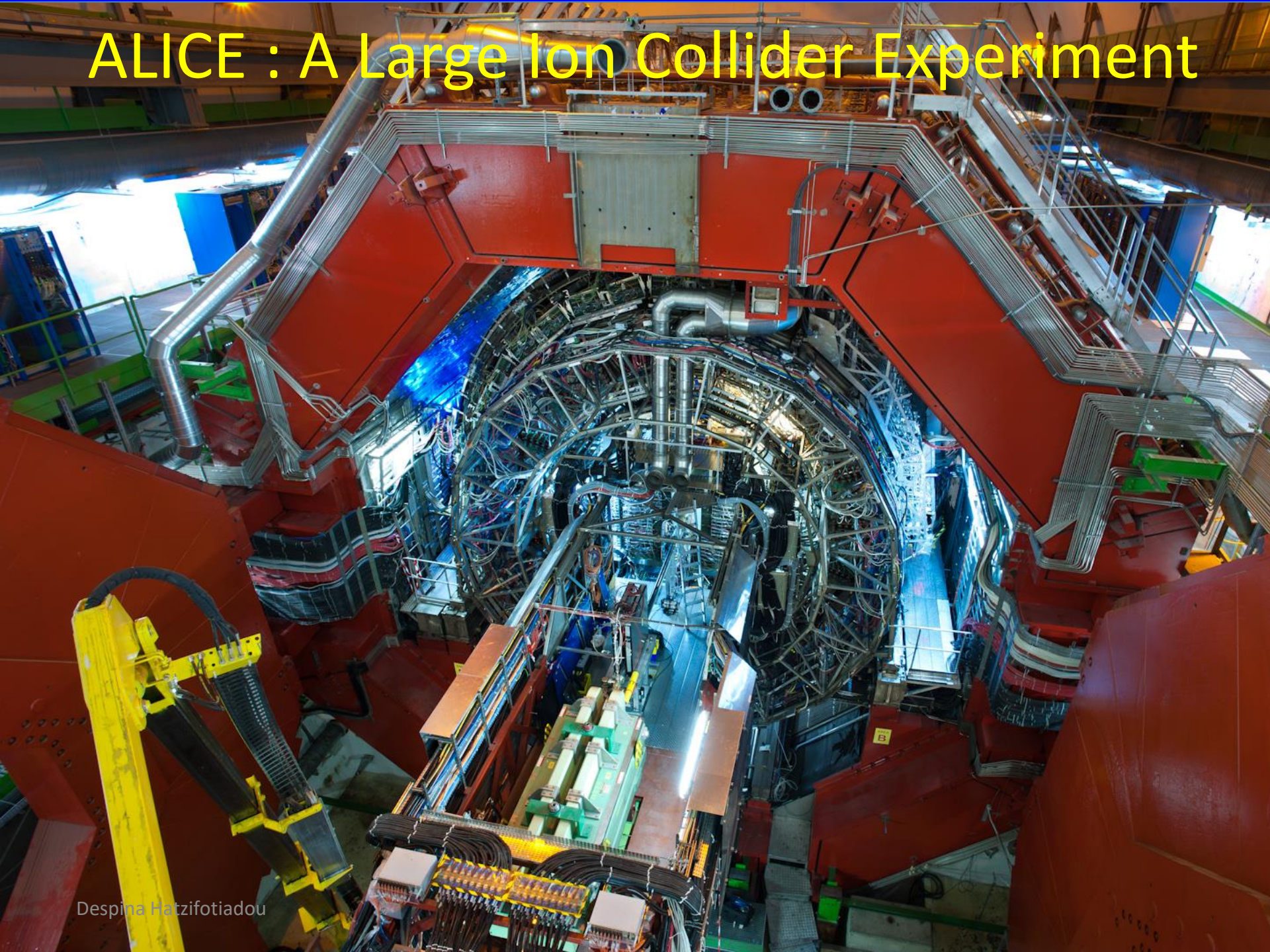
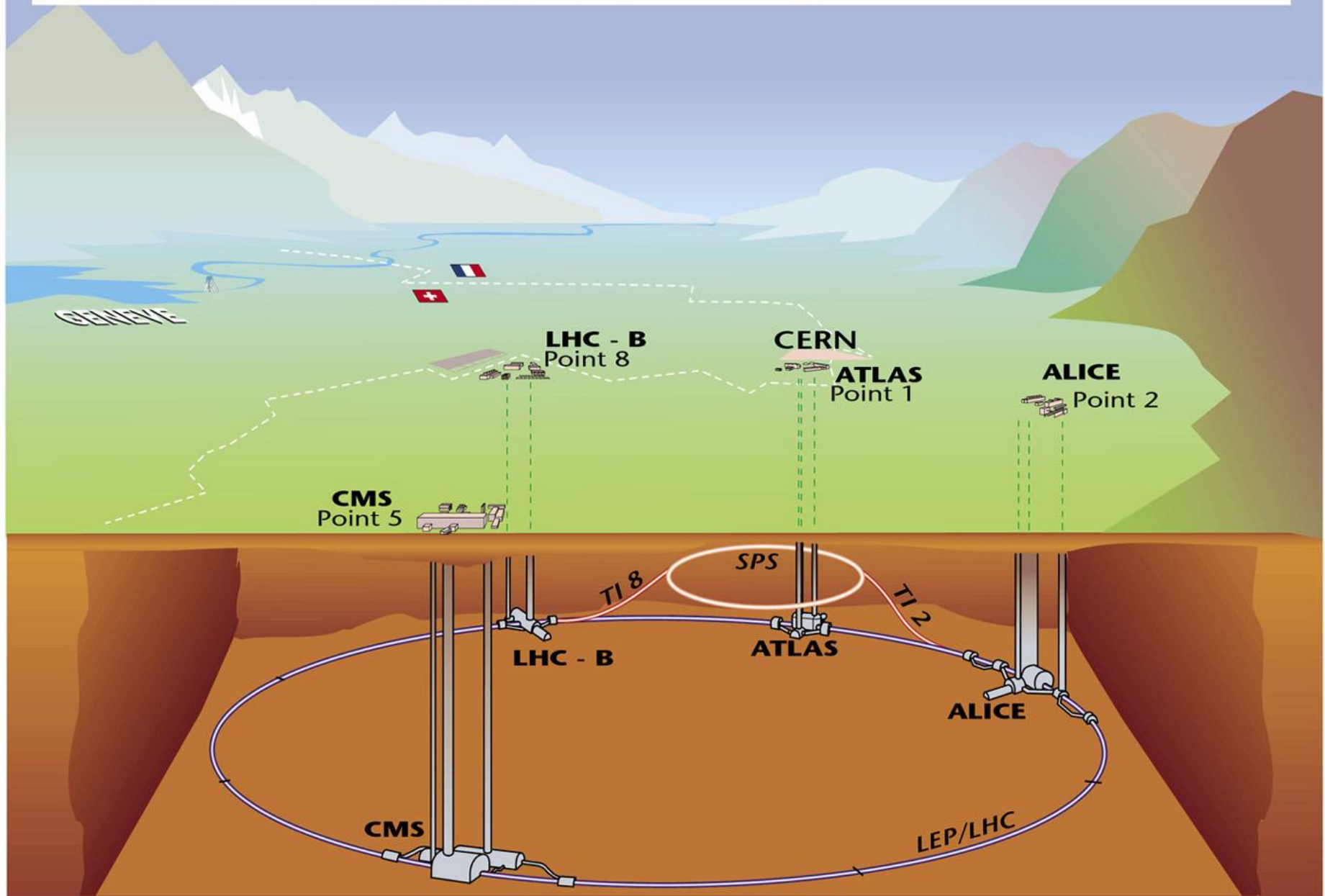


# ALICE : A Large Ion Collider Experiment



# Overall view of the LHC experiments.



## Heavy ions at LHC

In addition to protons, LHC accelerates and collides lead ions

isotope Pb <sup>208</sup> with 82 protons and 126 neutrons in the nucleus

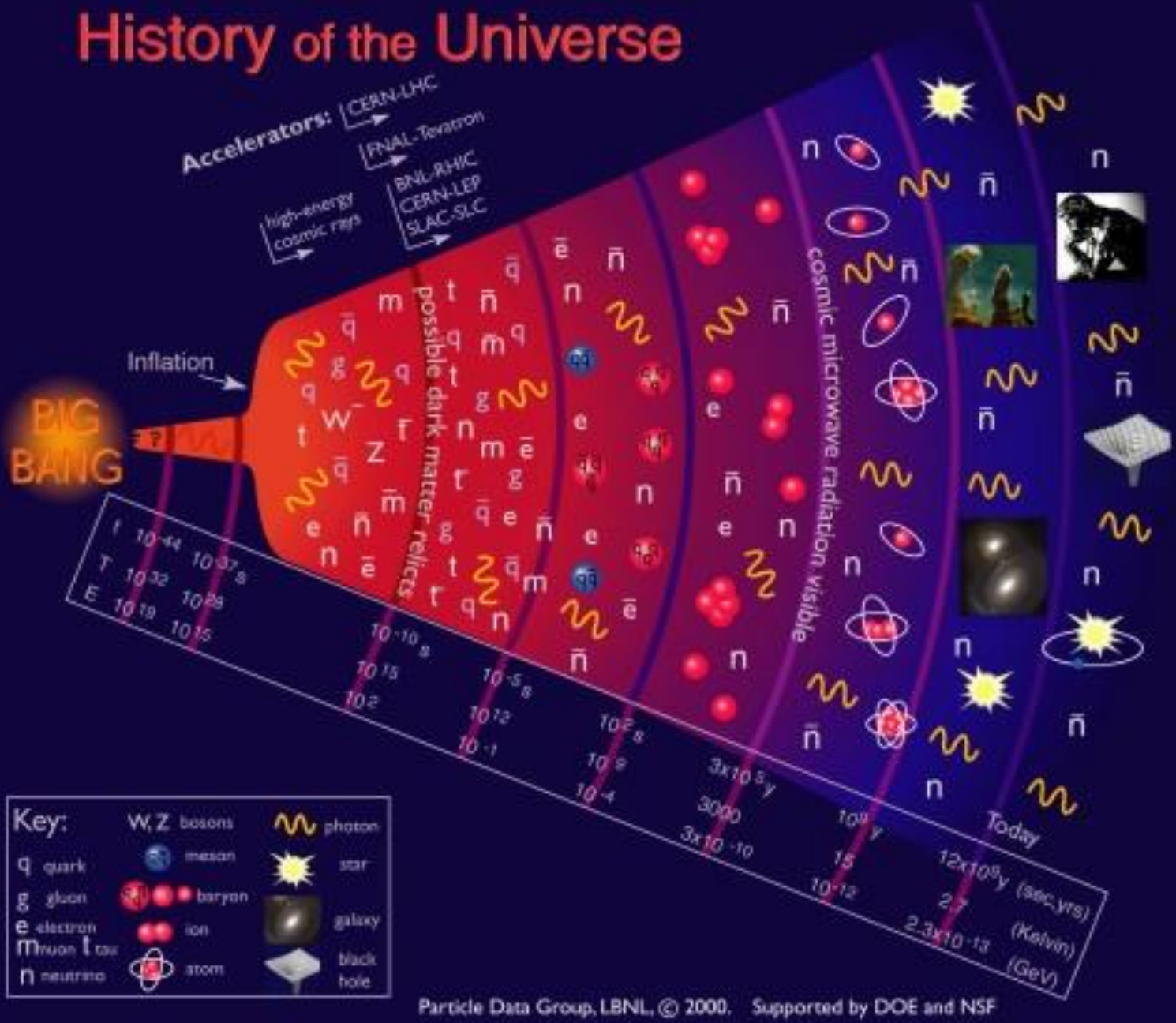
Pb atom  $\rightarrow$  Pb<sup>29+</sup>  $\rightarrow$  Pb<sup>54+</sup>  $\rightarrow$  Pb<sup>82+</sup> (bare lead nucleus)

Beam energy 3.5 TeV x 82 = 287 TeV (574 TeV at the collision point)

6.5 TeV x 82 = 1066 TeV (574 TeV at the collision point)

Why are lead ion collisions at high energies of particular interest?

# History of the Universe



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

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

## Little Bang

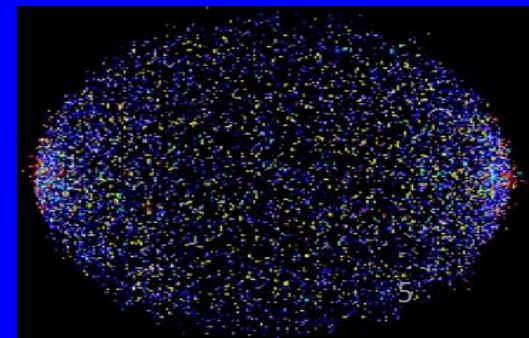
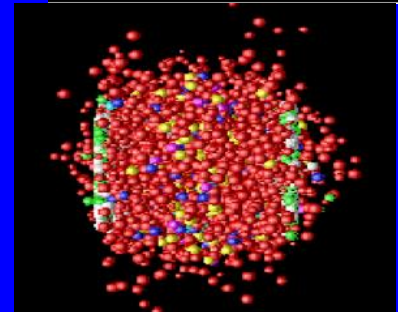
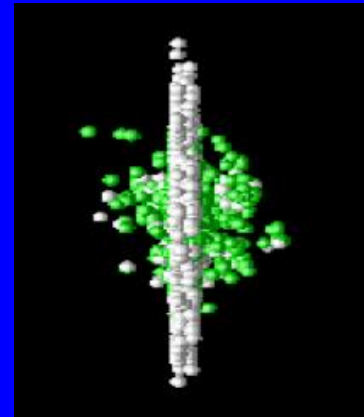
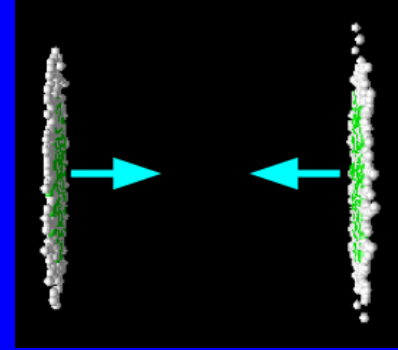
By colliding lead nuclei at very high energies we recreate the conditions of density and temperature which existed fractions of a second after the Big Bang

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

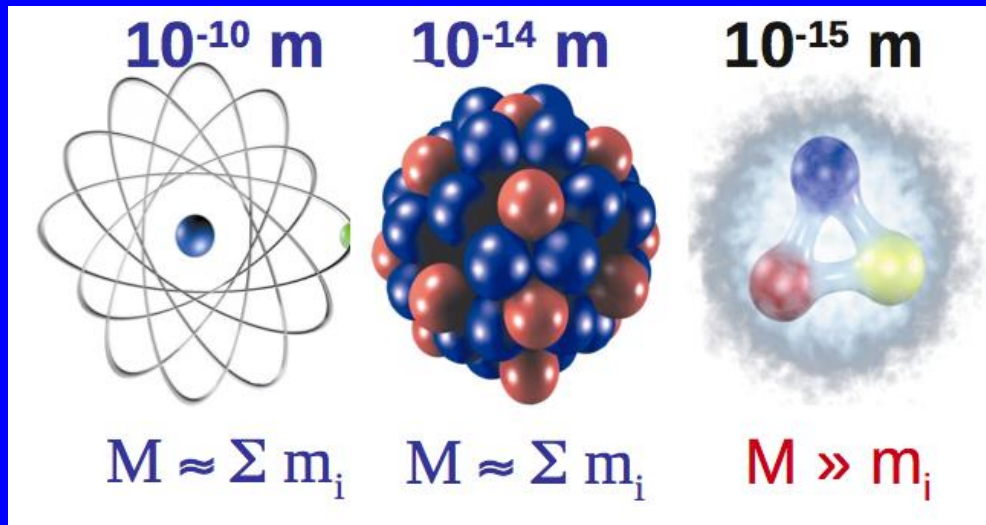
- We will understand better the processes which took place during the first fractions of a second in the life of the universe
- We will understand better the strong interaction and how the protons and neutrons acquire their mass



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 :  $938 \text{ MeV}/c^2$

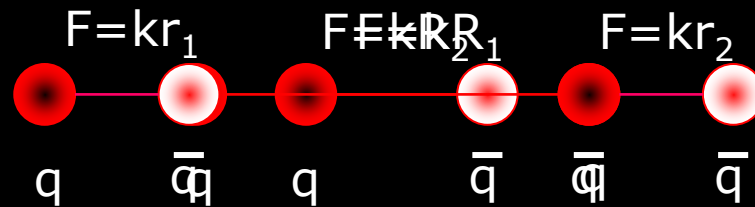
up quark mass :  $1.7 - 3.3 \text{ MeV}/c^2$

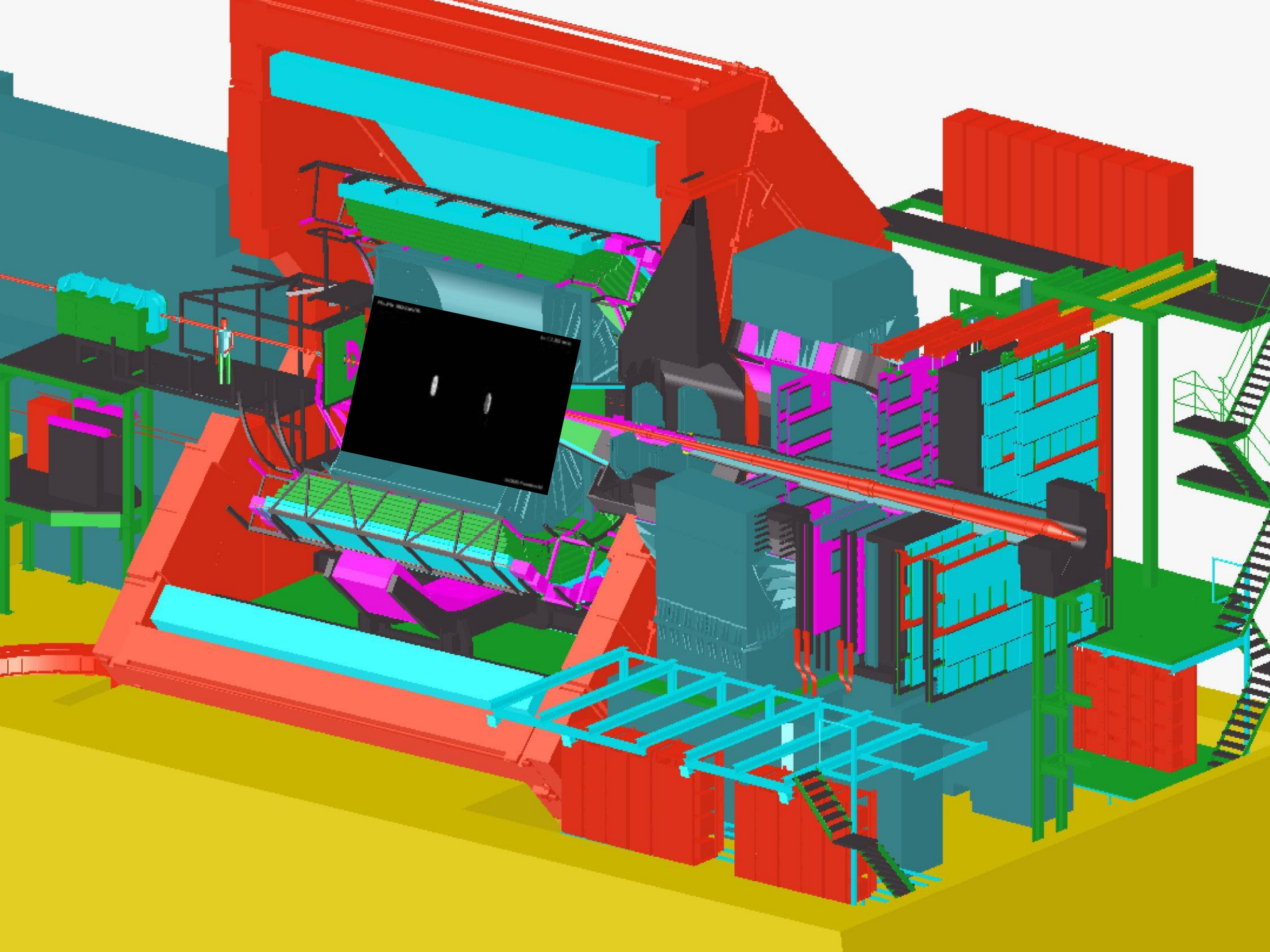
down quark mass :  $4.1 - 5.8 \text{ MeV}/c^2$

Sum :  $7.5 - 12.4 \text{ MeV}/c^2$

ALICE studies strong interactions..

Why are quarks permanently confined inside hadrons?



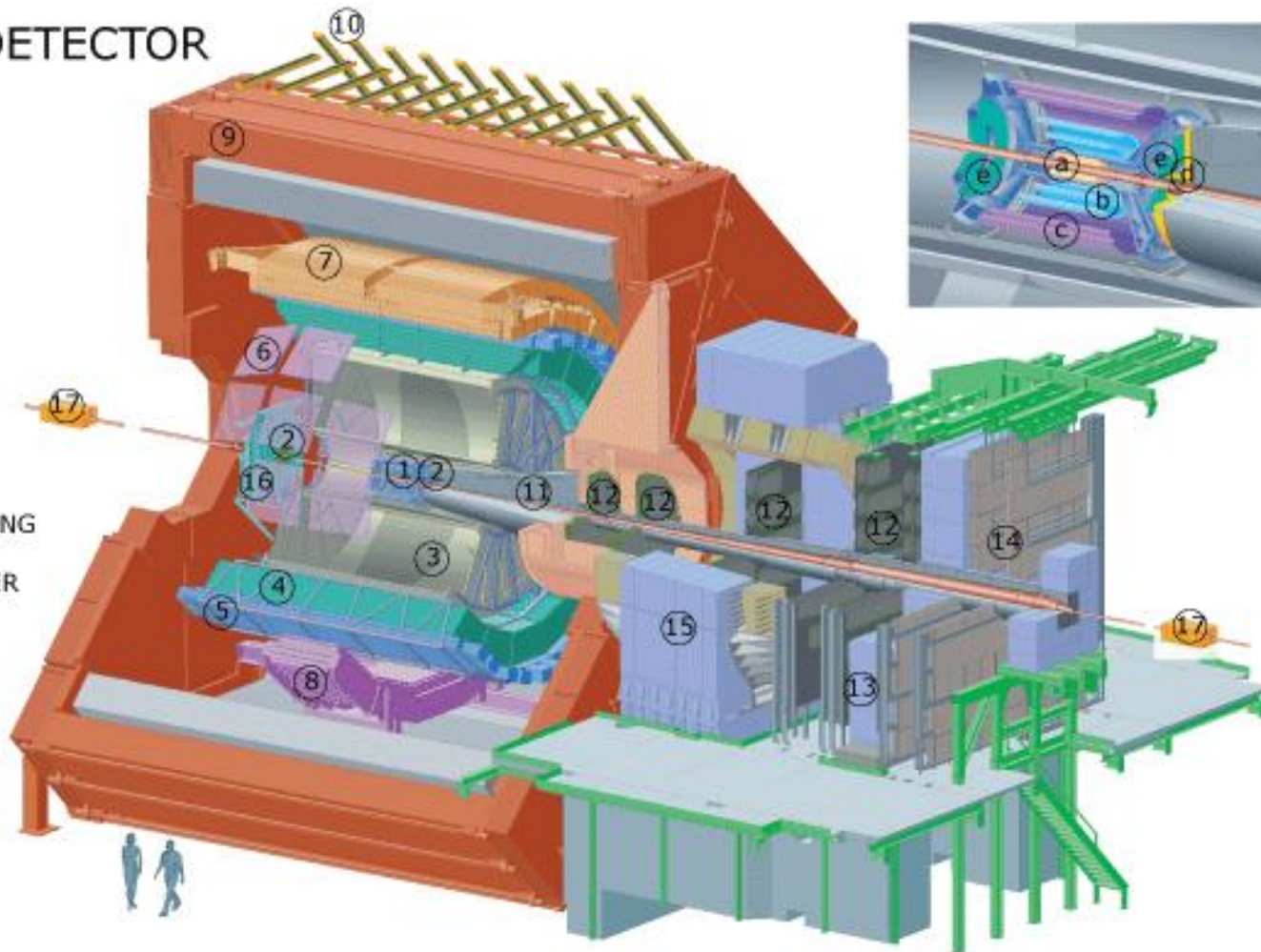




# ALICE : A Large Ion Collider Experiment

## THE ALICE DETECTOR

1. ITS
2. FMD , T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCAL
8. PHOS CPV
9. MAGNET
10. ACORDE
11. ABSORBER
12. MUON TRACKING
13. MUON WALL
14. MUON TRIGGER
15. DIPOLE
16. PMD
17. ZDC



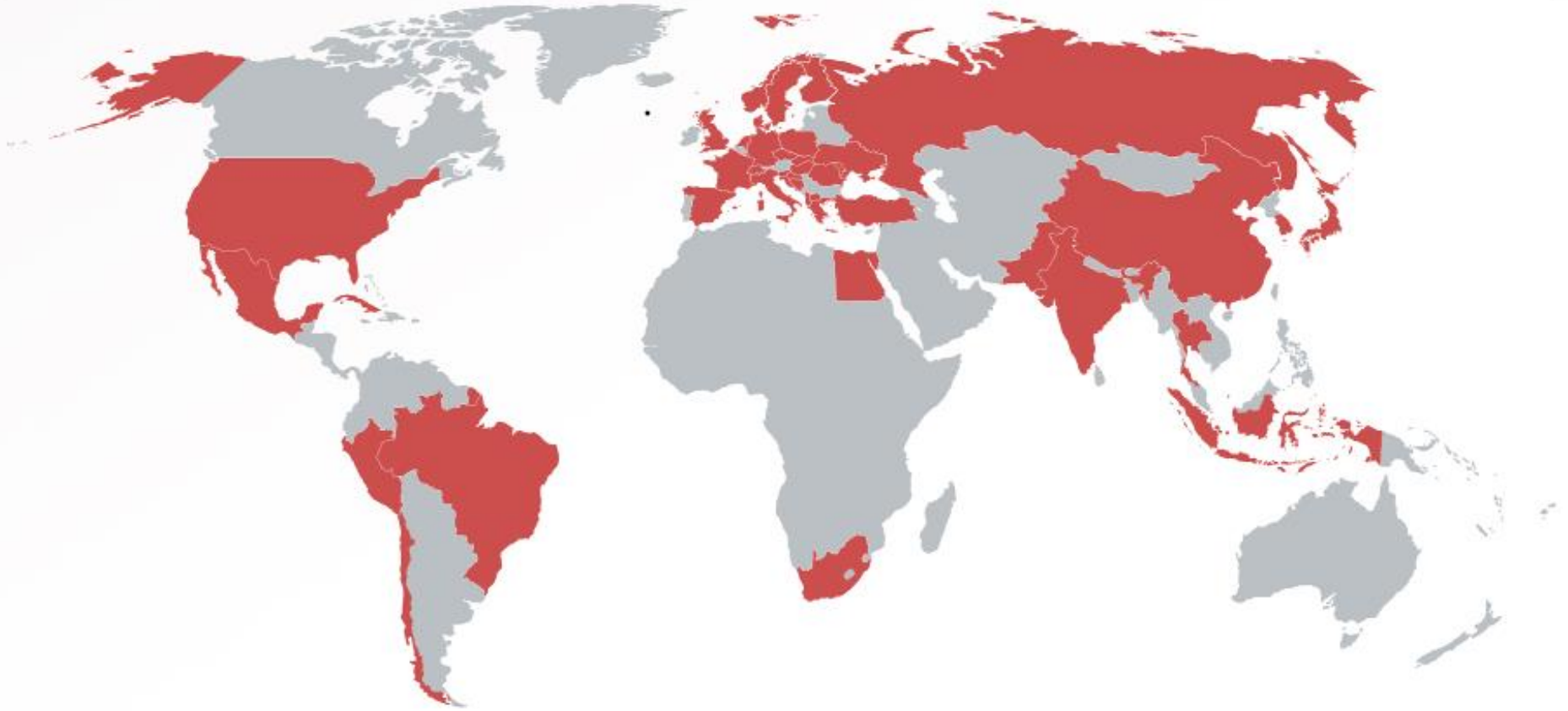
- a. ITS SPD Pixel
- b. ITS SDD Drift
- c. ITS SSD Strip
- d. V0 and T0
- e. FMD

16 m x 16 m x 26 m 10 000 tons installed at point 2 of LHC, 56 m underground 9



**ALICE**

## The Collaboration

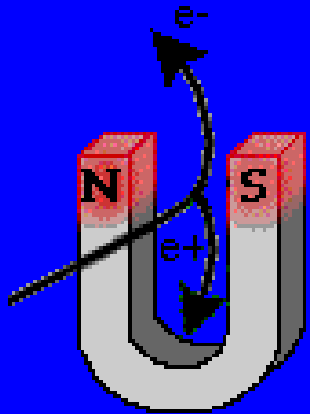


**37 countries, 131 Institutes, 1500 members**

# Particle Detectors

- They “see” the particles produced from beam-beam or beam-target 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 energy (calorimeters)
  - The particle type (particle identification)
  - Particle trajectory (tracking devices)

# The magnetic field



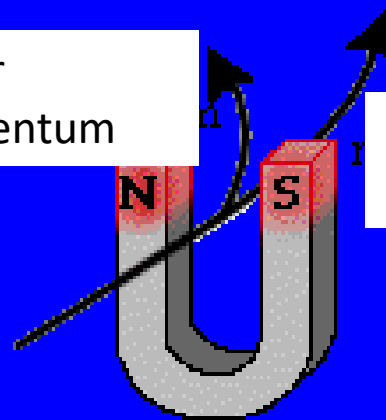
Identifies the charge

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

$$R = p/qB$$

Lower  
momentum

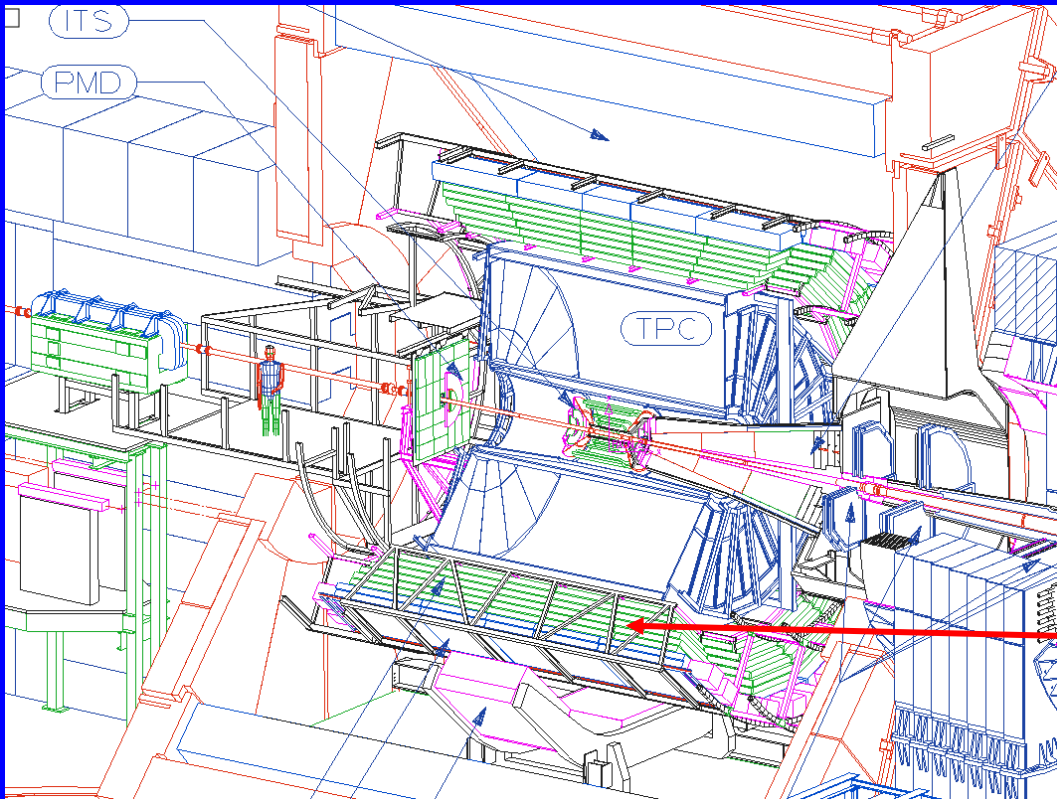
Higher  
momentum



Measures momentum

# ALICE : 18 different detection systems

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

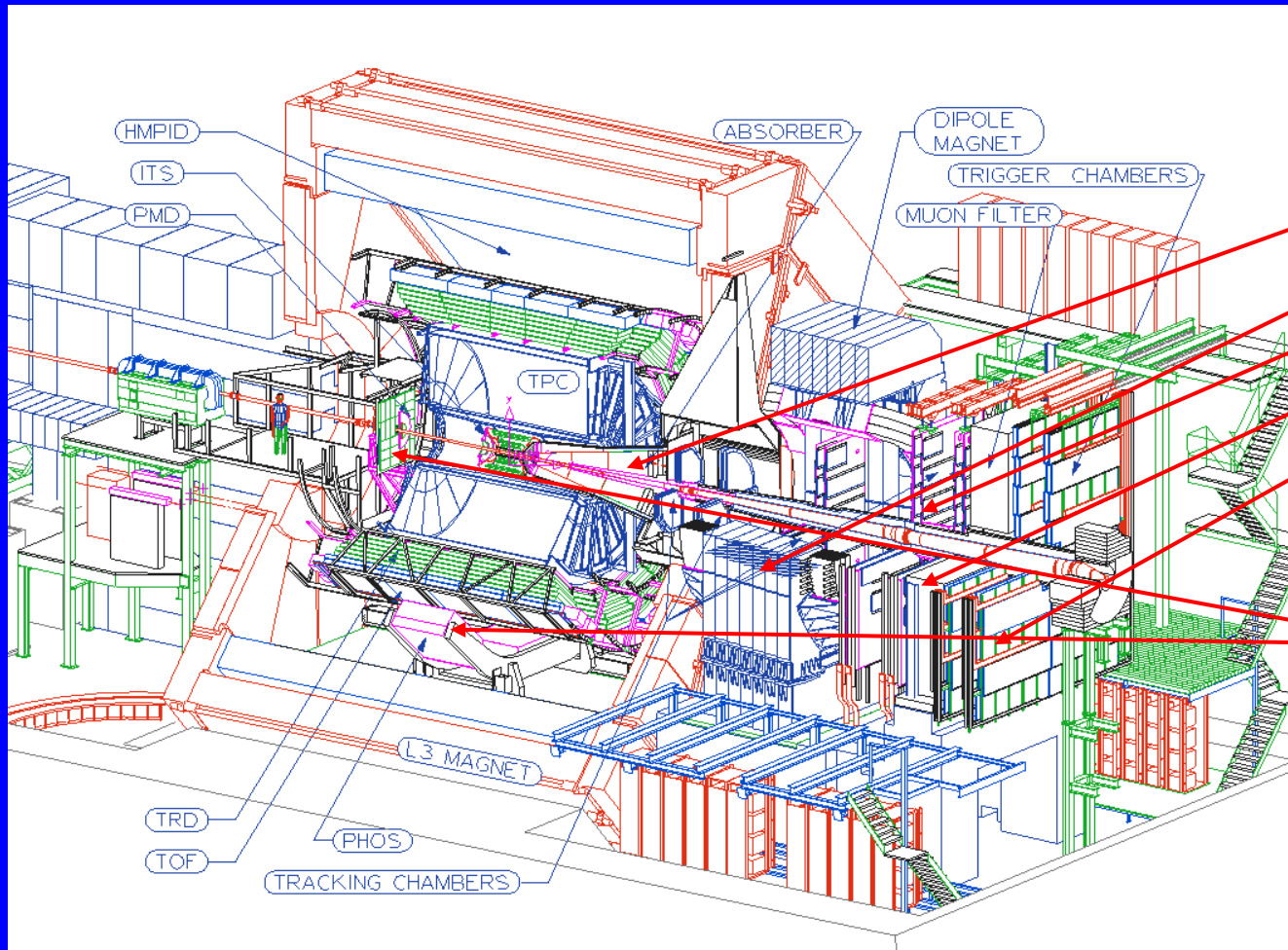


Inner Tracking System  
(ITS): p, pid

Time projection  
chamber (TPC) : p, pid

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

## ... and some more specialised detectors

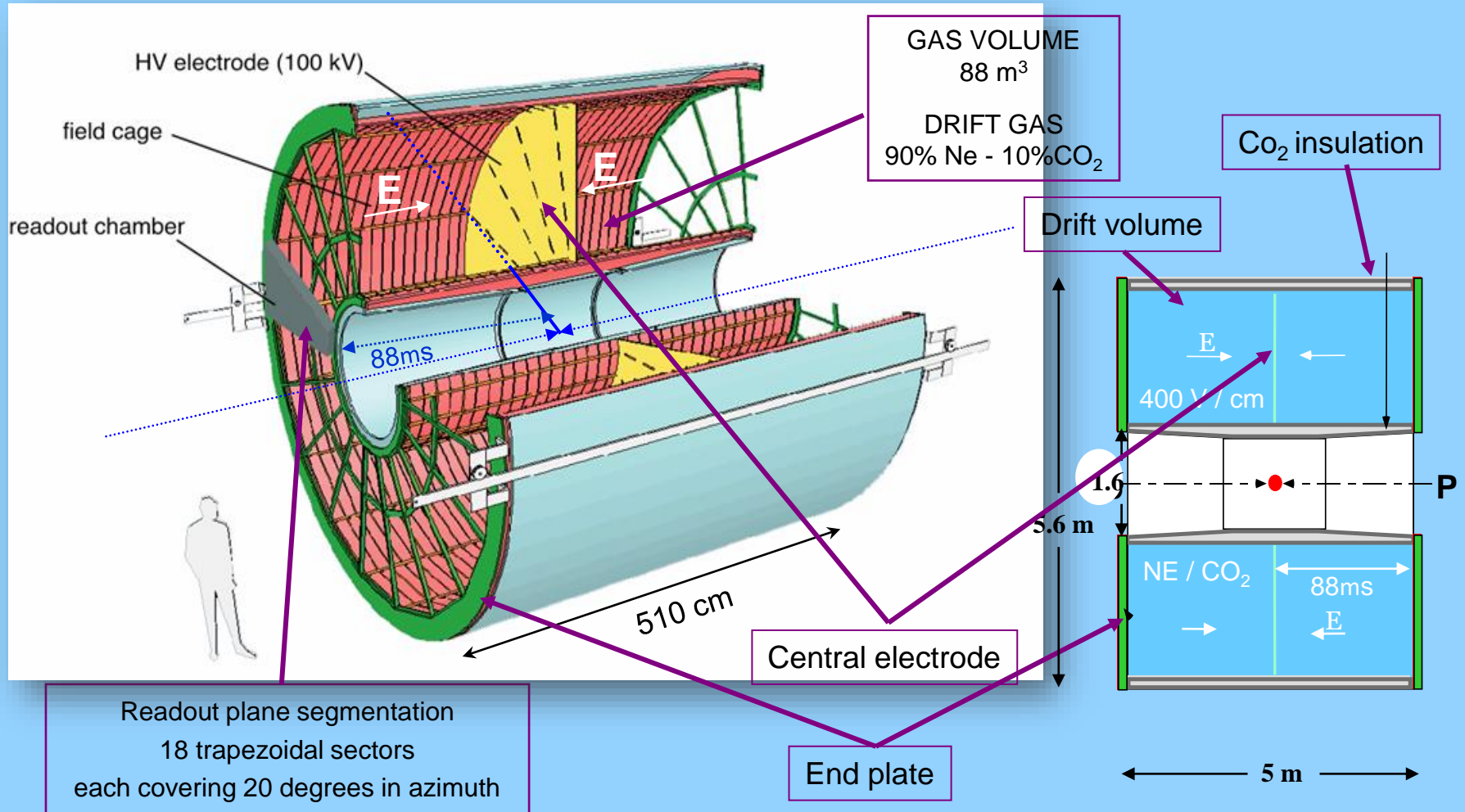


### Muon spectrometer:

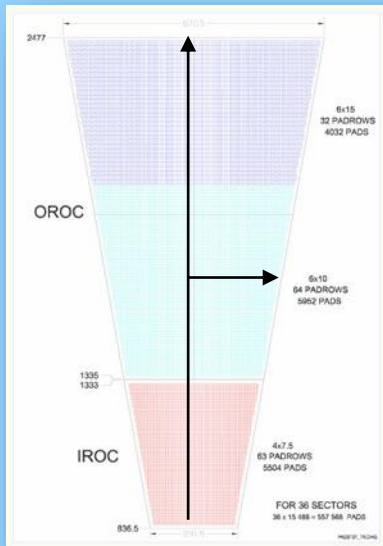
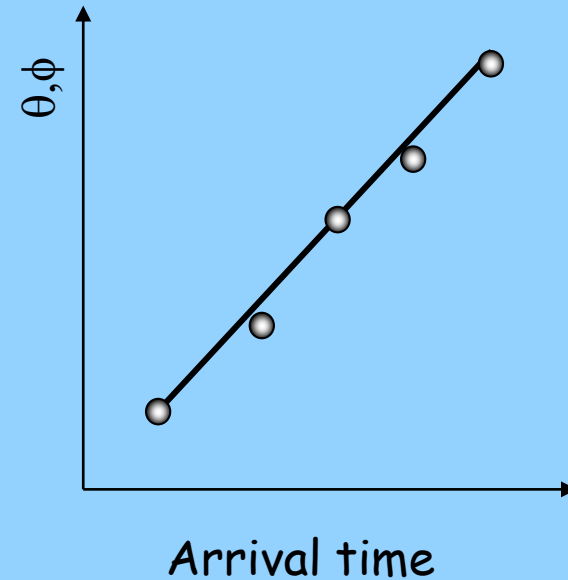
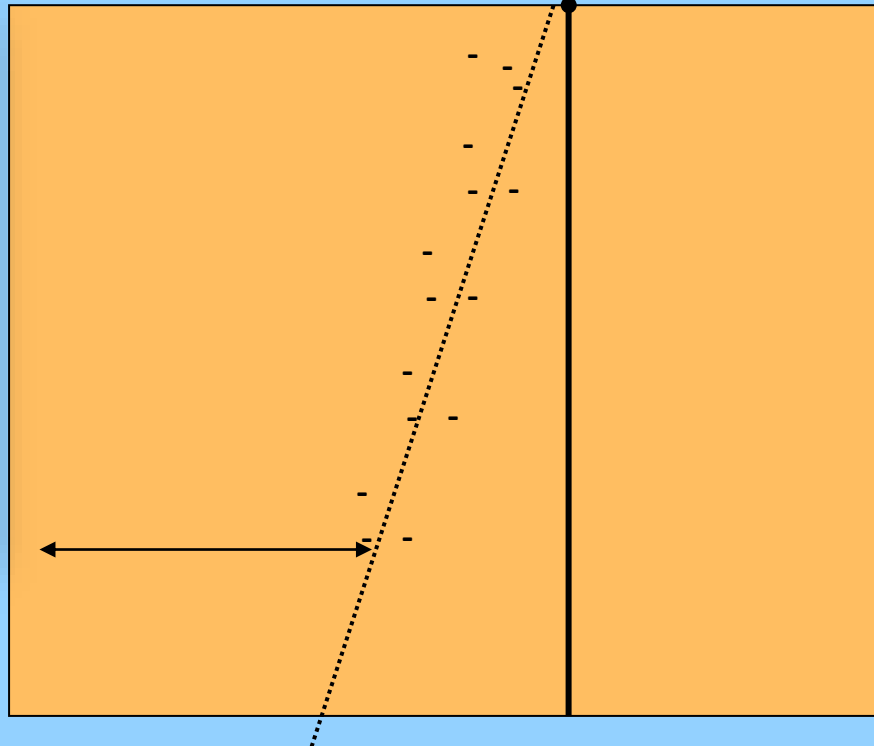
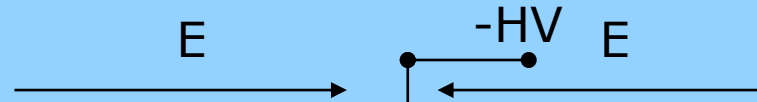
- Absorber
- Dipole magnet
- $\mu$  tracking chambers
- Filter
- Trigger

Photon detectors

# Time Projection Chamber (TPC)



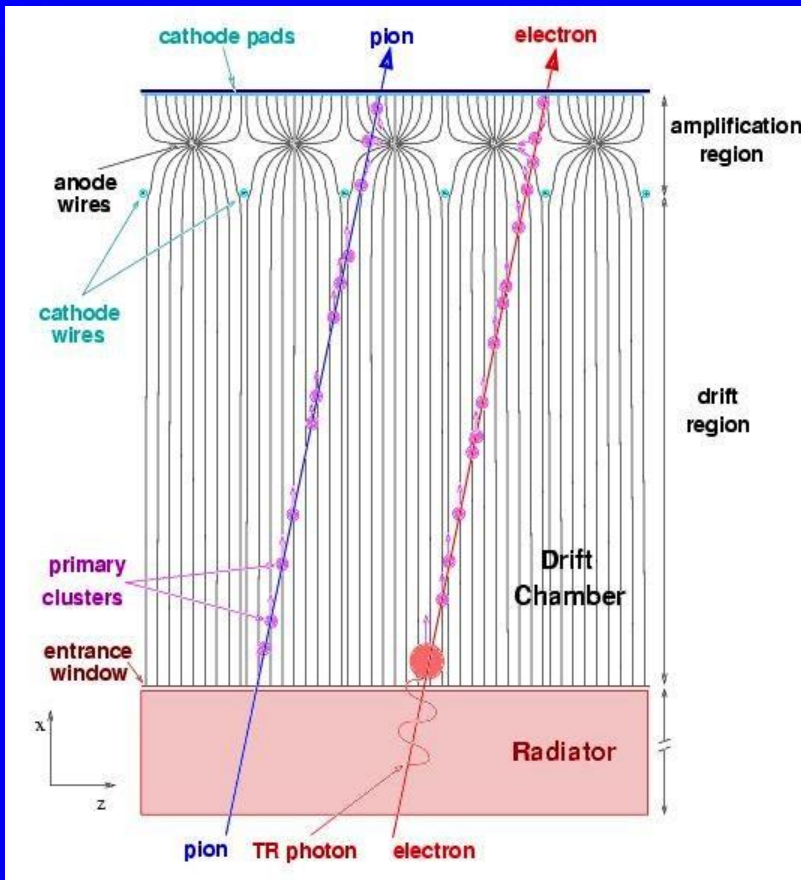
# Time Projection Chamber (TPC)





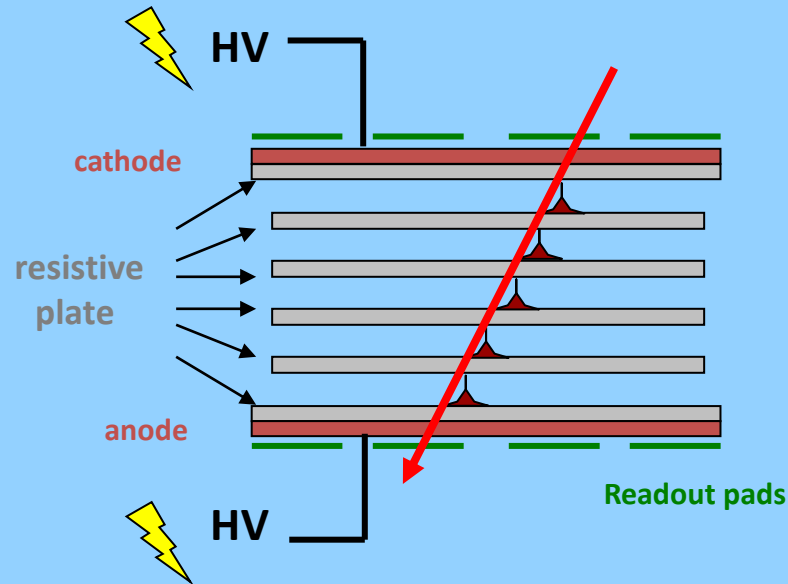
# Transition Radiation Detector

- 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)

# 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

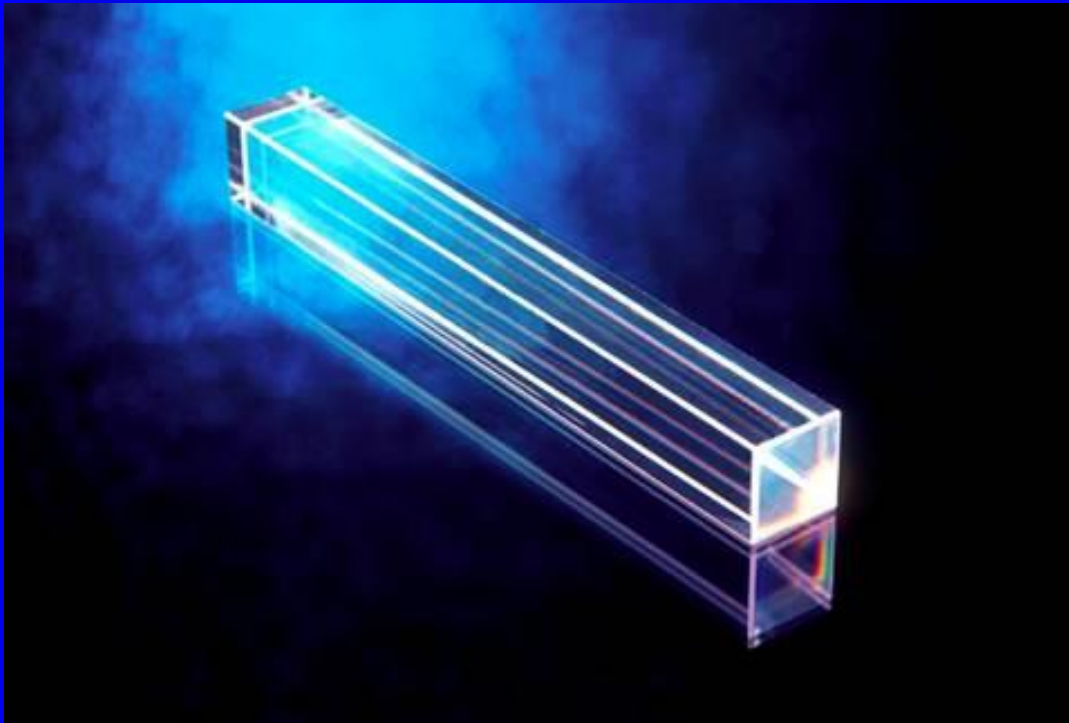
Time and trajectory length (known from tracking detectors) give the particle velocity

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

$\text{PbWO}_4$  : heavy and transparent



- 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 photons to electrons

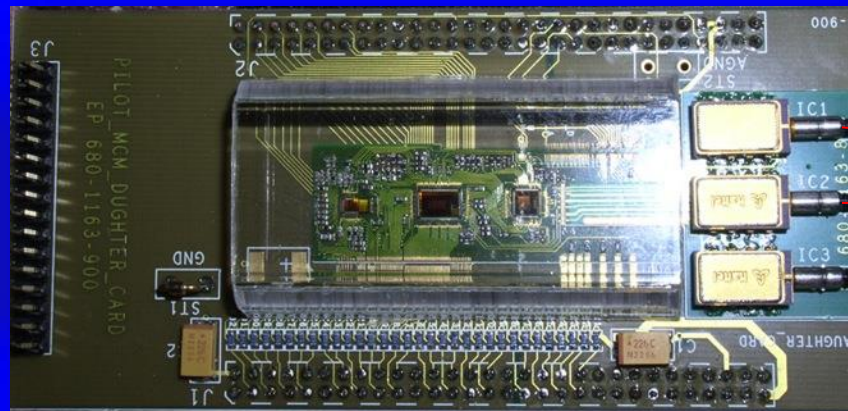
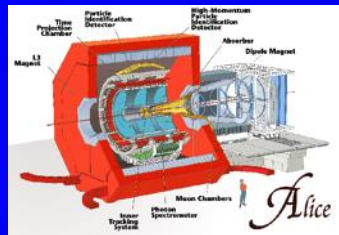
Electromagnetic calorimeter



Electric signal

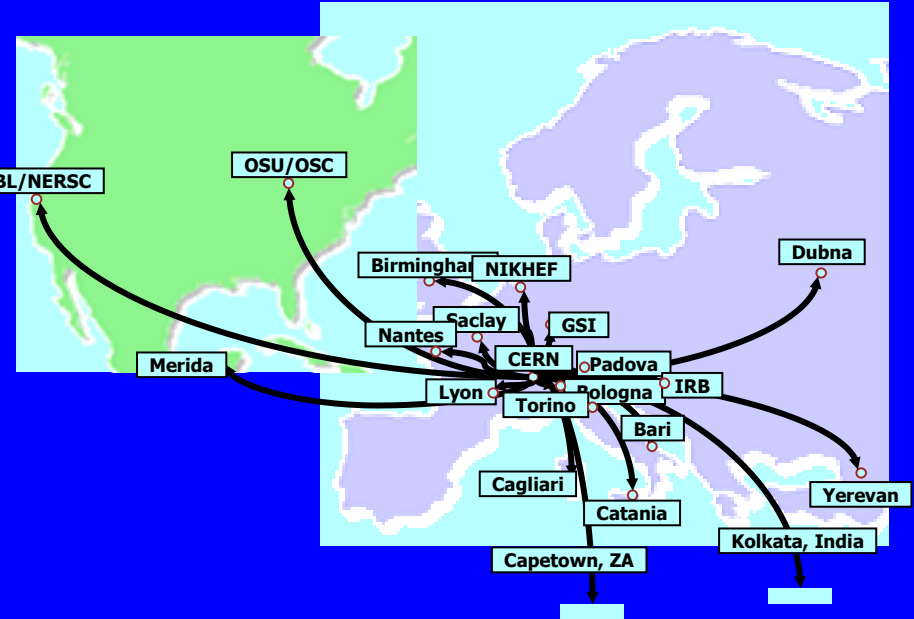
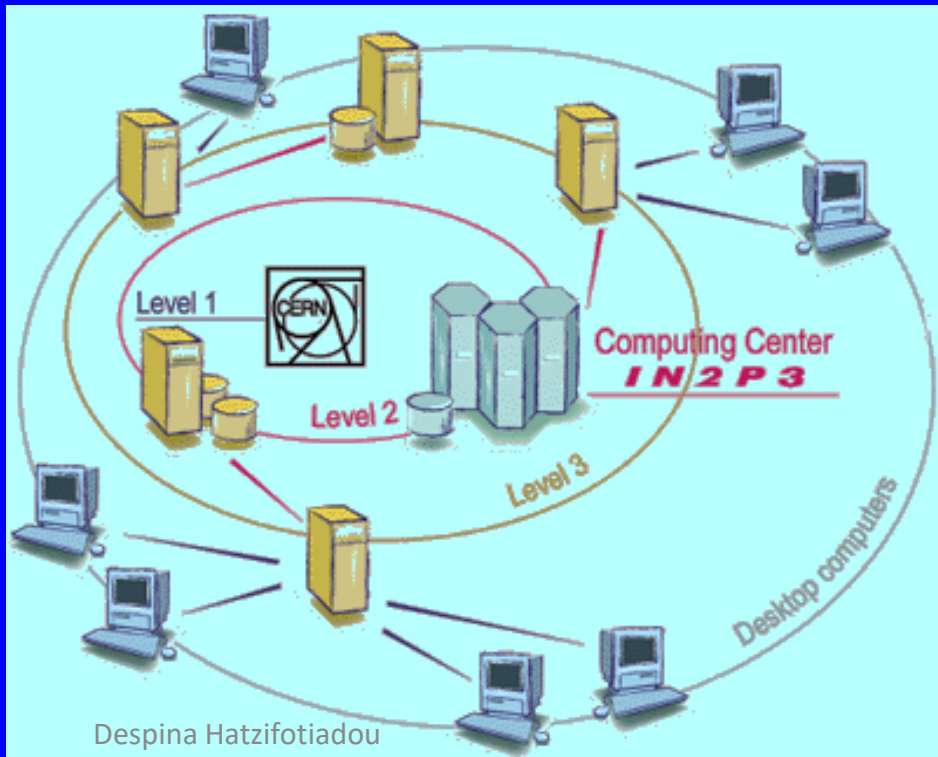
# Signal processing

- The signal from each detection element ( $\sim 16$  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

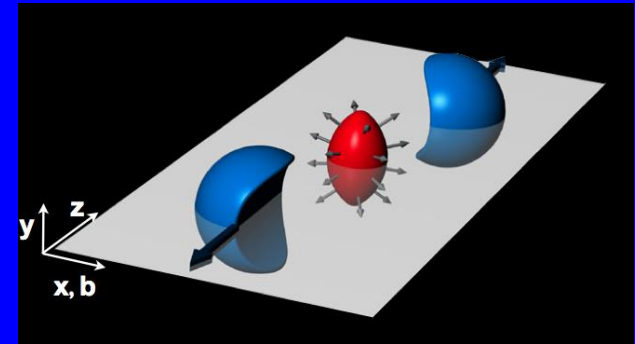
# A perfect liquid at LHC

The primordial matter recreated by high energy lead ion collisions 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.**

**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



Almond shape

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

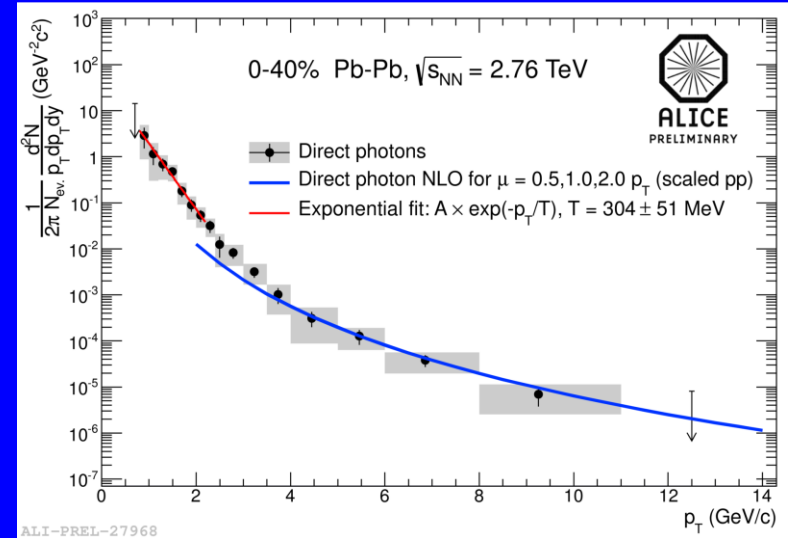
# Highest man-made temperature

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



**HIGHEST MAN-MADE TEMPERATURE**

Tweet 16 | +1 0 | Like | Send | 3 people like this. Be the first of your friends.



**FOR THE RECORD**

**WHO:**  
BROOKHAVEN NATIONAL  
LABORATORY'S  
RELATIVISTIC HEAVY ION  
COLLIDER

**WHAT:**  
HIGHEST MAN-MADE  
TEMPERATURE

**WHERE:**  
UNITED STATES

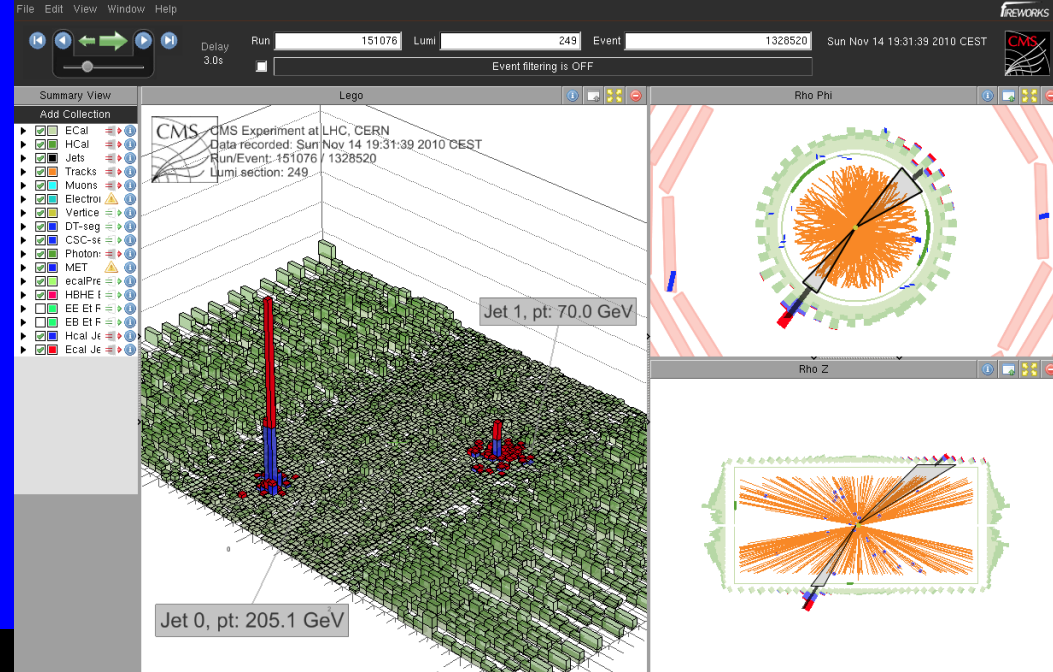
**WHEN:**  
01 JAN 2010

**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  $\sim$  equal energies

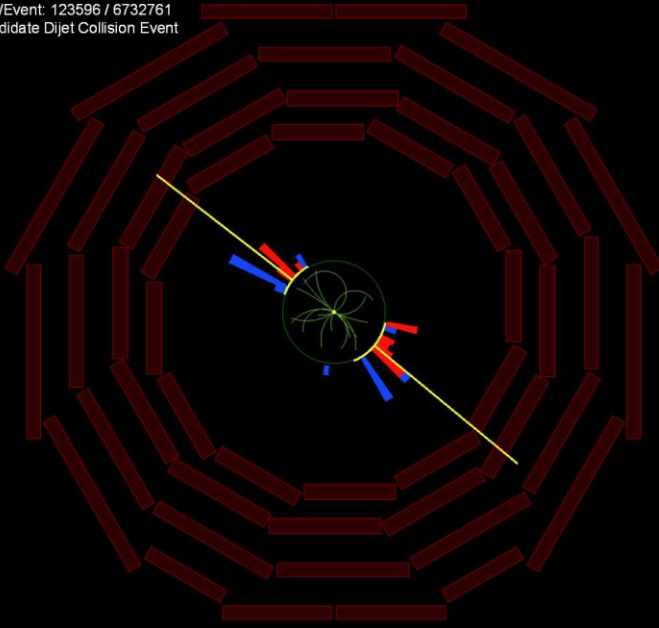


## Lead ion collision event

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

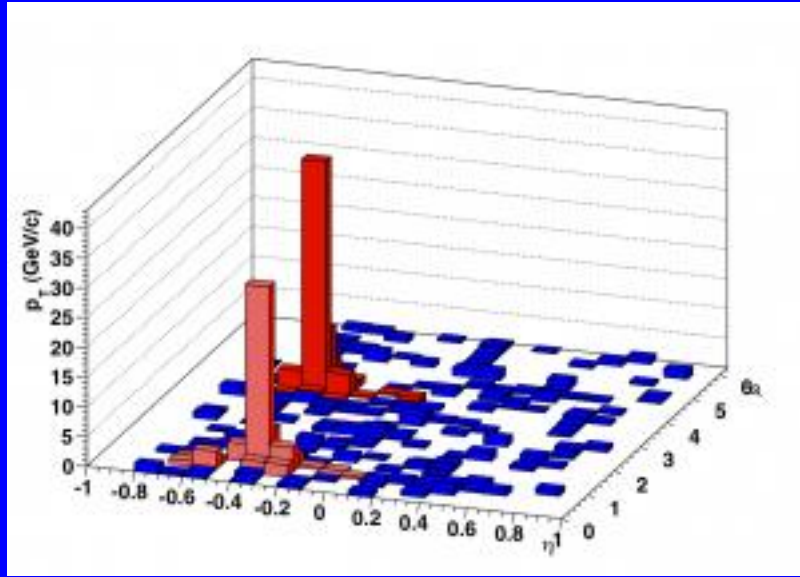
CMS Experiment at the LHC, CERN  
Date Recorded: 2009-12-06 07:18 GMT  
Run/Event: 123596 / 6732761  
Candidate Dijet Collision Event



Proton collision event – two jets with energy of  $\sim$ 20 GeV

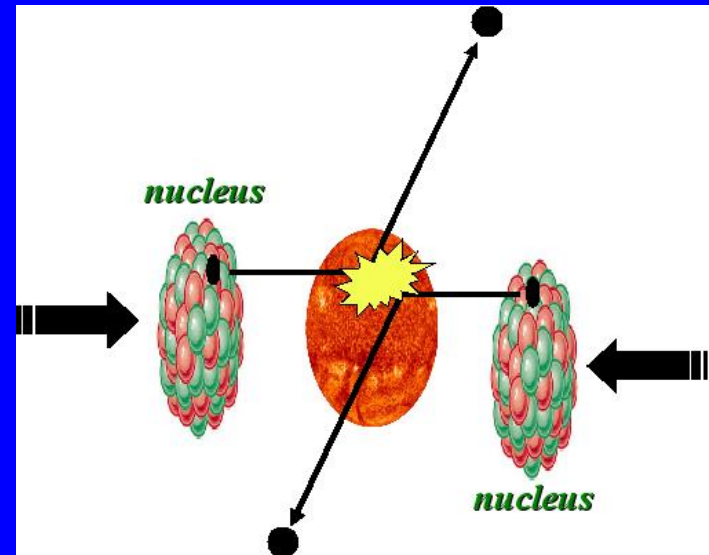
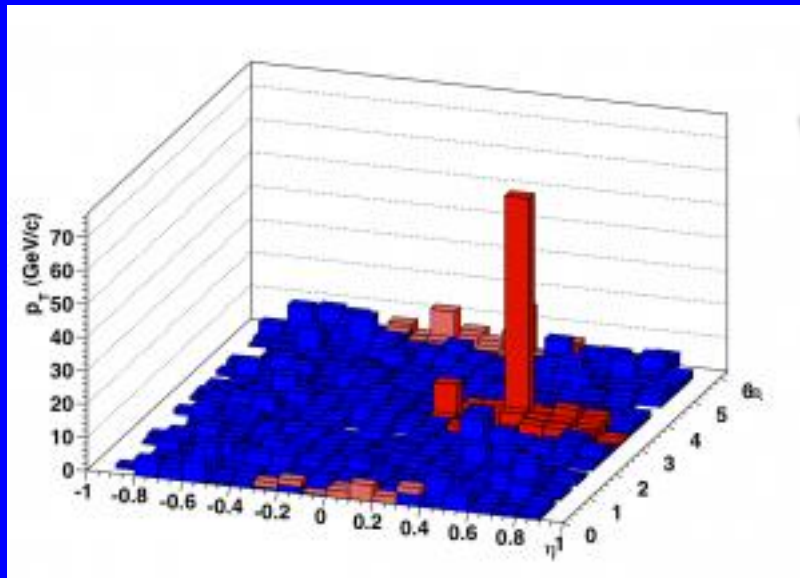


# Jet Quenching



ALICE – peripheral lead ion collisions- two jets

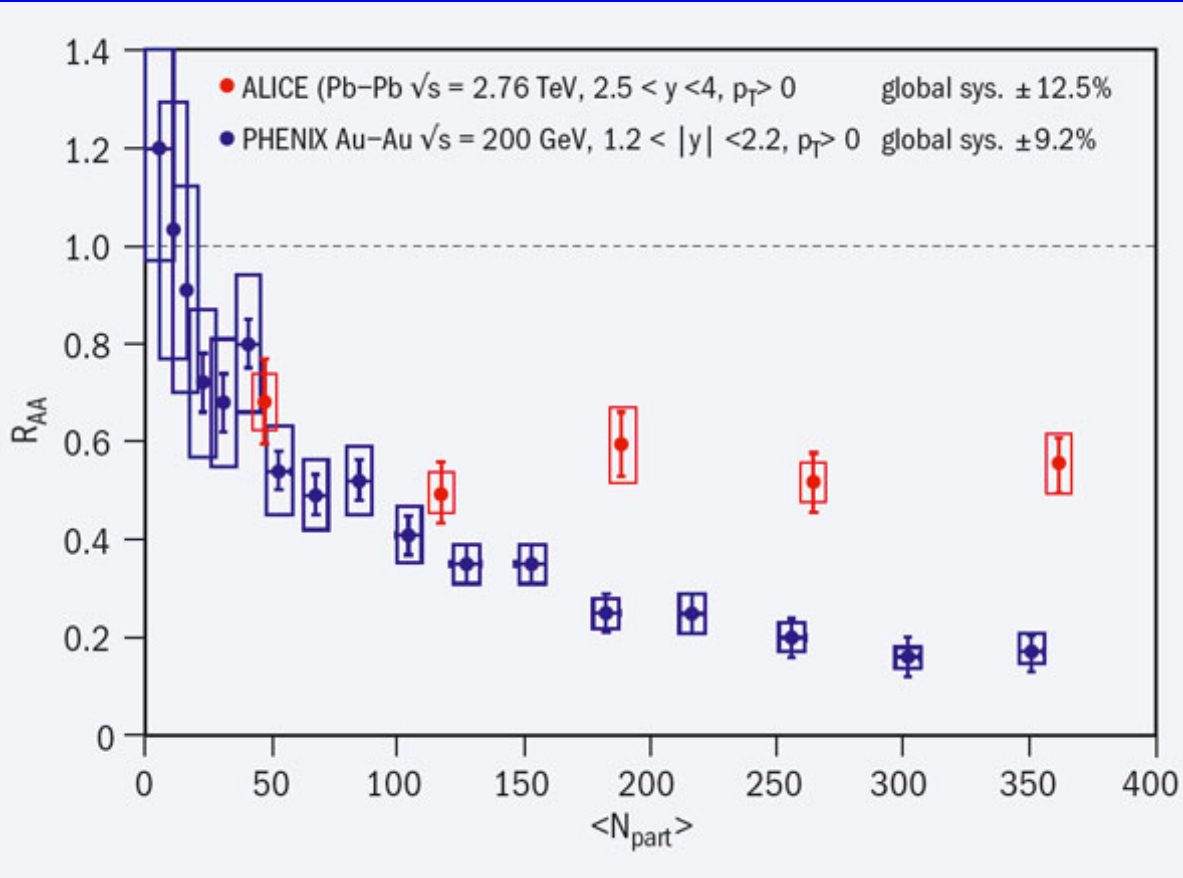
ALICE – central lead ion collisions  
1 jet is visible, the other has been absorbed while travelling through the QGP and does not come out



# The $J/\psi$ mystery

- $J/\psi$  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  $J/\psi$  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  $J/\psi$  disappears
- Suppression of the observed  $J/\psi$  signal  
( $J/\psi \rightarrow \mu\mu$  and  $J/\psi \rightarrow e^+e^-$ )
- Suppression depends on QGP temperature

# The J/ψ mystery

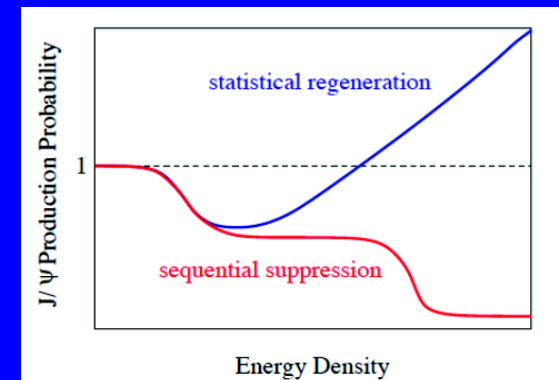


- Regeneration of J/ψ at very central collisions
- Two competing phenomena
- Suppression of J/ψ due to interaction with the quark gluon plasma
- Creation of many J/ψ due to the high number of c – anti-c pairs created from the huge collision energy

Nuclear modification factor  $R_{AA}$

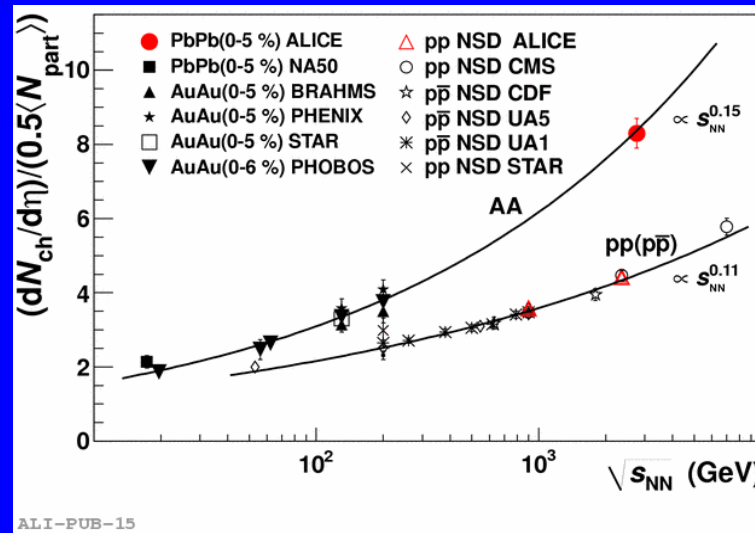
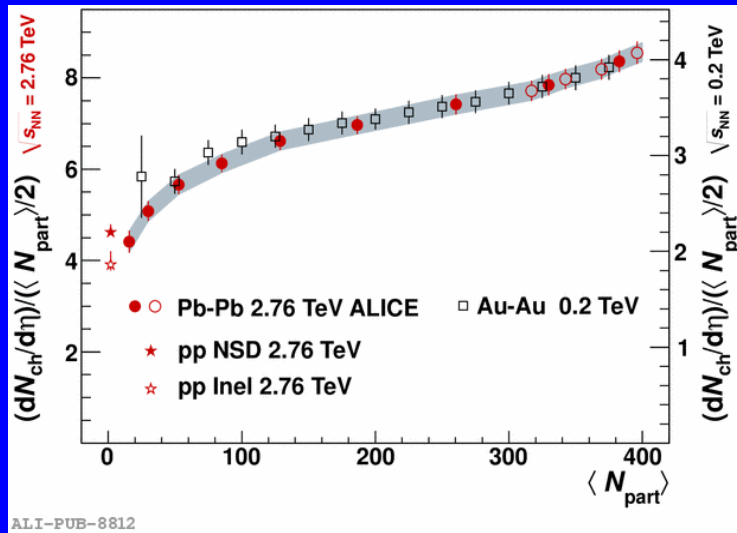
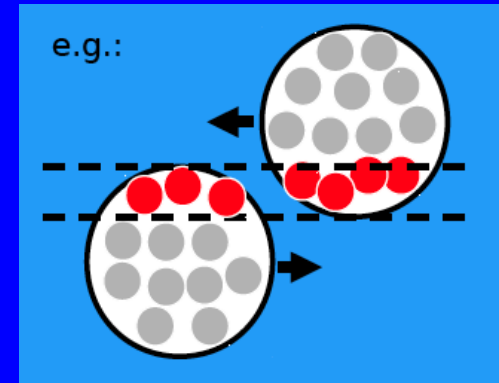
number of J/ψ observed in lead ion collisions

number of J/ψ observed in proton collisions



When lead nuclei collide **all nucleons** (protons and neutrons) **can take part in the collision (central) or only some (peripheral)**

$N_{\text{part}}$ : number of nucleons participating in the interaction



The number of charged particles produced depends on the centrality of the collision. It gives information on how the quarks and gluons are transformed into the particles (pions, Kaons,..) which we detect.

From the number of charged particles we deduce the energy density : it is 3 times higher than at RHIC.