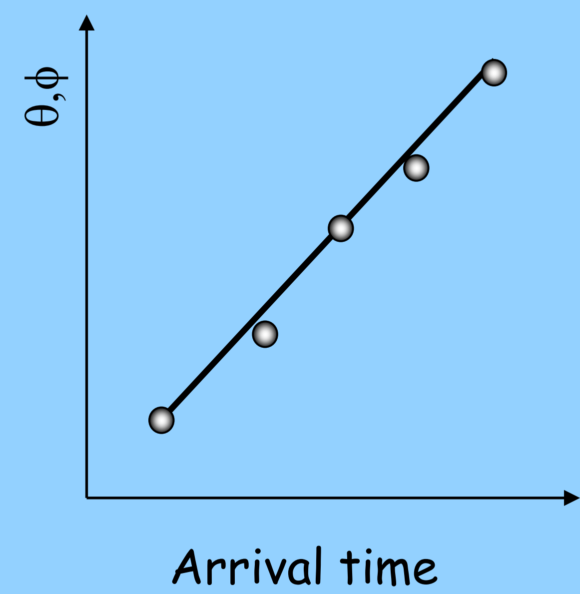
Time Projection Chamber (TPC)

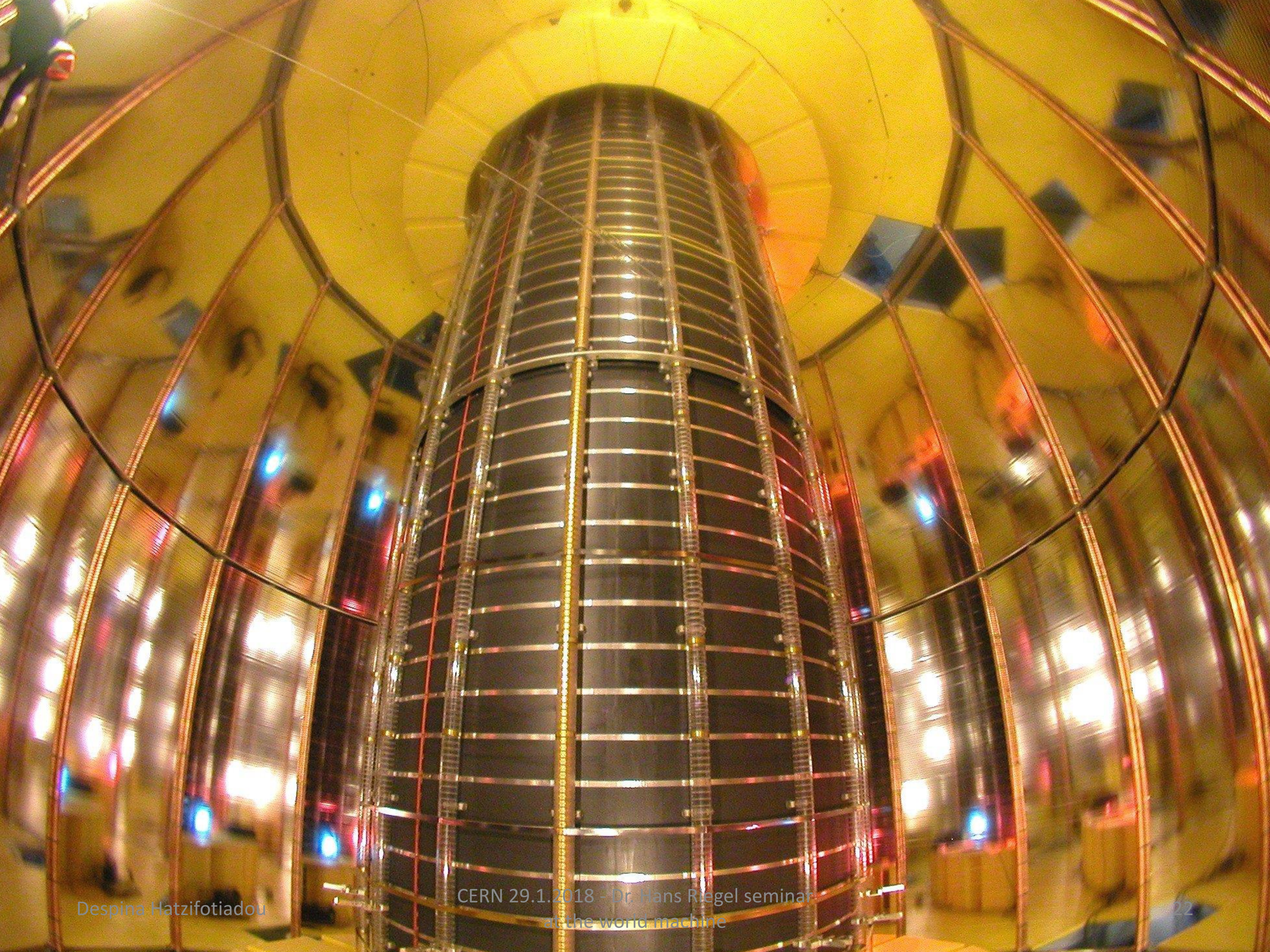


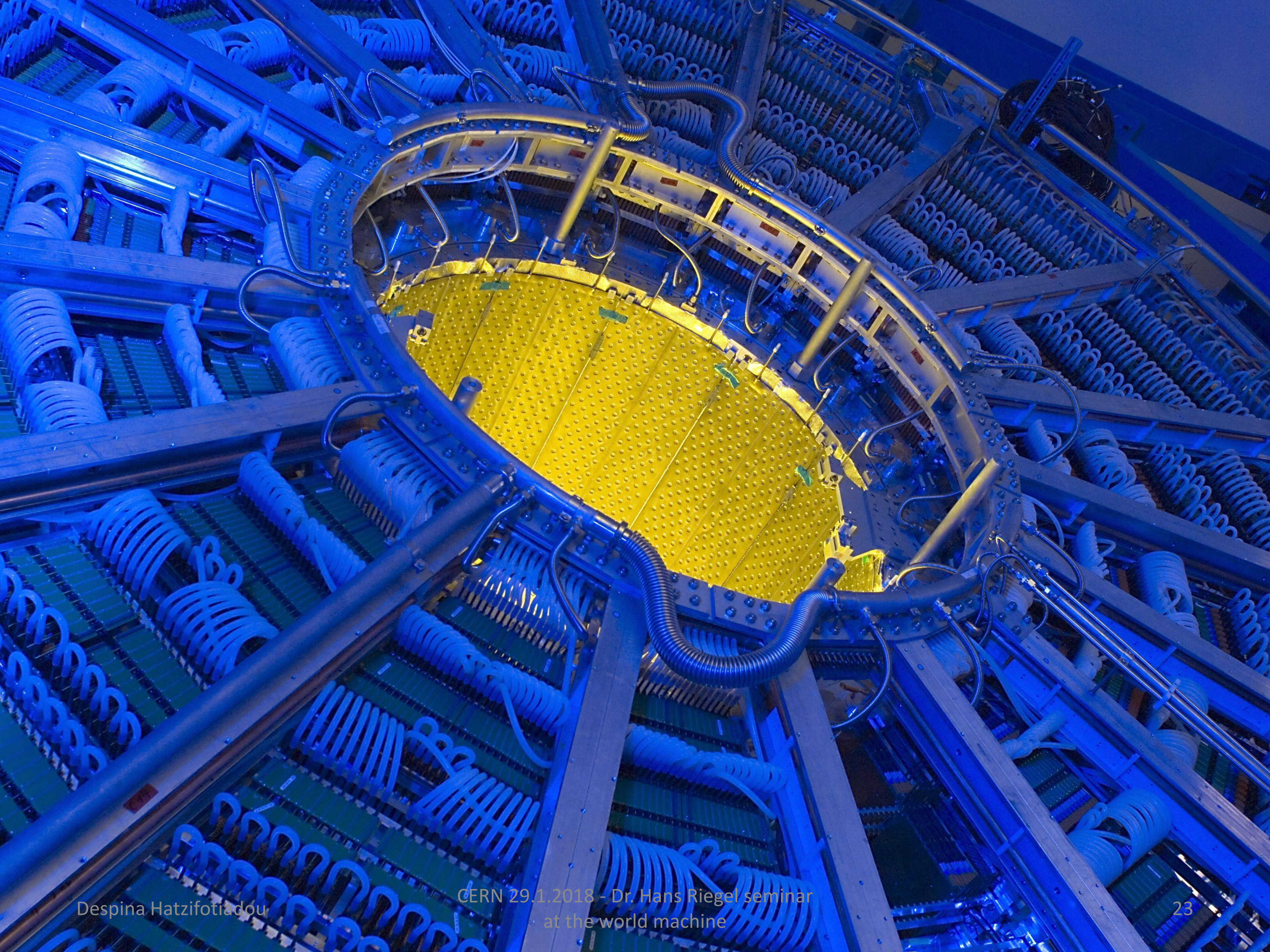
Time Projection Chamber (TPC)

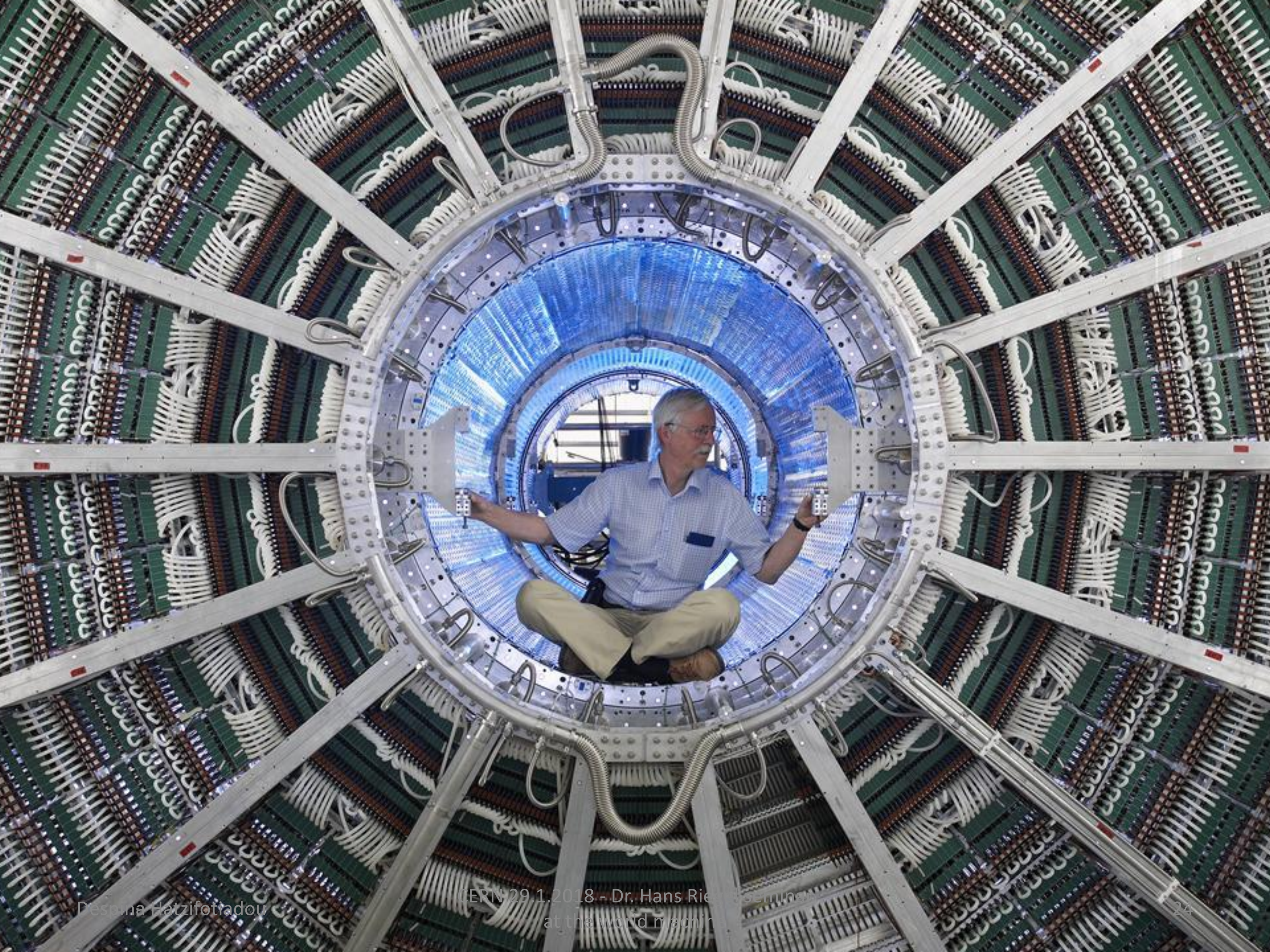






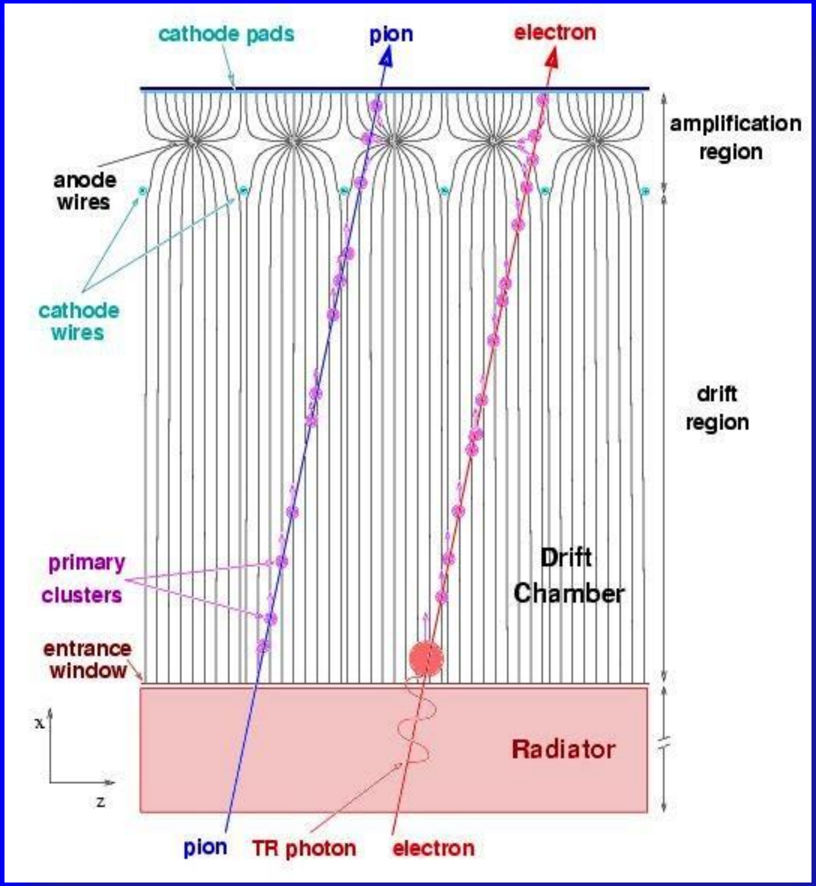






Transition Radiation Detector

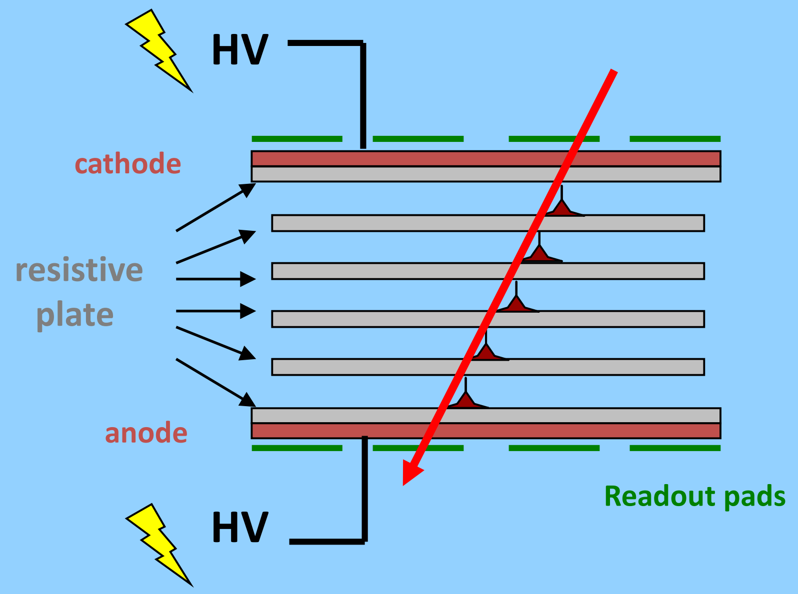
- It separates electrons from pions



- A relativistic particle going through an inhomogeneous medium emits transition radiation (X rays)
- The medium is chosen in such a way that electrons only emit X-rays
- We detect both charged particles and X-rays
- Multiwire proportional chamber with a heavy gas (Xe)


20t
High voltage
A

Time of Flight



Multigap Resistive Plate Chamber

It measures the time of flight (from the point of generation to the point of detection) of charged particles with a precision of 70 ps

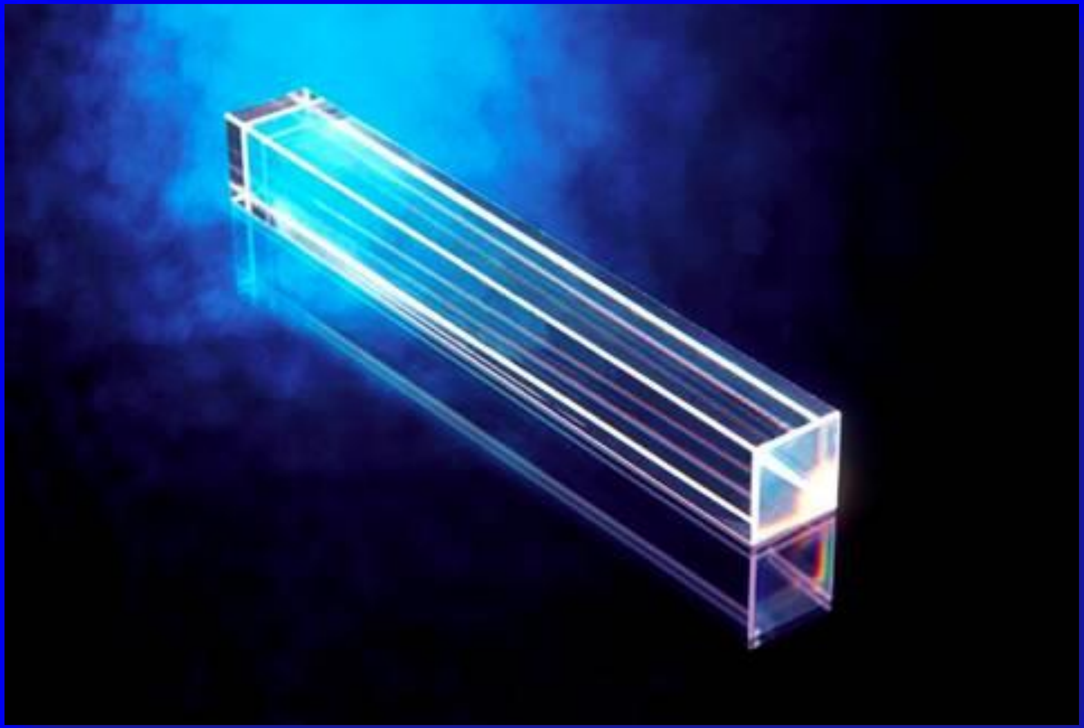
Time and trajectory length (known from tracking detectors) give the particle velocity

From the tracking detectors we find the trajectory, thus the curvature of the track and therefore the momentum

Momentum and velocity give us the mass, which identifies a particle uniquely

PHOS : PHOton Spectrometer

$PbWO_4$: heavy and transparent



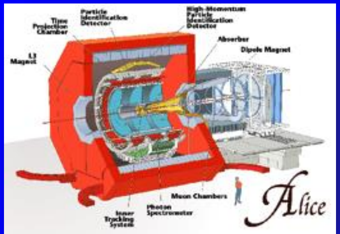
Electromagnetic calorimeter

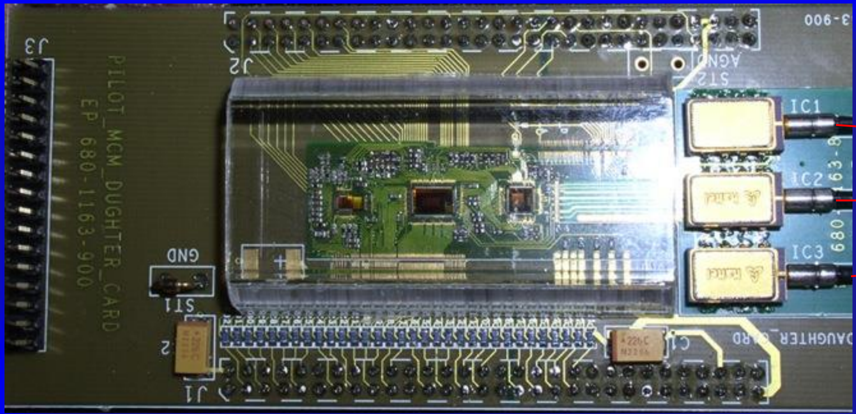
- Photons are converted into electron-positron pairs
- Electrons excite the atoms of the crystal
- Excitation is followed by de-excitation -> emission of light (UV photons)
- UV photons are detected by a photodiode at the end of the crystal, which converts phtons to electrons

Electric signal

Signal processing

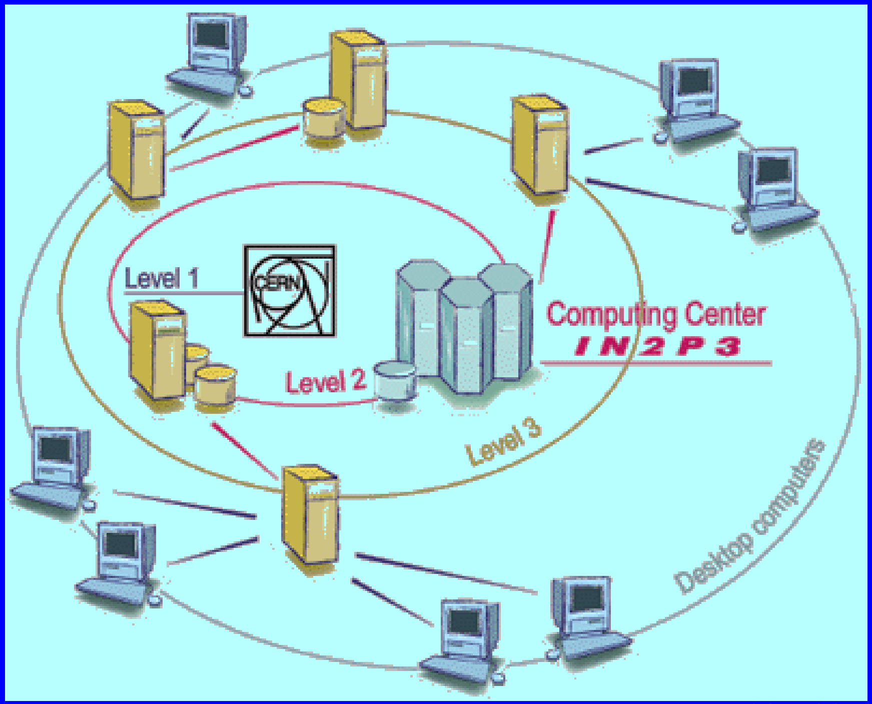
- The signal from each detection element (∼16 million) is first processed by specialised electronics (front end electronics)
- These electrical signals are digitised (readout electronics) and read out by computers
- The information is transferred by optical fibers and recorded.

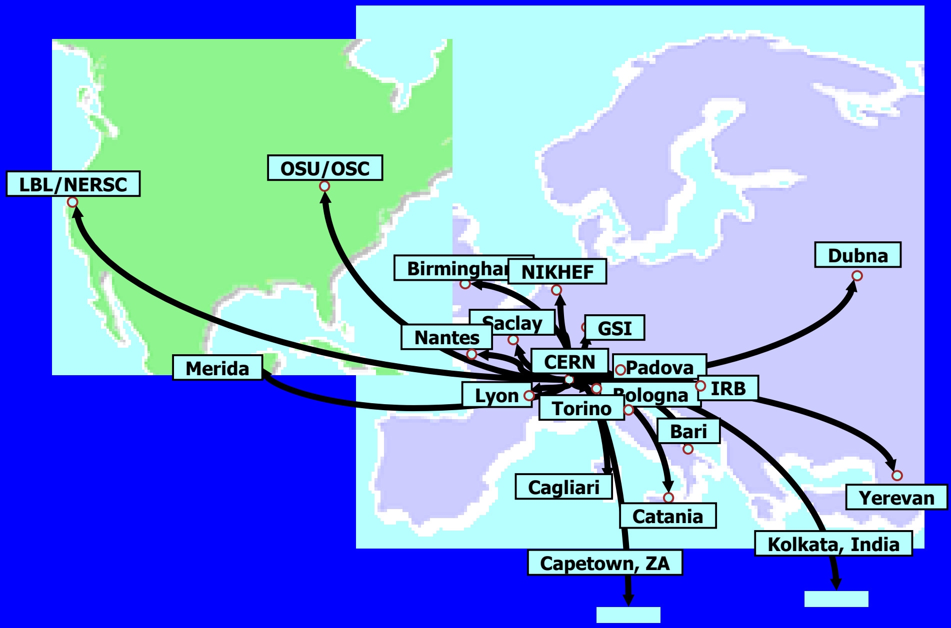




Data analysis

Thousands of computers in computer centres all over the world are connected to the GRID. They share their storage capacity and processing power.



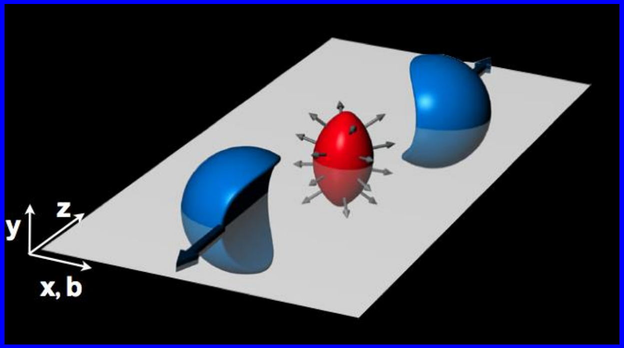


The GRID

What have we found?
Few examples..

A perfect liquid at LHC

The primordial matter recreated by high energy lead ion collisons at the LHC was initially expected to behave like a gaseous plasma; instead, it appears to behave like a perfect liquid, with coordinated collective motion ("flow") among the constituent particles.



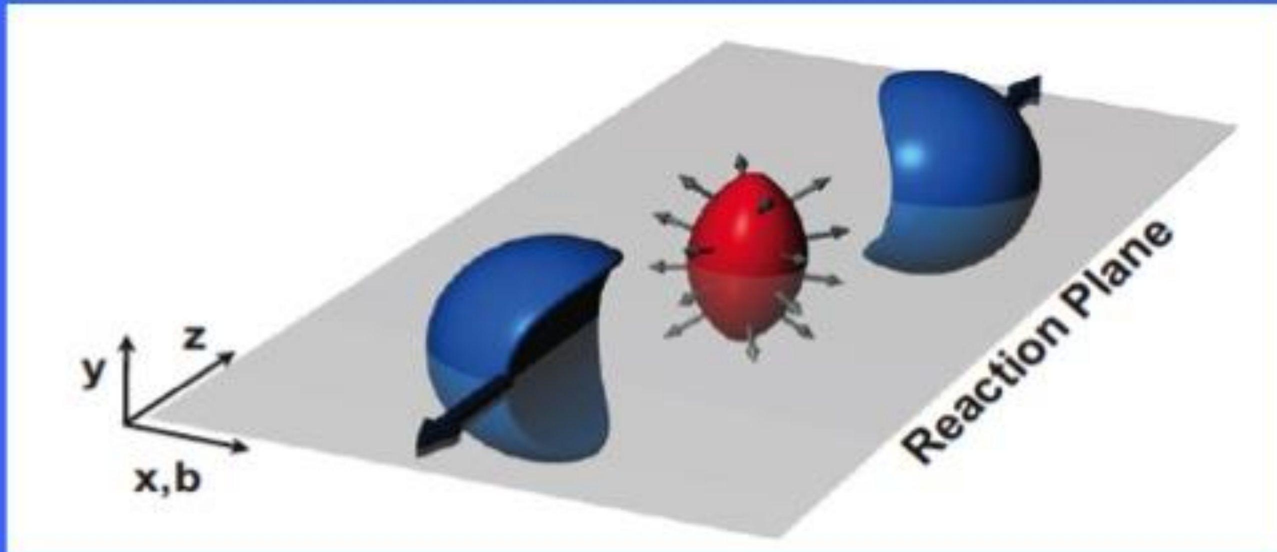
Almond shape

More hadrons are observed parallel to the interaction plane than in the plane perpedicular to it

This had already been announced by experiments at RHIC

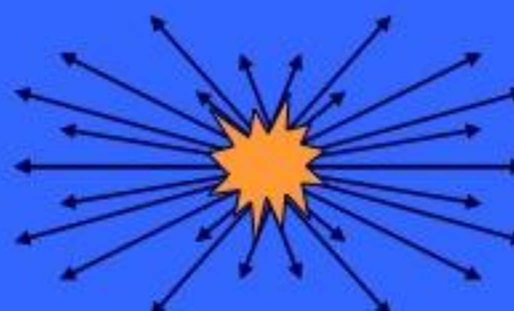
The dense matter created by lead collisions flows almost with no friction (like water, which has low viscosity) and not like honey (which has high viscosity)

One of the most spectacular results of heavy-ion experiments



QGP : perfect liquid

Superposition of independent proton collisions



Evolution of the Pb-Pb collision system : many more hadrons parallel to the reaction plane than to the perpendicular one

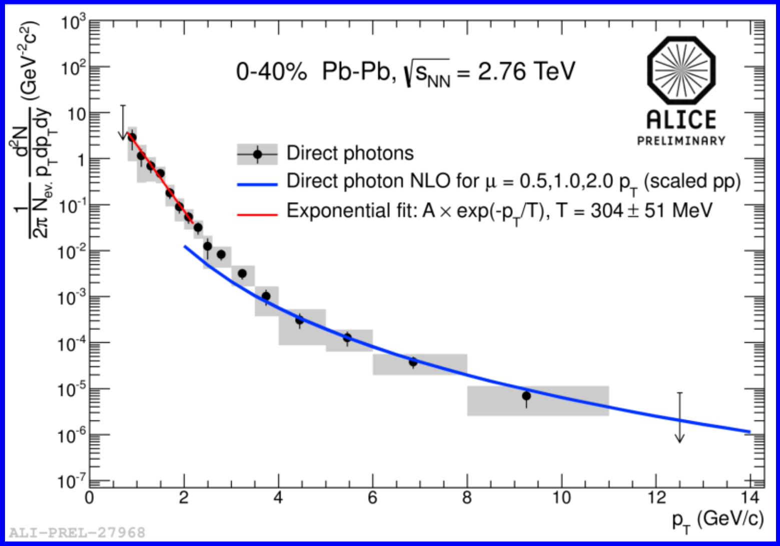
Highest man-made temperature

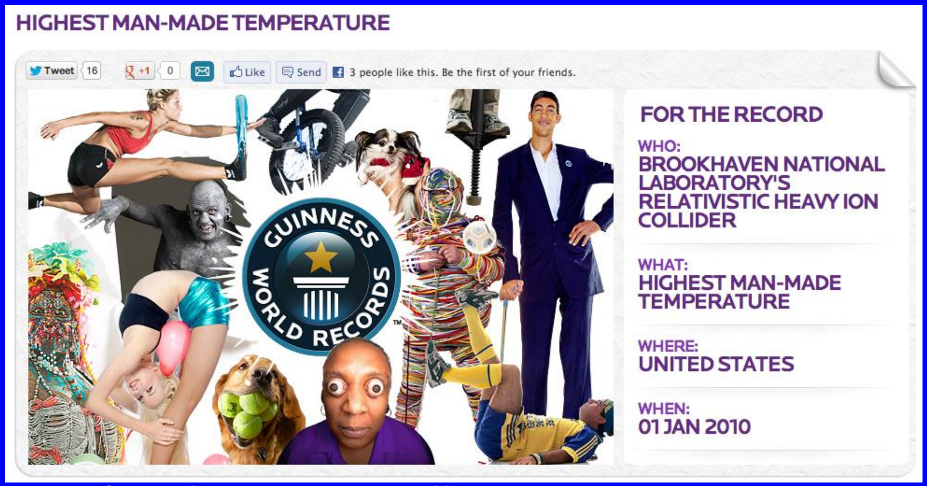
Thermal photons, radiated by the quark gluon plasma ("direct" photons, not coming from decays of hadrons) reflect the temperature of the system.

The inverse slope of the distribution of these photons suggests that the initial temperature of the system created by lead collisions is some trillion of degrees Kelvin.

This temperature is 250 000 times higher than the temperature in the core of the sun

The hottest piece of matter ever formed



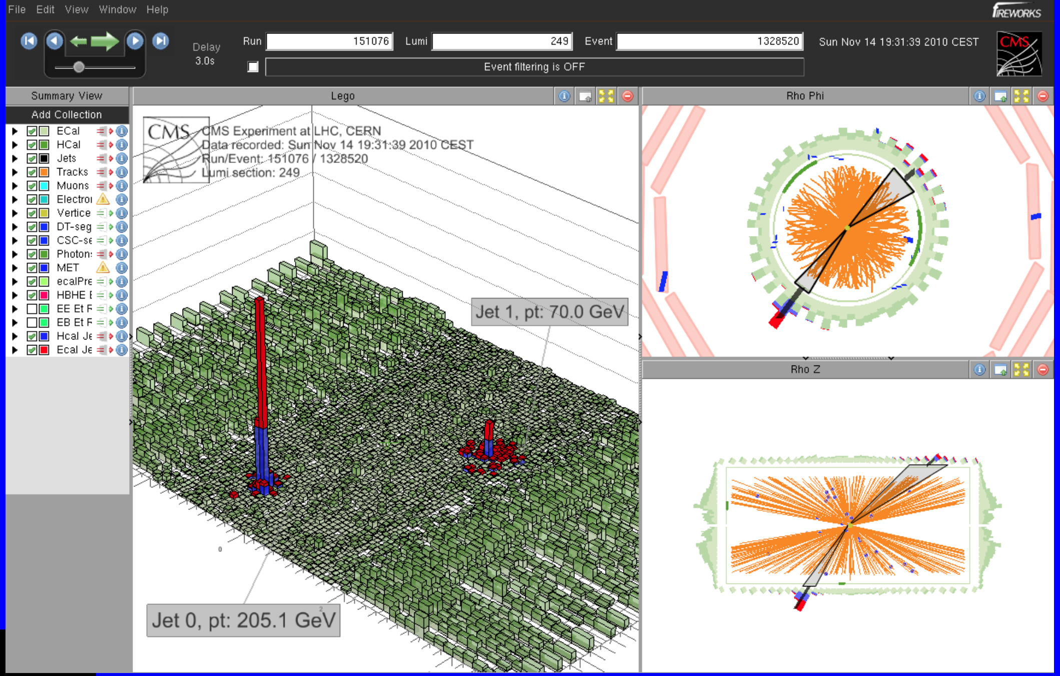


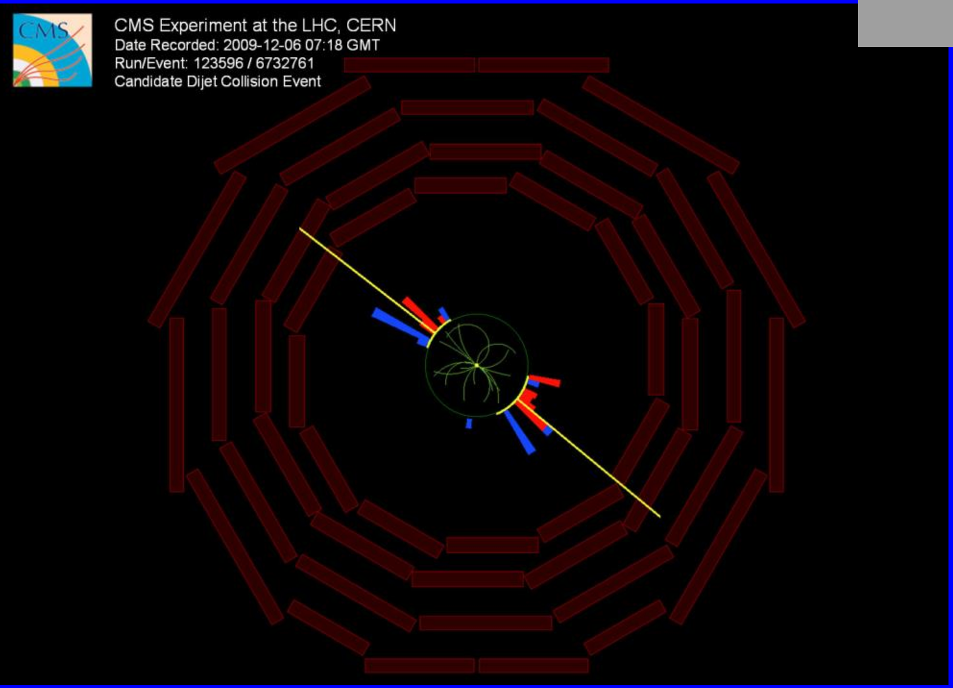
Before heavy ion collisions at LHC

Energy loss

One of the first announcements from the first lead ion run at LHC, December 2010)

Jets going in opposite directions have ~ equal energies



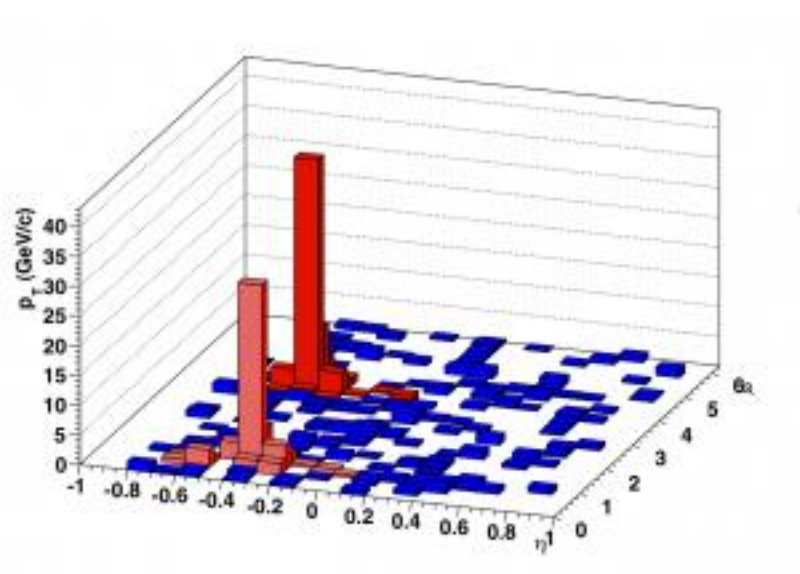


Lead ion collision event

One jet has much less energy than the other.
The jet produced near the QGP surface has high energy whereas the one that traverses the QGP is absorbed and scattered by the dense medium losing big part of its energy

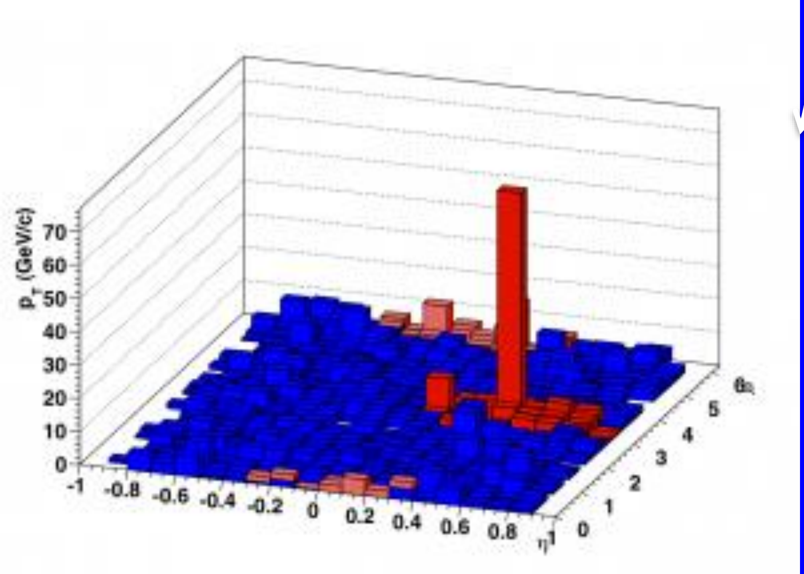
Proton collision event – two jets with energy of ~20 GeV

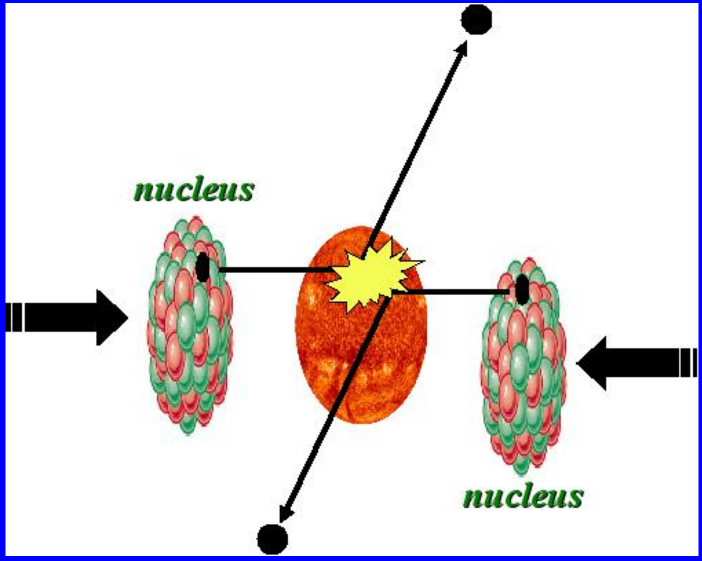
Jet Quenching



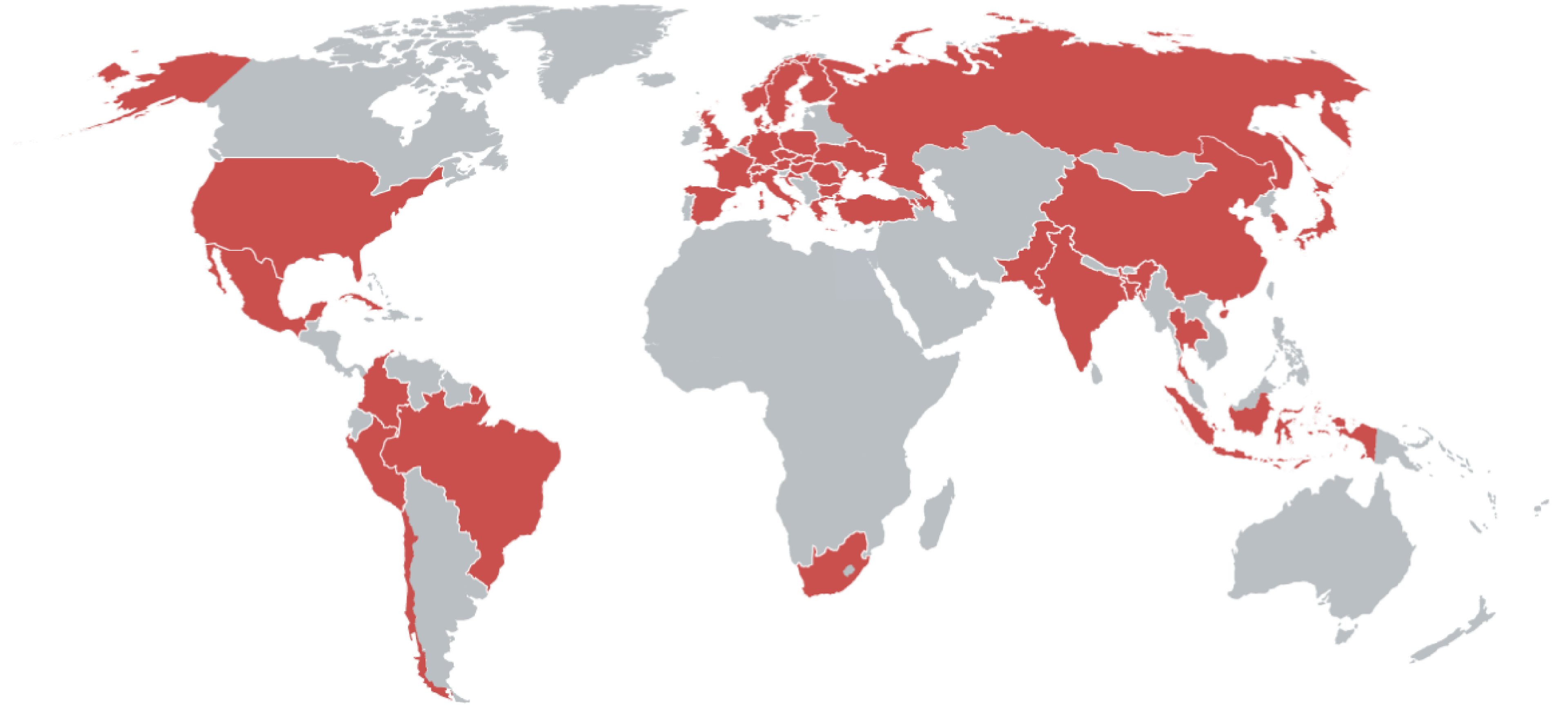
ALICE – peripheral lead ion collisions- two jets

ALICE – central lead ion collisions
1 jet is visible, the other has been absorbed while travelling through the QGP and does not come out





The Collaboration



41 countries, 178 Institutes, 1800 members

Thanks for your attention

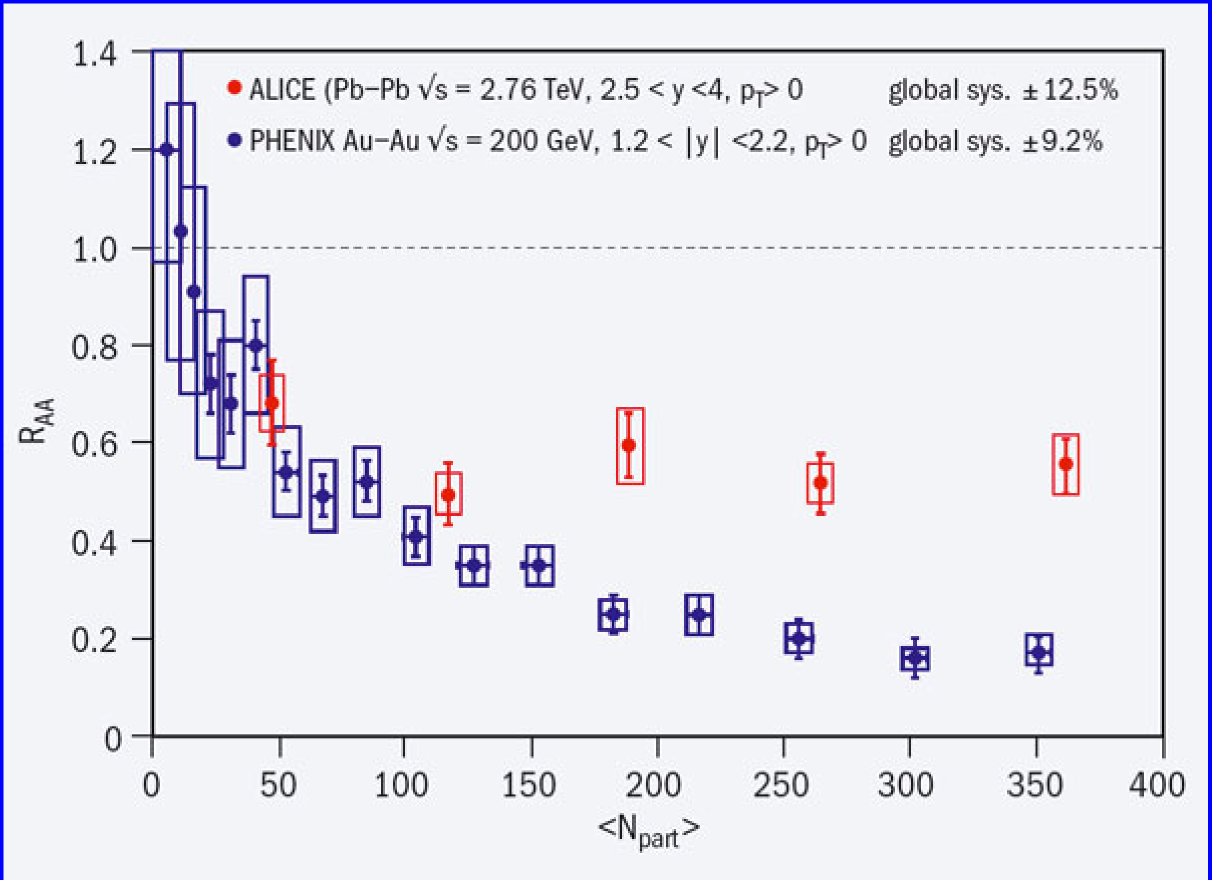
The J/Ψ mystery

- J/Ψ Discovered in 1974, almost simultaneously, at Brookhaven (proton-nuclei collisions) and at SLAC (collisions e^+e^-)
- Bound state of a c quark and a c anti-quark (mass 3 GeV)
- The two "object" that make the J/Ψ are bound due to strong interaction

- Inside the quark gluon plasma, due to the high number of free colour charges, the binding between c-quark and c-antiquark becomes weaker, the pair disintegrates and the J/Ψ disappears
- Suppression of the observed J/Ψ signal
  (J/Ψ -> μμ and J/Ψ -> e^+e^-)

- Suppression depends on QGP temperature

The J/Ψ mystery



- Regeneration of J/Ψ at very central collisions
- Two competing phenomena
- Suppression of J/Ψ due to interaction with the quark gluon plasma
- Creation of many J/Ψ due to the high number of c – anti-c pairs created from the huge collision energy

Nuclear modification factor R_{AA}

$$R_{AA} = \frac{\text{number of J/Ψ observed in lead ion collisions}}{\text{number of J/Ψ observed in proton collisions}}$$