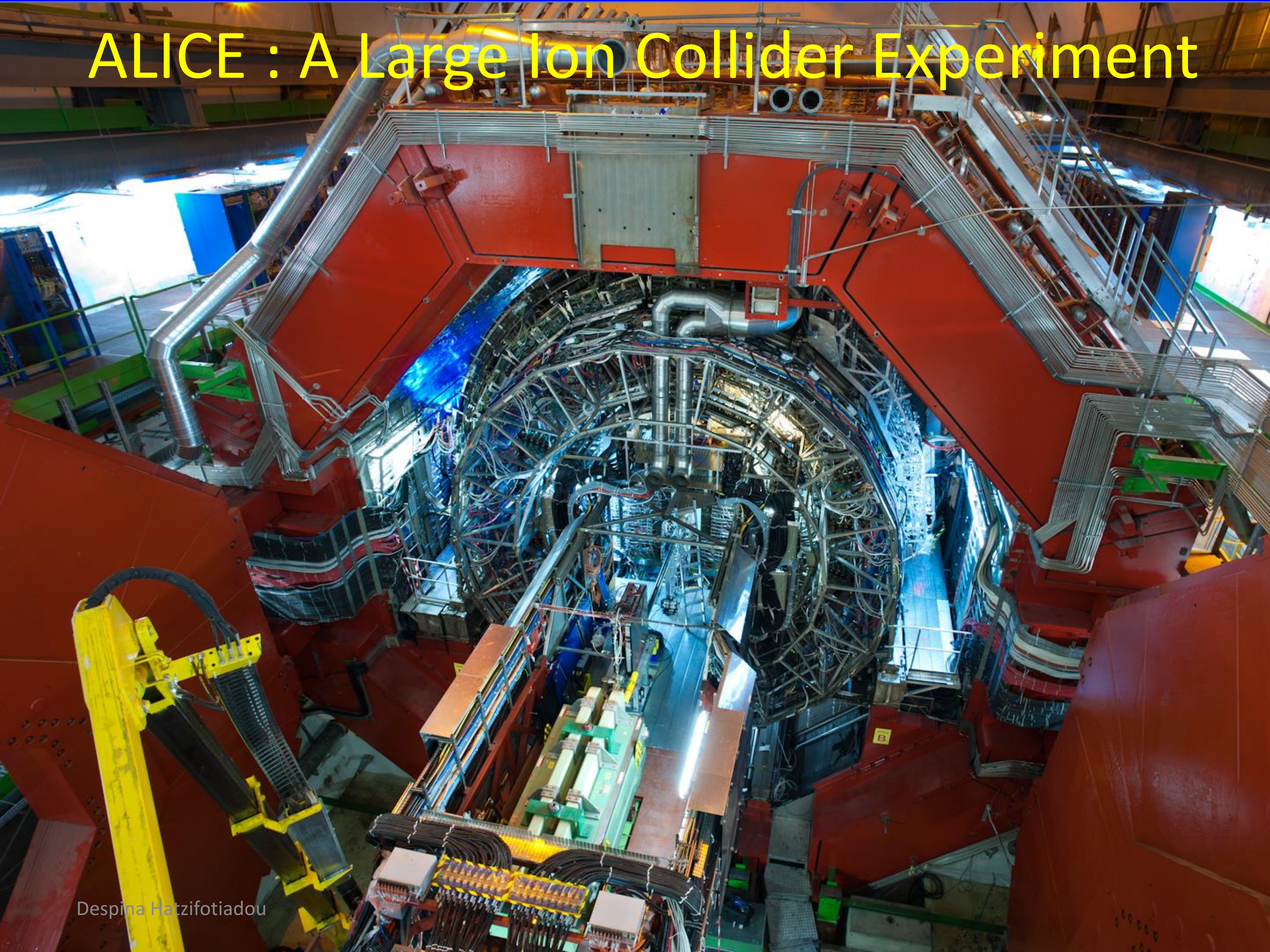
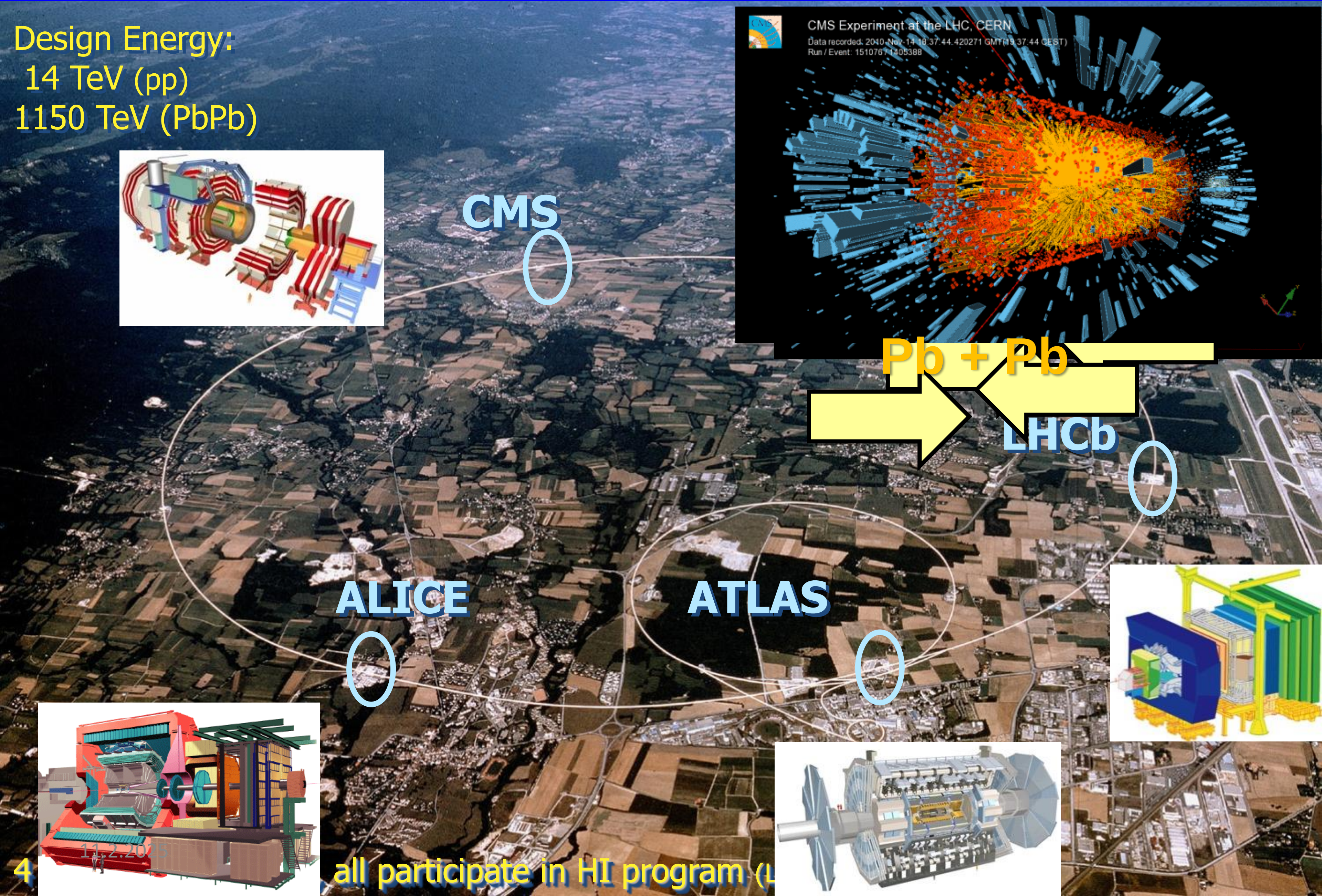
# ALICE : A Large Ion Collider Experiment



Despina Hatzifotiadou

# Large 'Hadron Collider'

# Collider of '<u>Large Hadrons</u>'



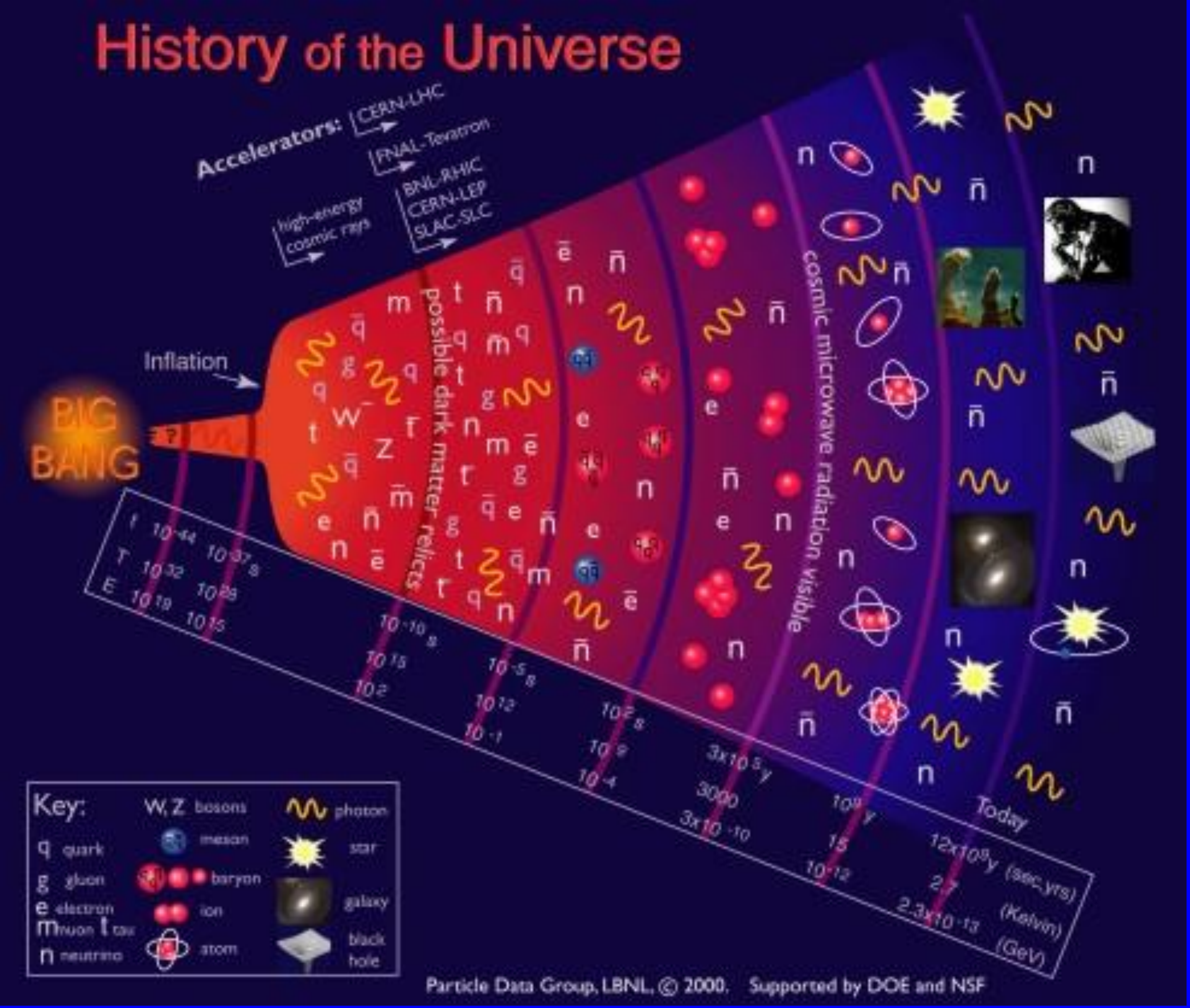
# Heavy ions at LHC

In addition to protons, LHC accelerates and collides lead ions

isotope Pb $^{208}$ with 82 protons and 126 neutrons in the nucleus
Pb atom -> $Pb^{29+}$ -> $Pb^{54+}$ -> $Pb^{82+}$ (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?




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

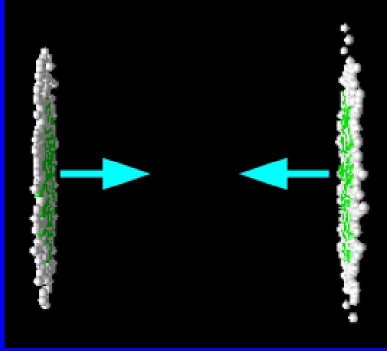
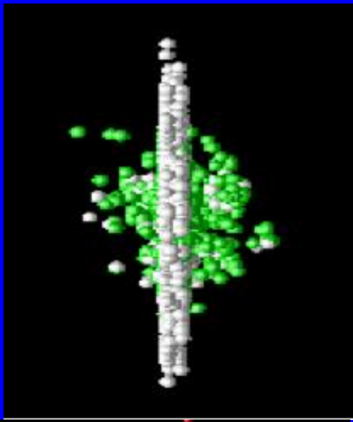
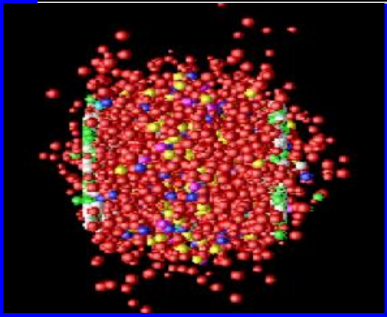
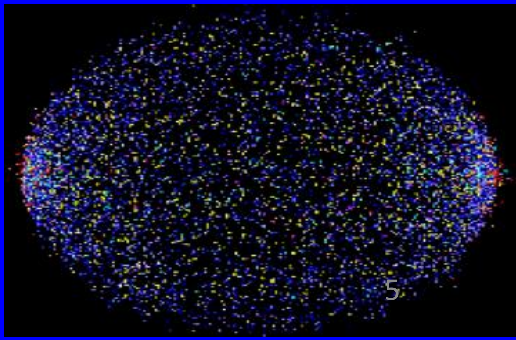
The protons and neutrons which constitute the lead nuclei melt liberating the quarks and gluons which are bound inside them

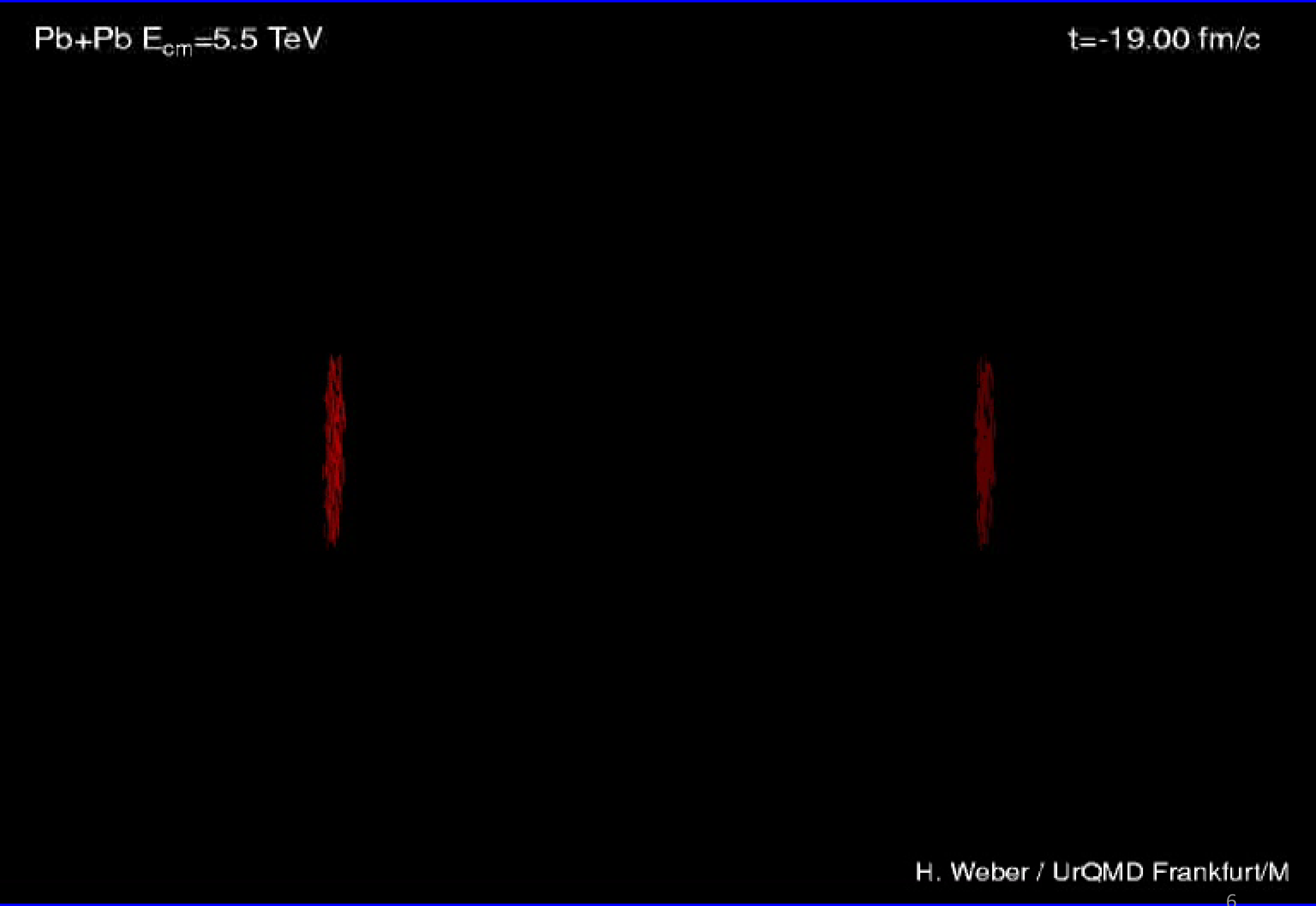
A new state of matter is created : the QUARK GLUON PLASMA

By studying its properties

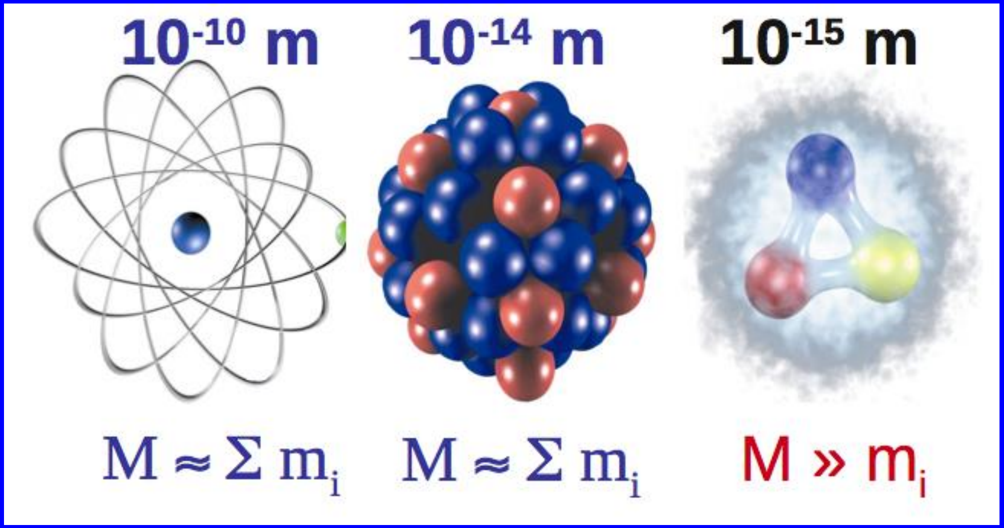
- We will understand better the processes which took place during the first fractions of a second in the life of the universe

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


Pb+Pb $E_{cm}$=5.5 TeV
t=-19.00 fm/c
H. Weber / UrQMD Frankfurt/M

atom nucleus nucleon

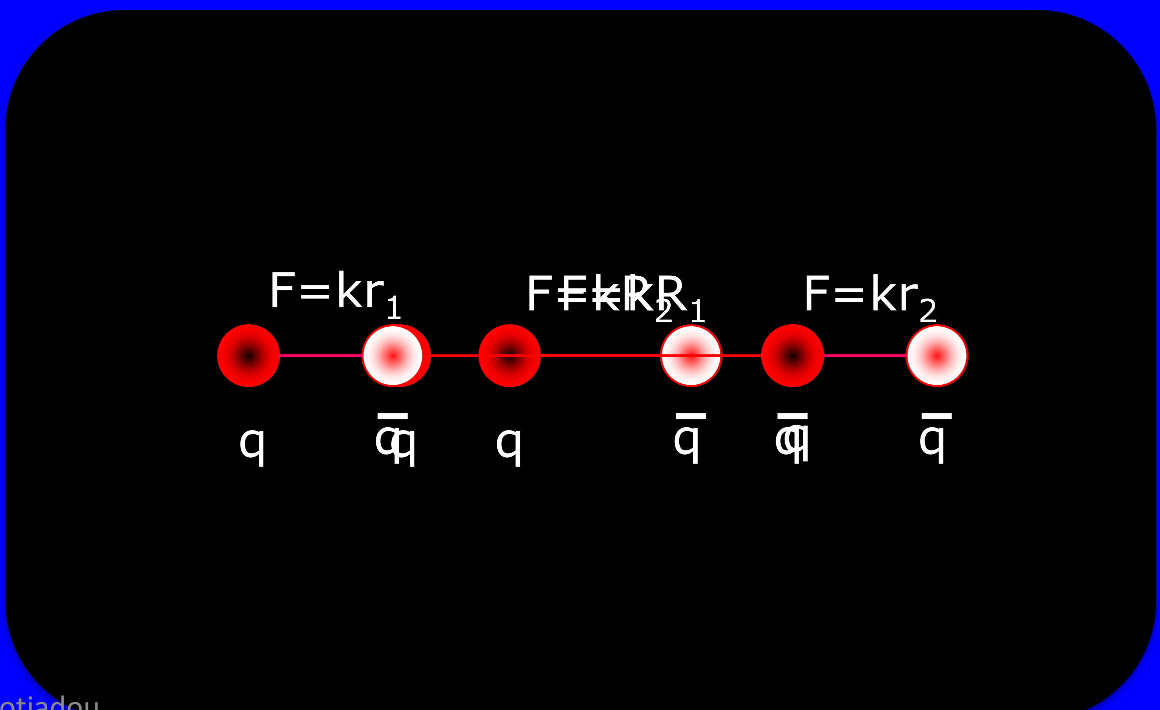


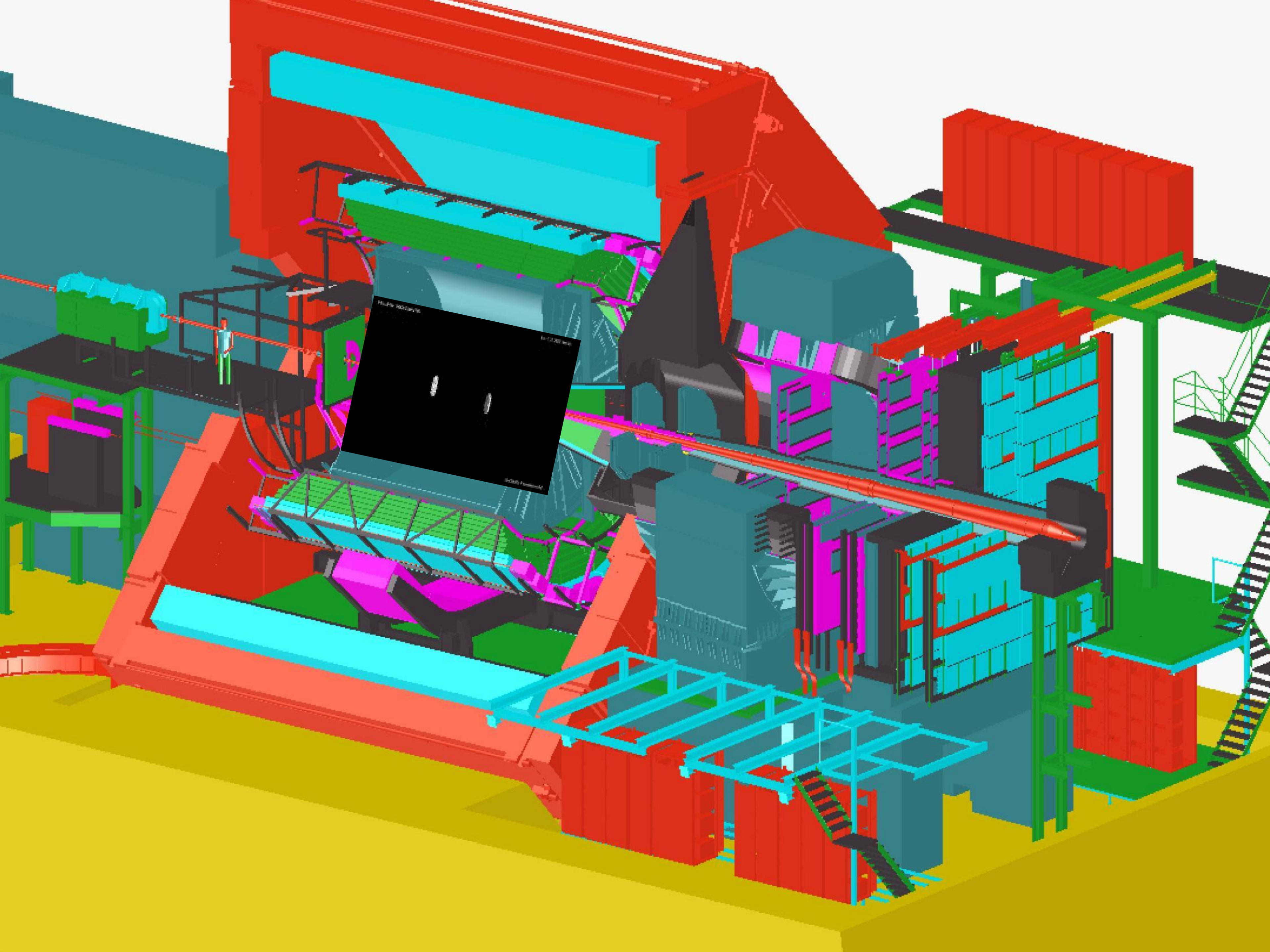

In nucleons (protons and neutrons) the mass is not defined by the sum of masses of their constituents but mainly from the energy due to the movement of quarks and the energy of the gluons

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/$c^2$

ALICE studies stong interactions..

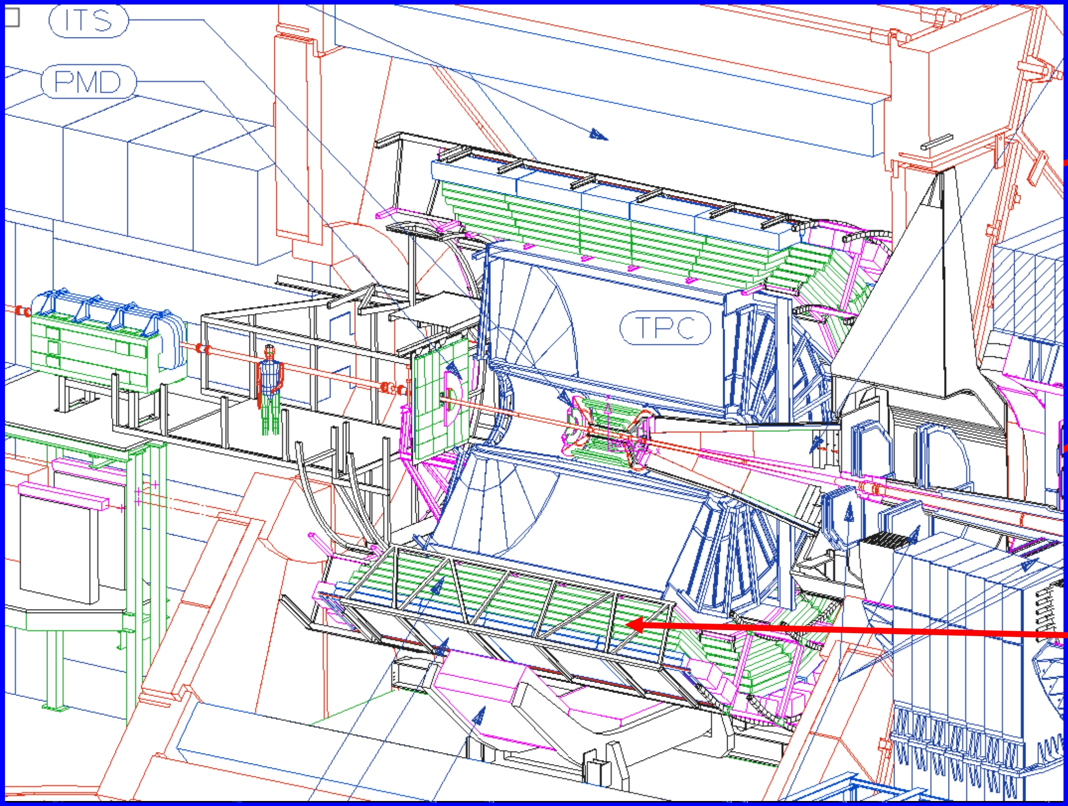
Why are quarks permanently confined inside hadrons?



# ALICE : 15 different detection systems

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

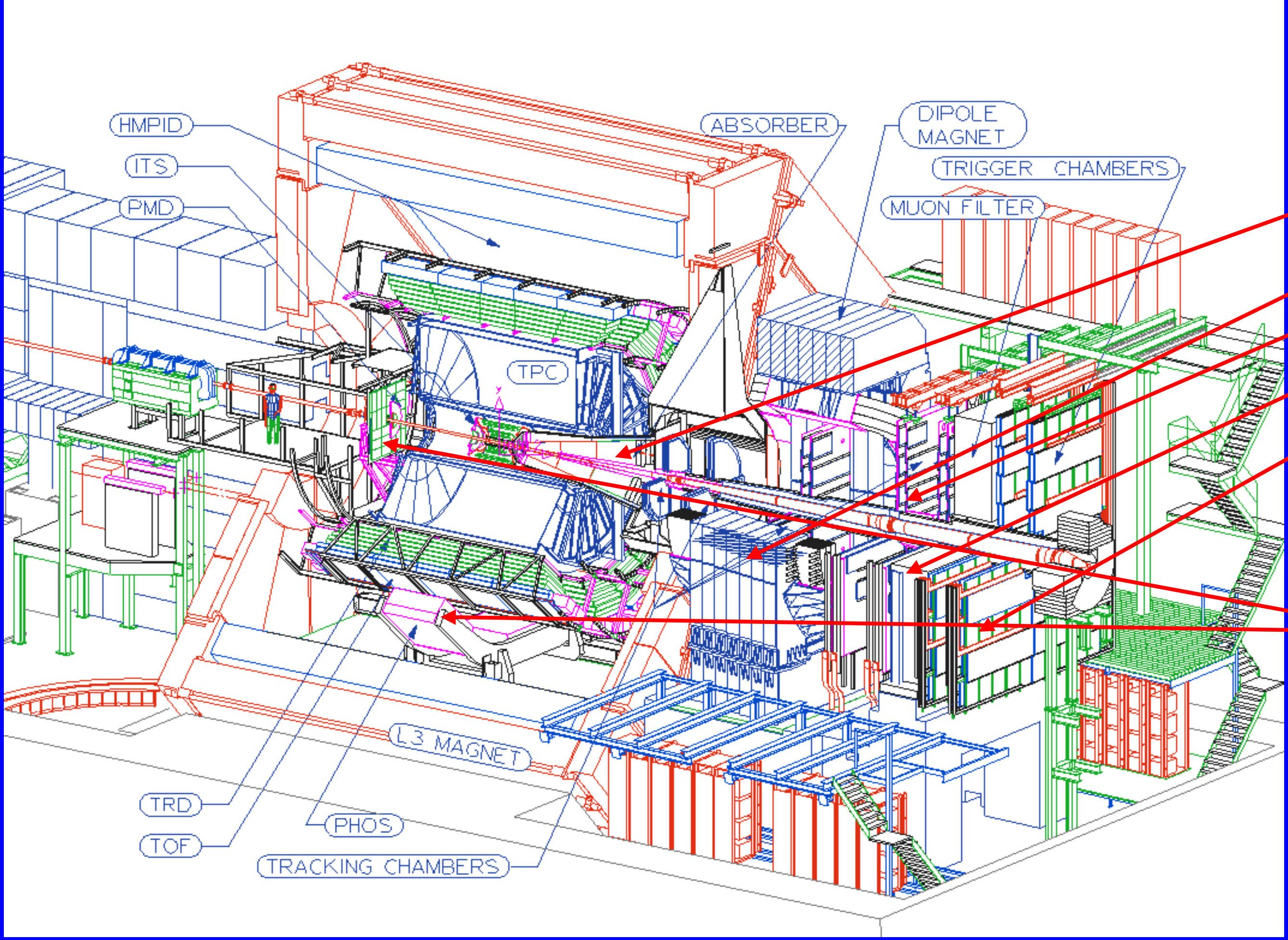



Inner Tracking System (ITS): p, pid

Time projection chamber (TPC) : p, pid

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

# … and some more specialised detectors

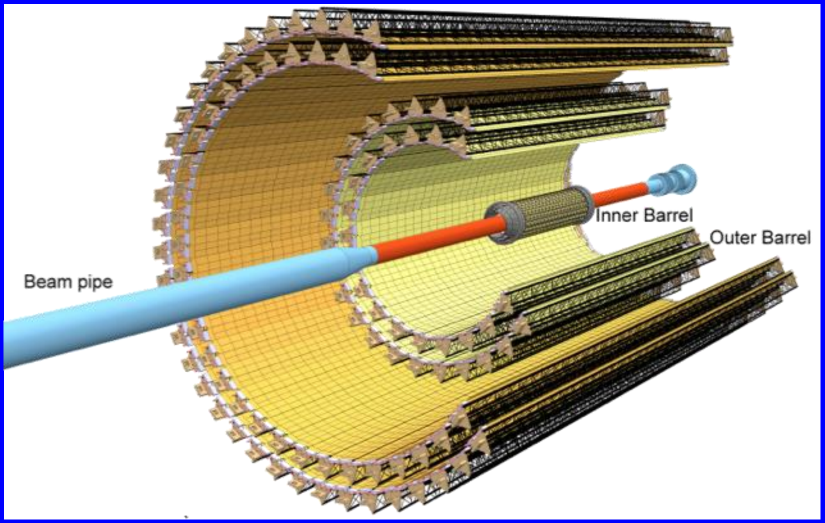



Muon spectrometer:

- Absorber
- Dipole magnet
- μ tracking chambers
- Filter
- Trigger

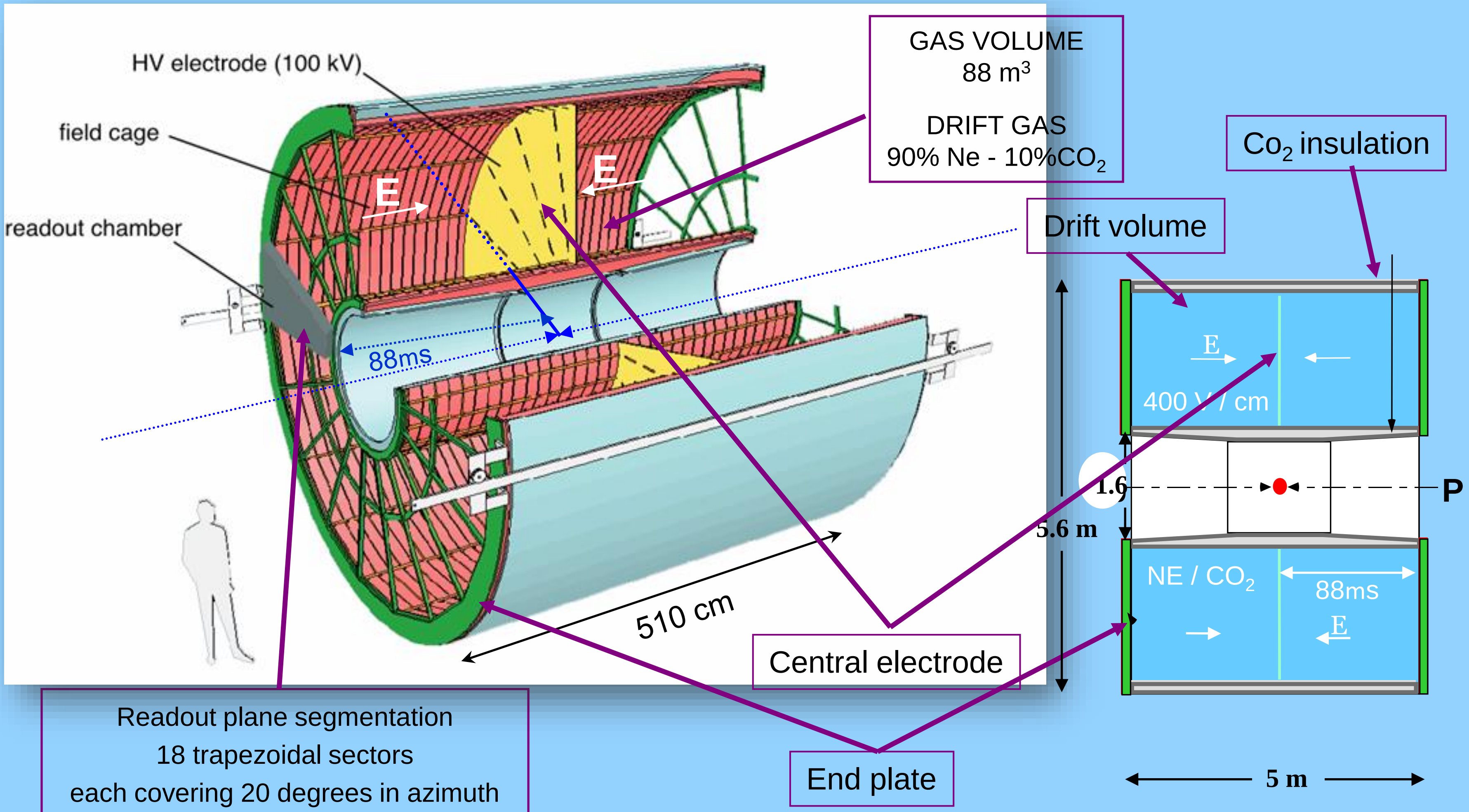
Photon detectors

# Inner Tracking System (ITS)

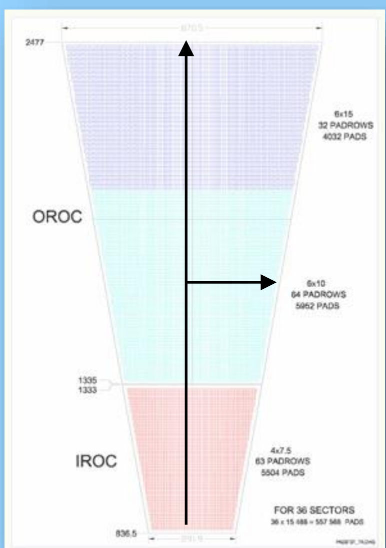


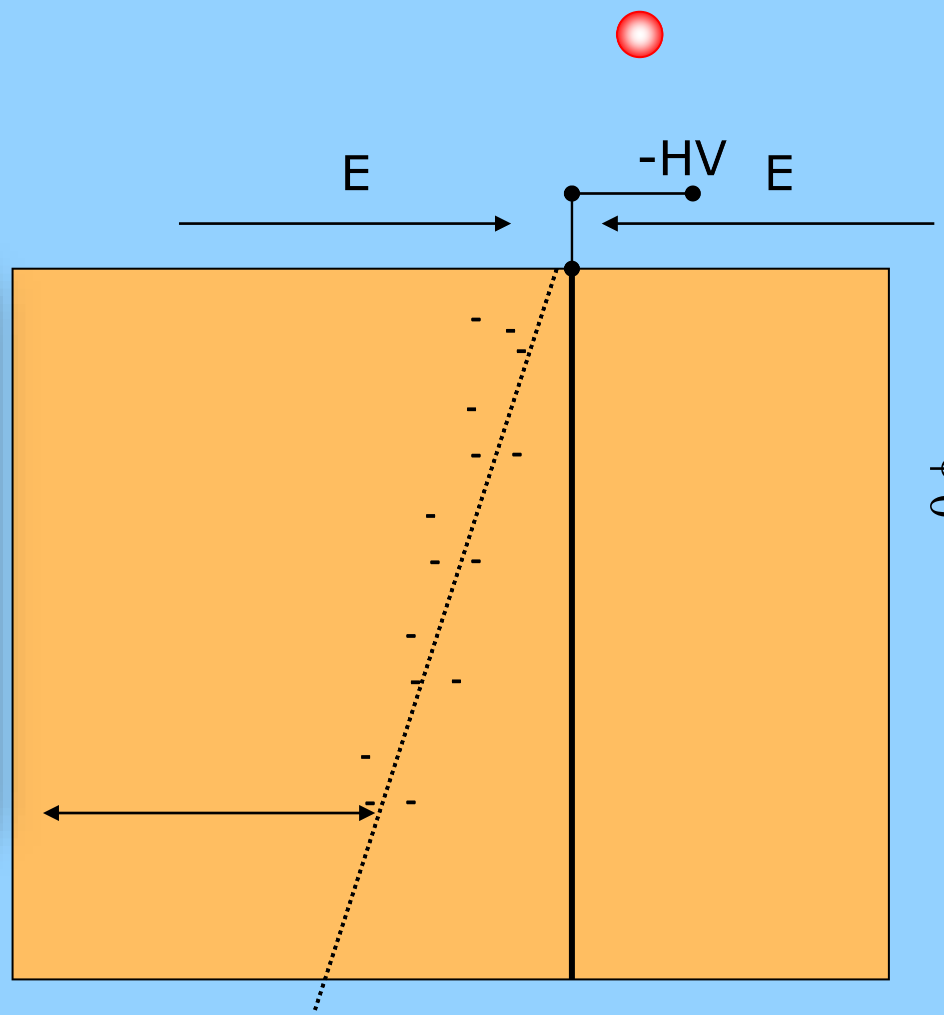

- 7-layer geometry (23 – 400mm), $|\eta| \leq 1.5$)
- 10 $m^2$ active silicon area (**12.5 G-pixels**)
- Pixel pitch 28 x 28 $\mu m^2$
- Spatial resolution ~5$\mu$m
- Power density < 40mW / $cm^2$
- Material thickness: ~0.3% / layer (IB)
- Maximum particle rate: 100 MHz / $cm^2$

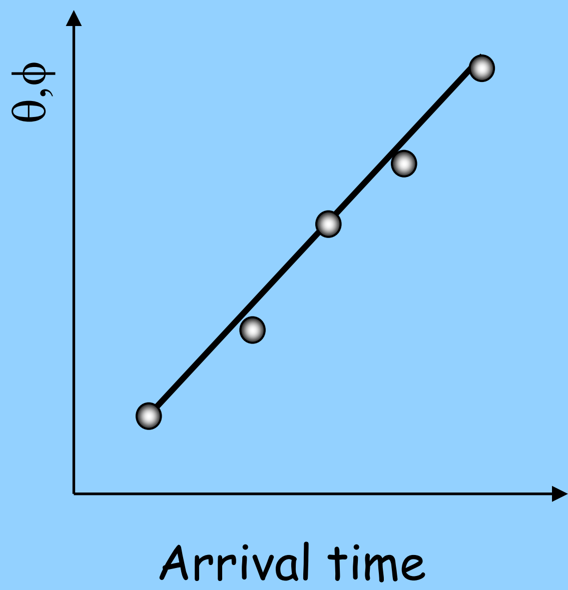
# Time Projection Chamber (TPC)



# Time Projection Chamber (TPC)

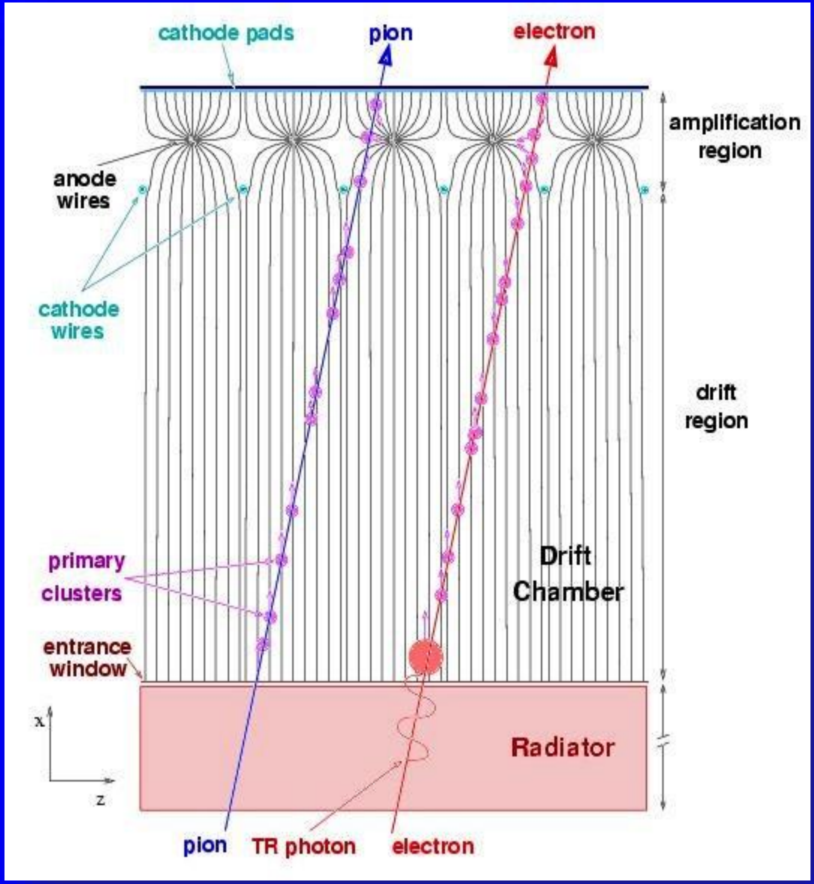


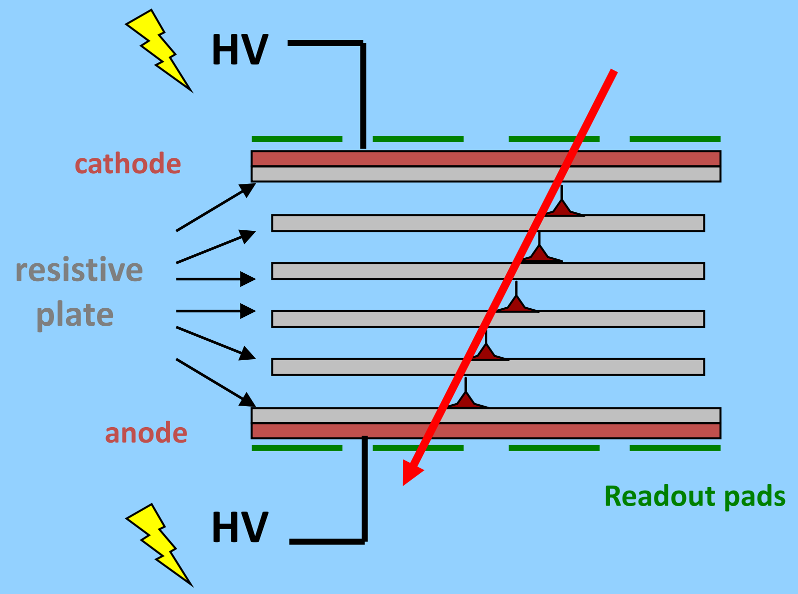
# Transition Radiation Detector

- 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

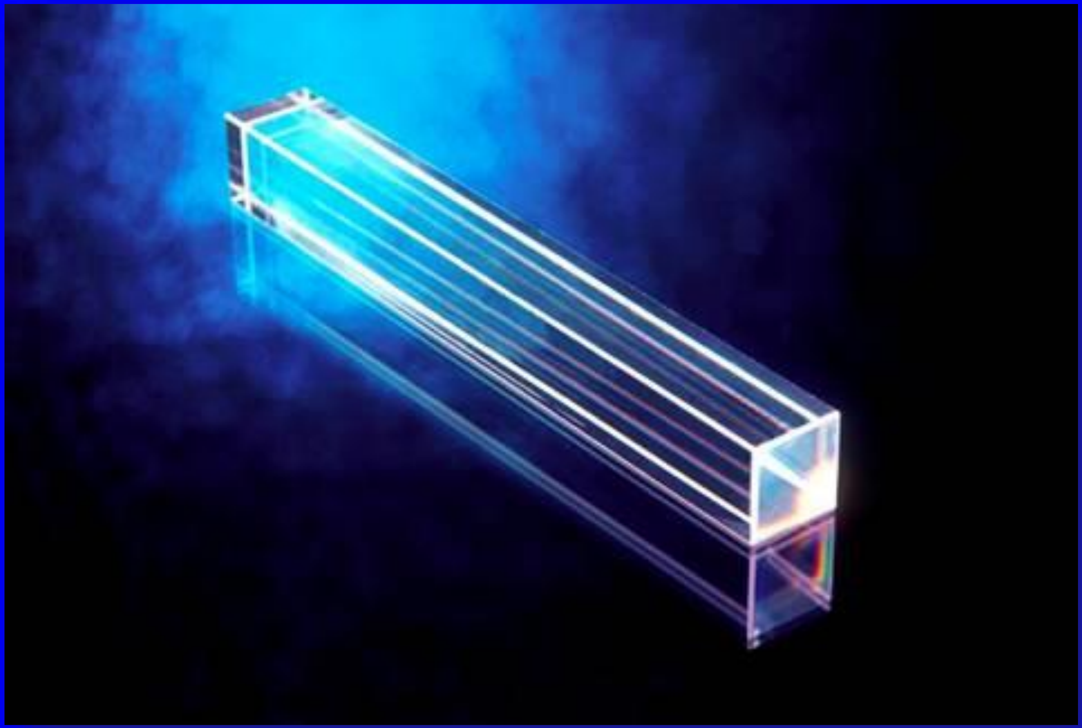
Time and trajectory length (known from tracking detectors) give the particle velocity

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

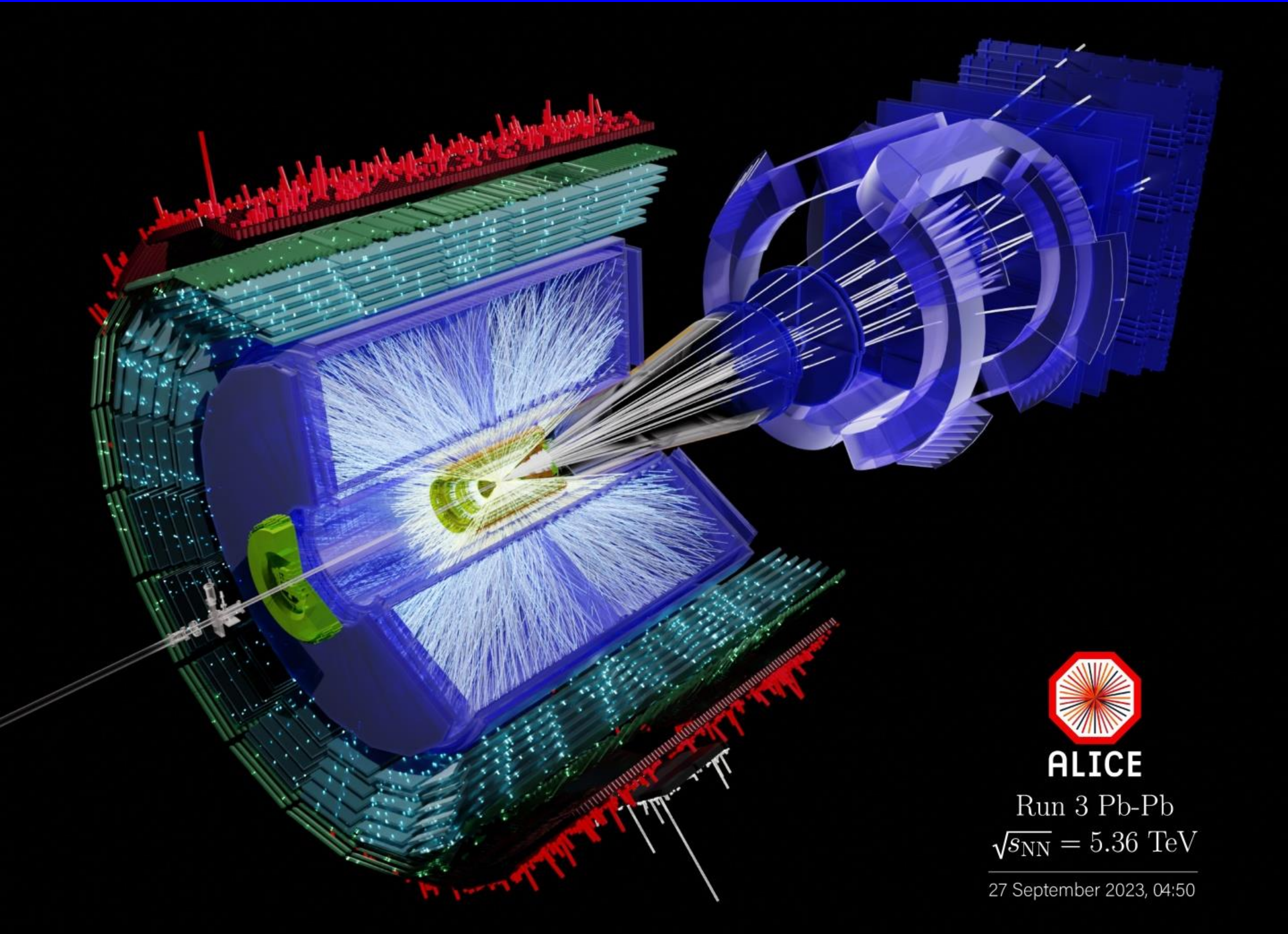
$PbWO_4$ : heavy and transparent



Electromagnetic calorimeter

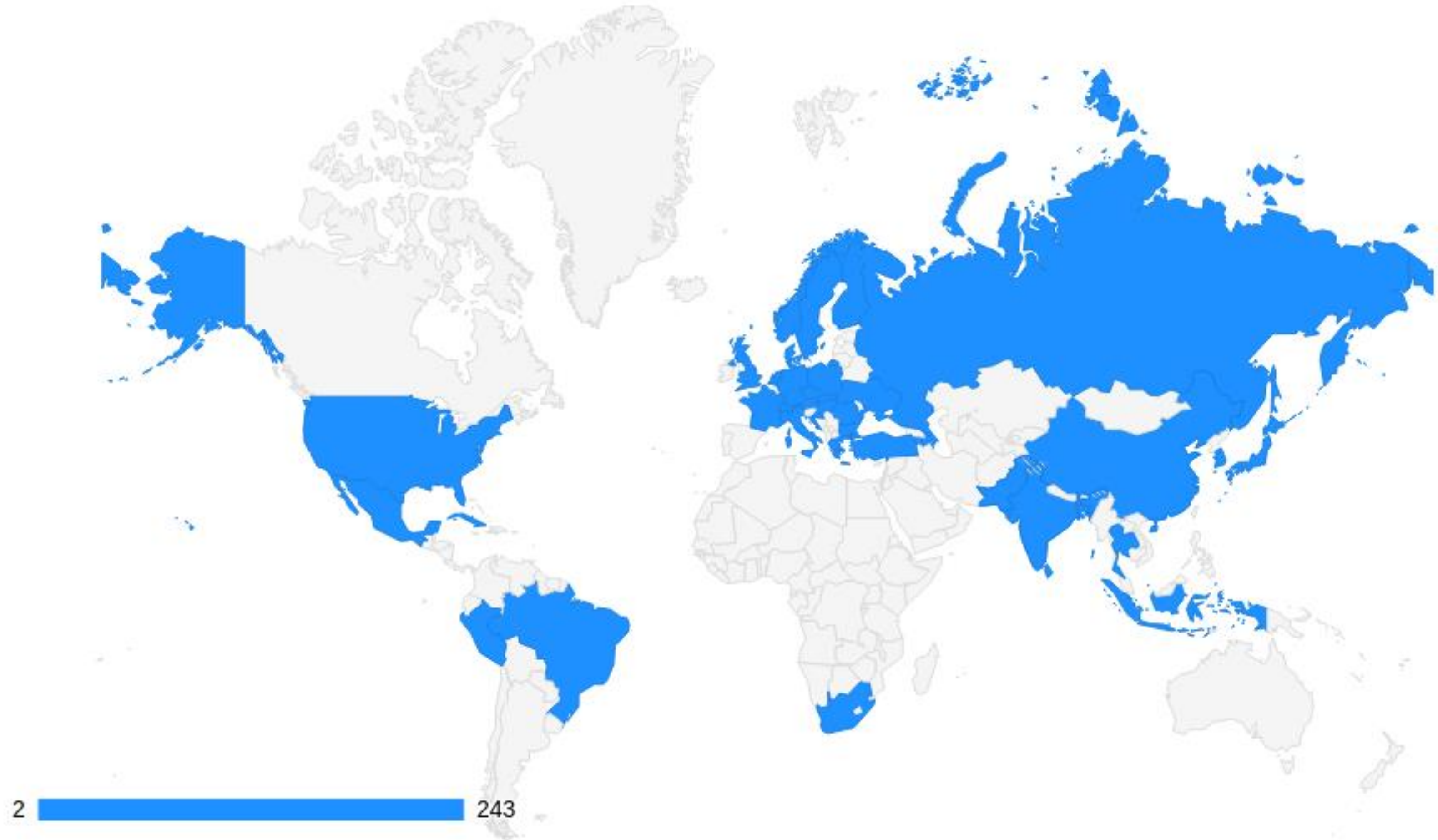
- Photons are converted into electron-positron pairs
- Electrons excite the atoms of the crystal
- Excitation is followed by de-excitation -> emission of light (UV photons)
- UV photons are detected by a photodiode at the end of the crystal, which converts phtons to electrons

→ Electric signal


ALICE
Run 3 Pb-Pb
$\sqrt{s_{NN}} = 5.36$ TeV
27 September 2023, 04:50

# ALICE Collaboration

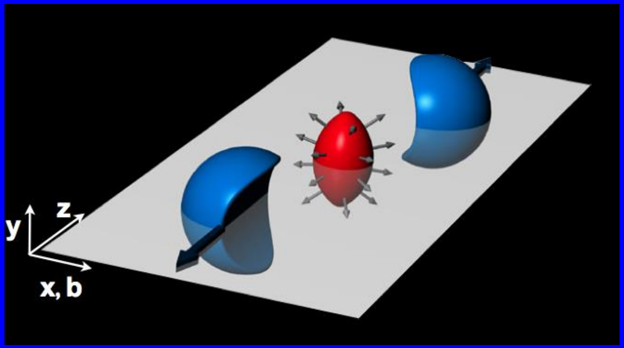
39 countries 163 institutes 1860 members



# Some results

# 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 then 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

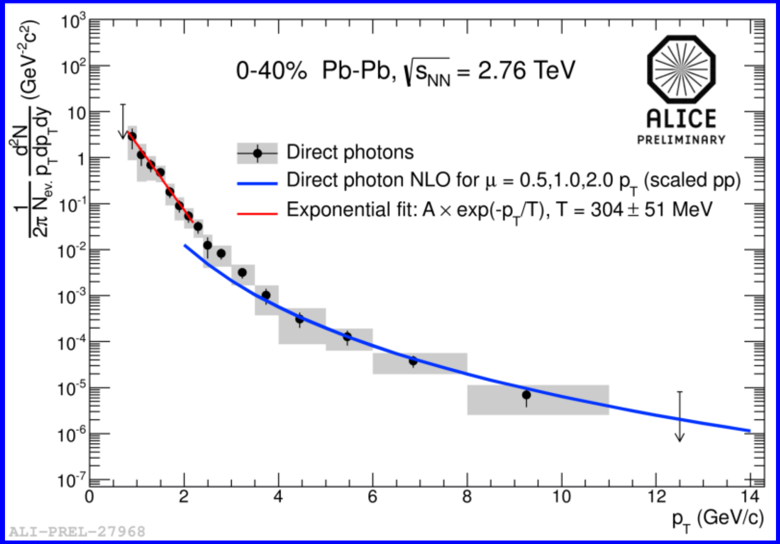
# Highest man-made temperature

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



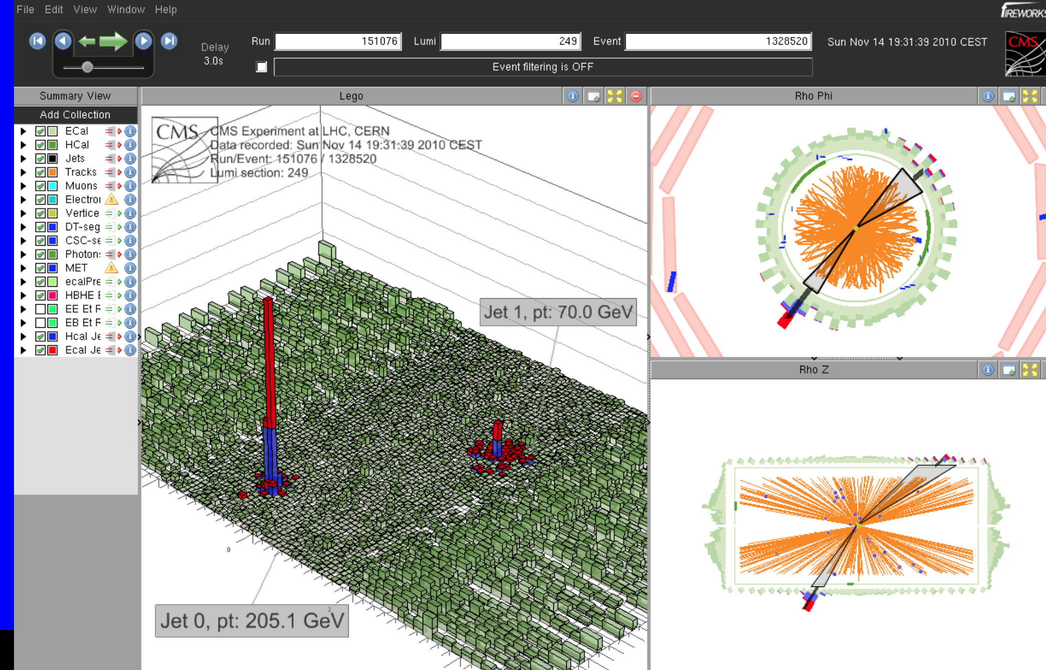


Before heavy ion collisions at LHC

# Energy loss

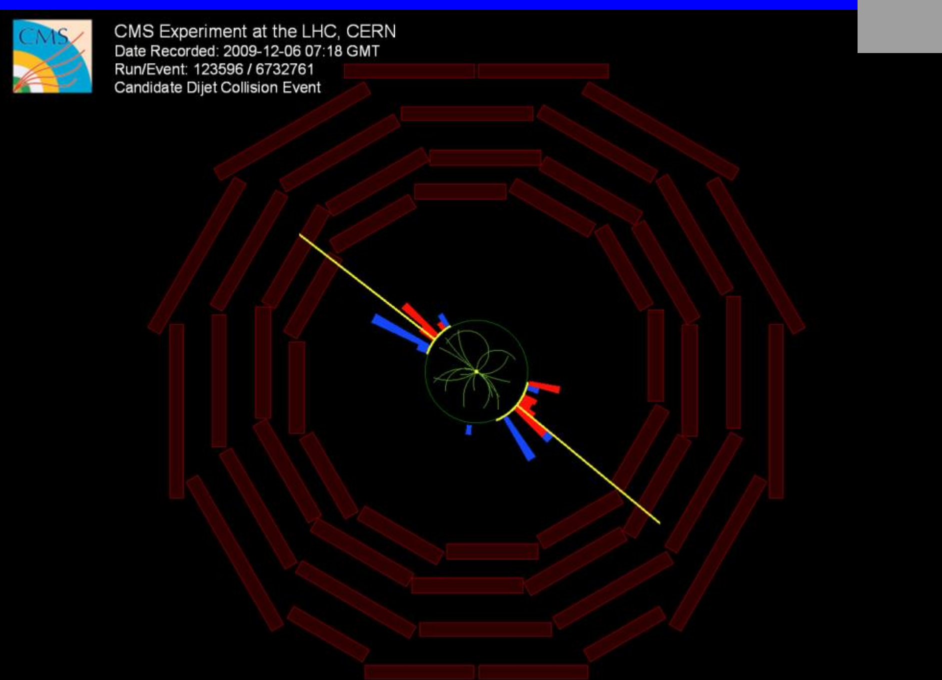
One of the first announcements from the first lead ion run at LHC, December 2010)

Jets going in opposite directions have ~ equal energies



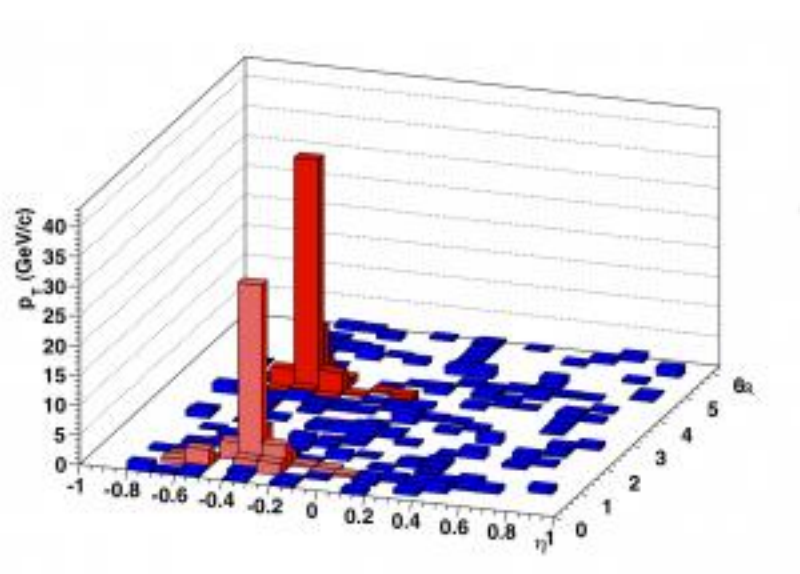

Lead ion collision event

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



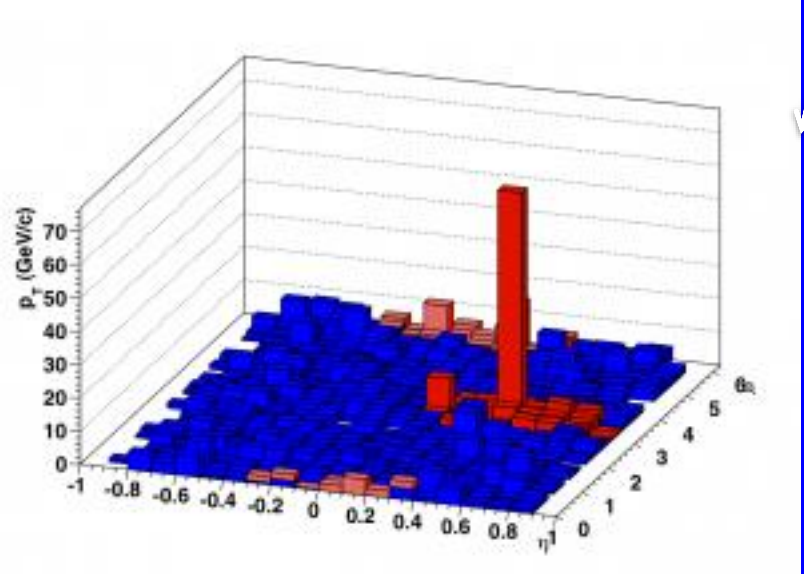

Proton collision event – two jets with energy of ~20 GeV

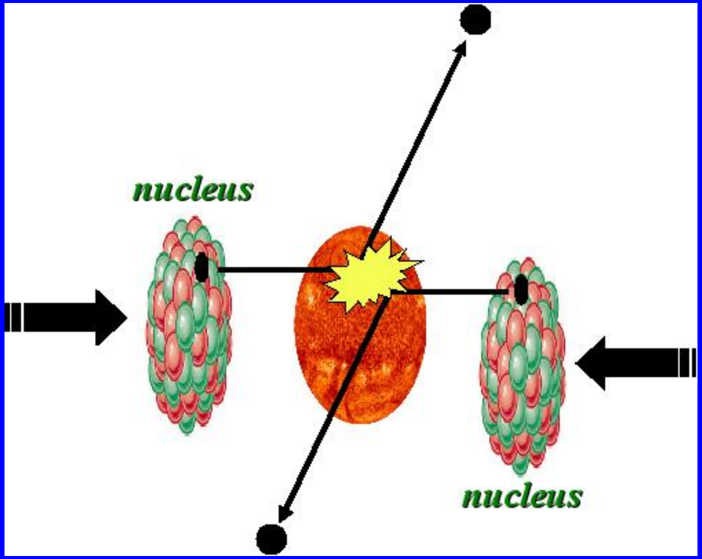
# Jet Quenching




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 J/Ψ mystery

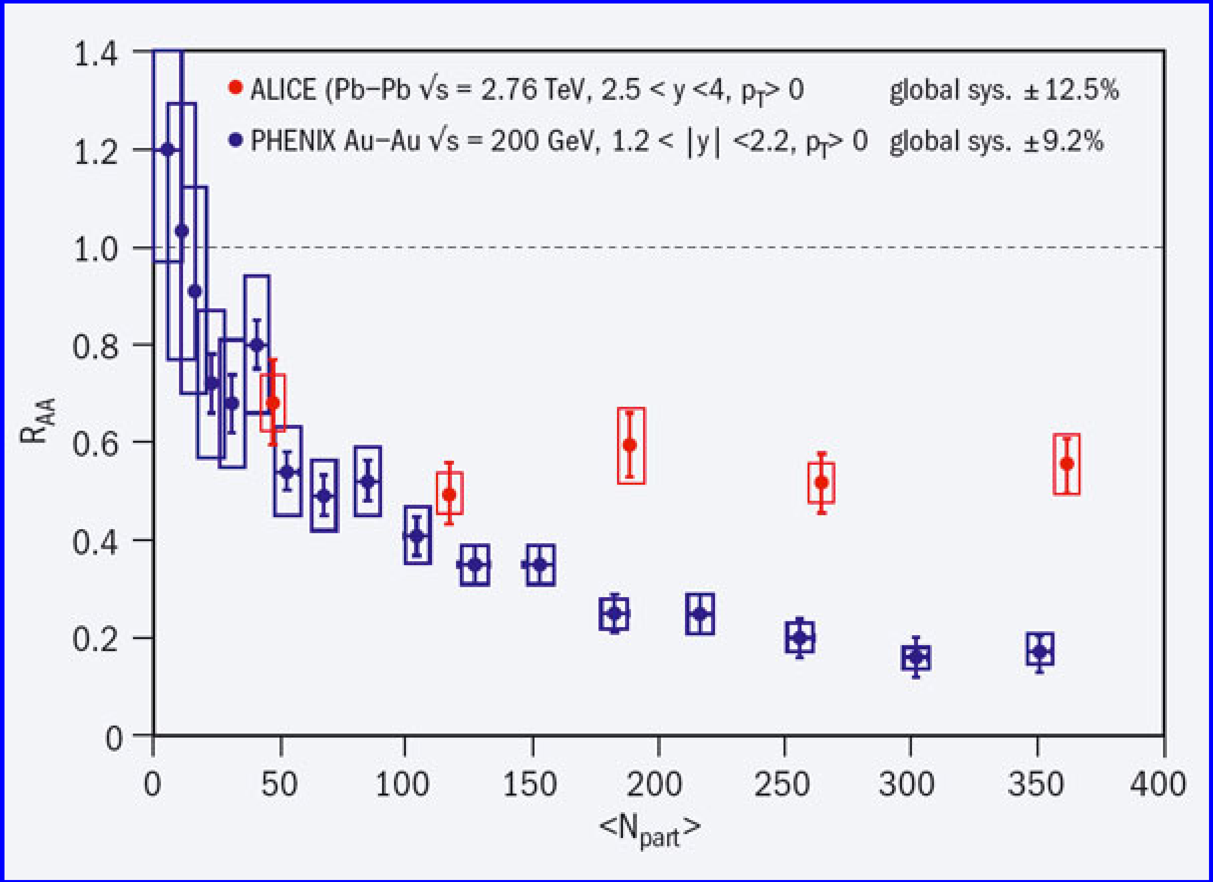
- J/Ψ Discovered in 1974, almost simultaneously, at Brookhaven (proton-nuclei collisions) and at SLAC (collisions $e^+e^-$)
- Bound state of a c quark and a c anti-quark (mass 3 GeV)
- The two “object” that make the J/Ψ are bound due to strong interaction

- 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

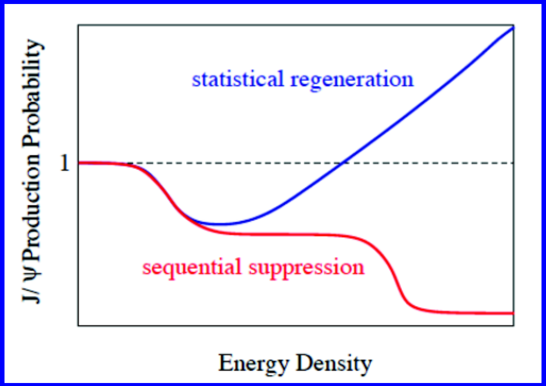
# The J/Ψ mystery




- 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

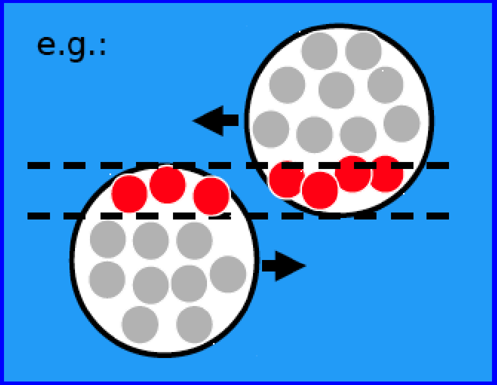
Nuclear modification factor $R_{AA}$

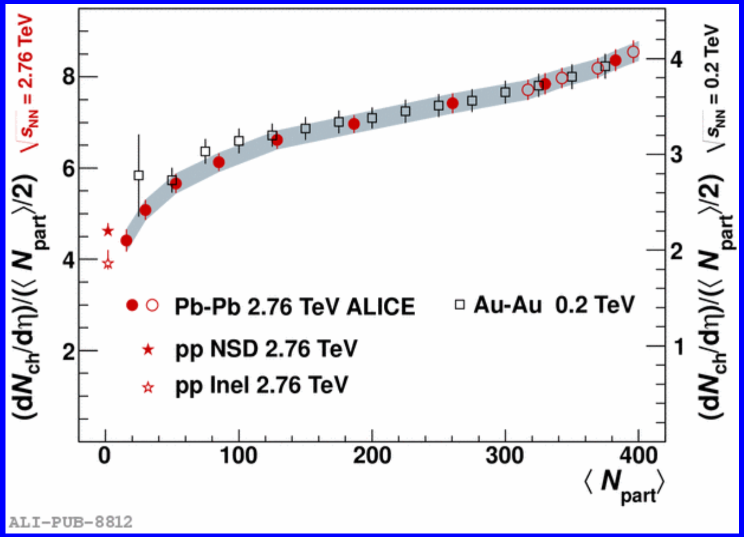
$$R_{AA} = \frac{\text{number of J/Ψ observed in lead ion collisions}}{\text{number of J/Ψ observed in proton collisions}}$$

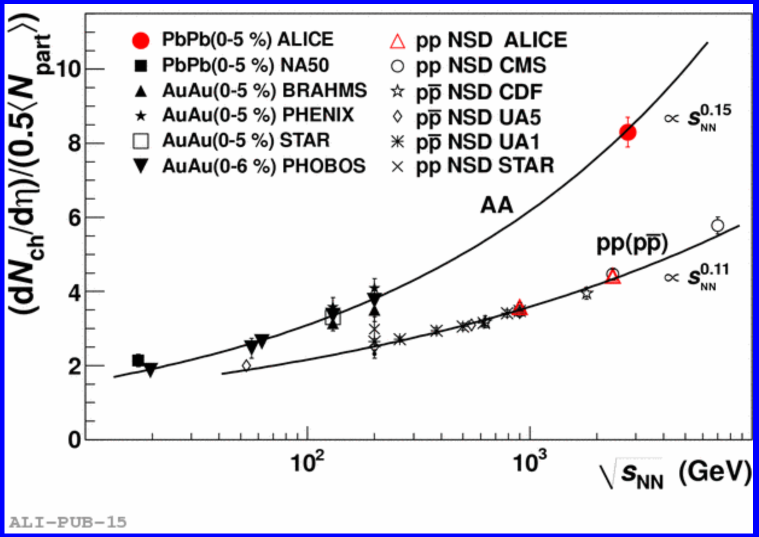


When lead nuclei collide all nucleons (protons and neutrons) can take part in the collision (central) or only some (peripheral)

$N_{part}$: 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.