ALICE : A Large Ion Collider Experiment

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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 $\rightarrow$ Pb$^{27+}$ $\rightarrow$ Pb$^{54+}$ $\rightarrow$ 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

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Tbilisi 22.10.2018 Masterclasses at GTU
Why are lead ion collisions at high energies of particular interest?
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.

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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/c²
up quark mass : 1.7 – 3.3 MeV/c²
down quark mass : 4.1 – 5.8 MeV/c²
Sum : 7.5 – 12.4 MeV/c²
ALICE studies strong interactions..

Why are quarks permanently confined inside hadrons?
ALICE : A Large Ion Collider Experiment

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

Identifies the charge

\[ p = \text{momentum} \]
\[ R = \text{radius of curvature} \]
\[ B = \text{magnetic field} \]
\[ q = \text{charge} \]

\[ R = \frac{p}{qB} \]
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
- $\mu$ tracking chambers
- Filter
- Trigger

Photon detectors
ITS: Inner Tracking System

6 layers of silicon detectors

- Silicon pixels
- Silicon drift detectors
- Silicon strips

> 10 million channels
Time Projection Chamber (TPC)

- **GAS VOLUME**: 88 m³
- **DRIFT GAS**: 90% Ne - 10% CO₂
- **End plate**
- **Central electrode**
- **Readout plane segmentation**: 18 trapezoidal sectors each covering 20 degrees in azimuth
- **Drift volume**
- **Co₂ insulation**
- **Drift volume**: 88 m³
- **Electric field**: 400 V/cm
- **5 m**
- **510 cm**
- **88 m³**

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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

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.

Multigap Resistive Plate Chamber
PHOS : PHOton Spectrometer

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 (∼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.
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 seen?
Few examples..
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
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 $\sim$ 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.
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 $J/\Psi$ mystery

- Regeneration of $J/\Psi$ at very central collisions
- Two competing phenomena
- Suppression of $J/\Psi$ due to interaction with the quark gluon plasma
- Creation of many $J/\Psi$ due to the high number of $c-\bar{c}$ pairs created from the huge collision energy

Nuclear modification factor $R_{AA}$

\[
\frac{\text{number of } J/\Psi \text{ observed in lead ion collisions}}{\text{number of } J/\Psi \text{ observed in proton collisions}}
\]
The Collaboration

41 countries, 178 Institutes, 1800 members
Thanks for your attention