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Quark Gluon Plasma in ALICE

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Fysikaalisten tieteiden laitos

Tentative outline

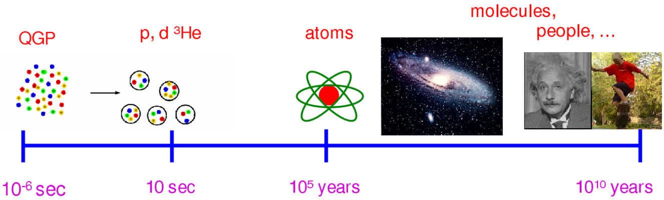
1. Quark Gluon Plasma: what is it?
2. Brief overview of the ALICE
3. 1 + 2, i.e. QGP at the ALICE

Quark Gluon Plasma?

- ”Normal” Plasma: Gas under such conditions that electrons break free from atoms (or molecules).
- Analogously Quark Gluon Plasma (QGP): State of strongly interacting matter where quarks and gluons are not confined to color neutral entitites.
- Asymptotic freedom: High energy $\rightarrow$ Interactions become weak
- High density:Hadrons ”overlap” $\rightarrow$ No more confinement

What's the point of all this?

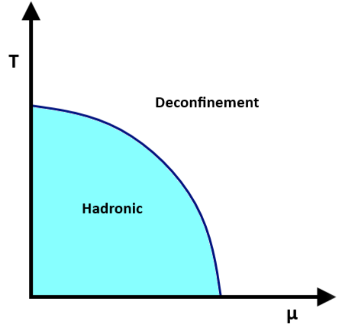
- Part of the standard model predictions
- Early universe conditions: High density, high temperature
- QGP existed at the early universe before the phase transition to hadronic matter



Thermodynamics I

- ”Standard” statistical mechanics approach
- T = temperature
- μ = Baryon chemical potential = baryon density

Quark Gluon Phase Diagram

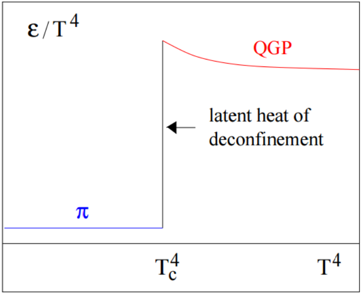


- Aside: High pressure, low temperature: Color superconductor

Thermodynamics II

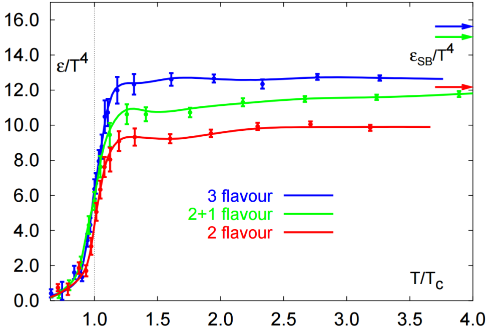
- Simplest model, ideal gas of pions
- $P_\pi \approx T^4/3$
- $P_{QGP} \approx 4T^4 - B$, B = pressure exerted by physical vacuum.
- System goes to lowest free energy state, Phase transition at $T_c \approx 150$ MeV, where $P_\pi = P_{QGP}$

Phase transition



More realistic models

- Based on lattice qcd, much more technical
- Large jump in energy density: latent heat of deconfinement
- Calculations indicate $T_c \approx 160$ - 180 MeV



How to detect?

- It is not possible to see ”inside” the collision, only the final state is measured
- Some possibilities:
  - EM radiation
  - quarkonium spectra
  - jet quenching

EM radiation

- Interactions within QGP produce real and virtual photons
- Photons can leave the plasma without further strong interactions
- In theory, a good probe
- Photons can be formed in all stages of the evolution $\rightarrow$ Need to find a way to identify thermal EM radiation from "background"

Quarkonium spectra

- Quarkonia: bound states of heavy quar-antiquark pairs.
- The relative multiplicites of produced particles depend on the temperature of the QGP
- These particels can survive in QGP above the deconfinement temperature
- "Melting temperature" different for different quarkonia
- $\rightarrow$ a very natural probe for measuring if the system is above or below certain temperature

Quarkonium spectra II

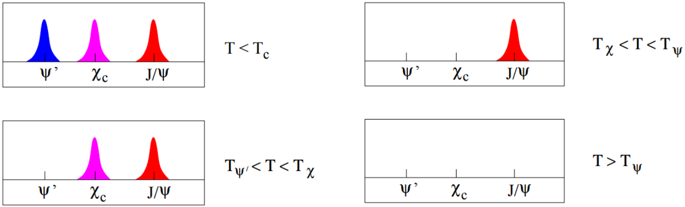


Figure: The multiplicities of emitted quarkonia depend on the temperature of the system

Jet Quenching

- Jets colored, interact much more strongly with QGP than color-neutral hadronic matter
- $\rightarrow$High p_T partons lose energy, energy loss higher in QGP than hadronic matter
- End result: If QGP is formed in the collision, we should observe lower number of jets and/or lower energy jets.

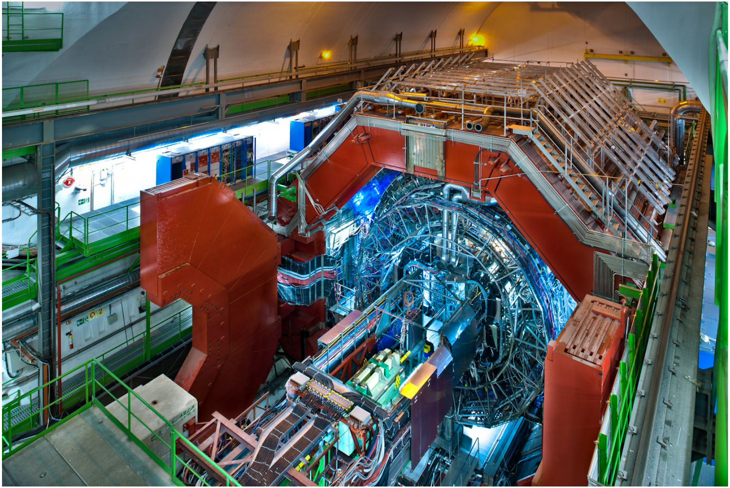


Figure: **A L**arge **I**on **C**ollider **E**xperiment

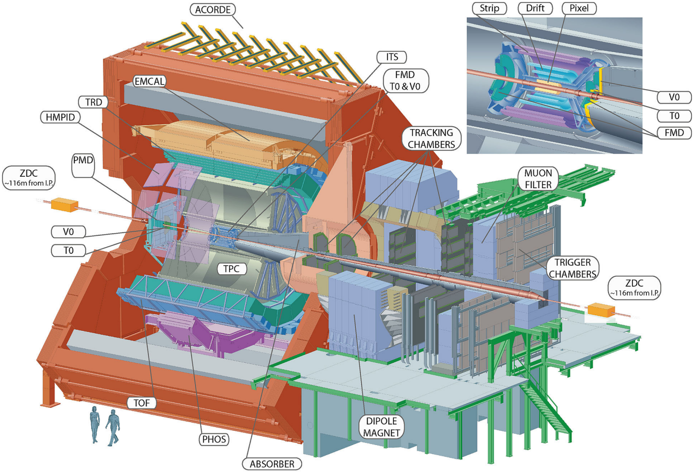


Figure: The detector setup of ALICE

Overview

- Primary design focus: heavy ion collisions
- Need to cope with high particle densities, $\frac{dN}{d\eta} \approx 8000$
- Low material budget in central region
  - Particle traverses 11-13% of radiation length before leaving Time projection chamber
  - cf. $\sim$40% in CMS and ATLAS
- Relatively low magnetic field 0.5 T (cf. ATLAS 2T, CMS 3.8T). This allows tracking of lower p_T
- pp programme also possible.
- central energy for Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

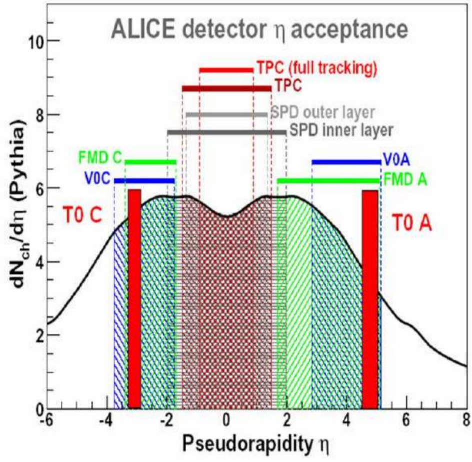
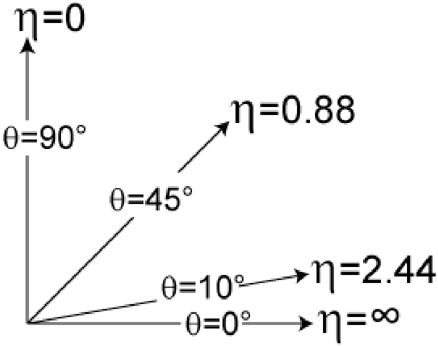


Figure: Pseudorapidity ranges of individual detectors[1]

[1] figure from Central Diffraction in ALICE, R. Schicker, 14th Workshop on Elastic and Diffractive Scattering, 2011

A quick reminder about pseudorapidity



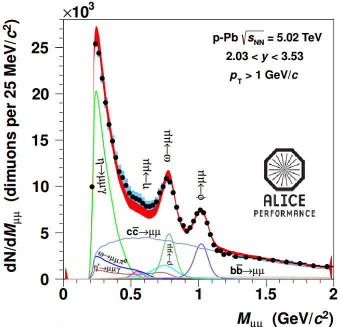
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

Central Detectors

- pseudorapidity range $-1.4 < \eta < 1.4$
- Inner tracking system (ITS): Combination of silicon detector technologies: pixel, drift and strip (SPD, SDD, SSD)
- Time projection chamber: main tracking and particle indentification device
- Time of flight detector: Multi-gap resistive plate chambers, resoltion $\sim$120 ps.

Muon Arm

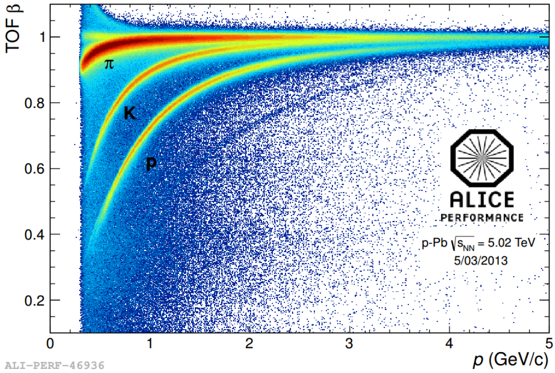
- Detect muons in rapidity range $-4.0 < \eta < -2.5$ and full azimuthal range
- Measure the complete spectrum of heavy-quark vector meson resonances and ϕ meson in $\mu^+\mu^-$ decay channel



Forward detectors

- VZERO (or V0): Asymmetrically placed scintillators to utilize arrival time of particles
- Forward multiplicity detector (FMD): Si-strip detector, measurement of forward multiplicity density, centrality information
- Zero degree calorimeter (ZDC): 115m away from the interaction point, along the beamline. Detect the energy of the spectator nucleons

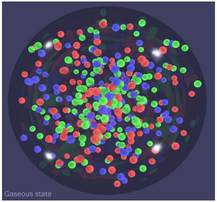
PID

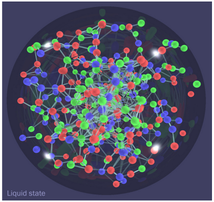


- Using basically all available techniques

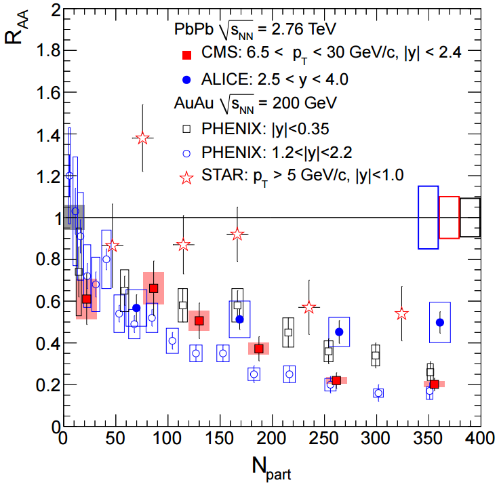
Before ALICE

- CERN SPS: Circumstantial evidence for QGP
- RHIC: Au-Au collisions: QGP behaves as perfect fluid
  - Movement of particles is correlated





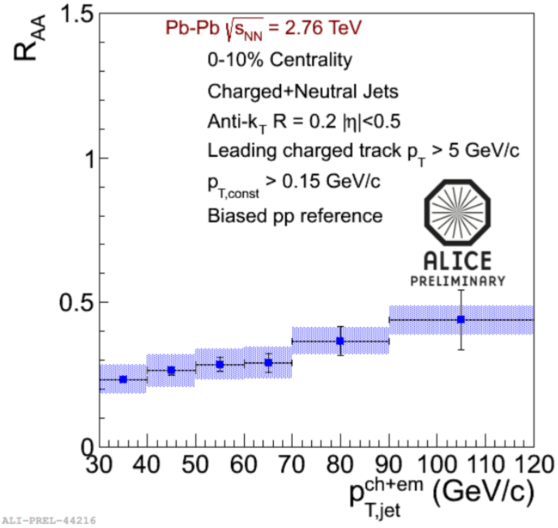
Results from ALICE I



Results from ALICE II

- Fist year perfomance: Heavy ion collision properties qualitatively similar to those of RHIC
- Nearly perfect, QGP-liquid formed
- Evidence: e.g. J/ψ production clearly suppressed with increasing centrality (see previous page)

Jet Quenching in ALICE



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