Quarkonia production in ultra-relativistic heavy-ion collisions with the ALICE experiment

Journées de Rencontre des Jeunes Chercheurs 2011

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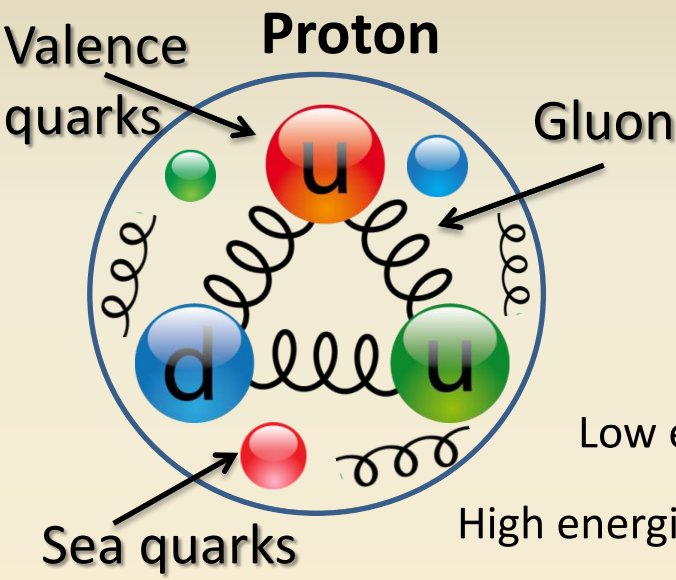
Plan

- Motivations.
- The LHC and the Pb-Pb collisions.
- The ALICE experiment & the Muon Spectrometer.
- The 2010 analysis: details on the tracking efficiency.
- 2010 results.
- Conclusions and outlook for 2011.

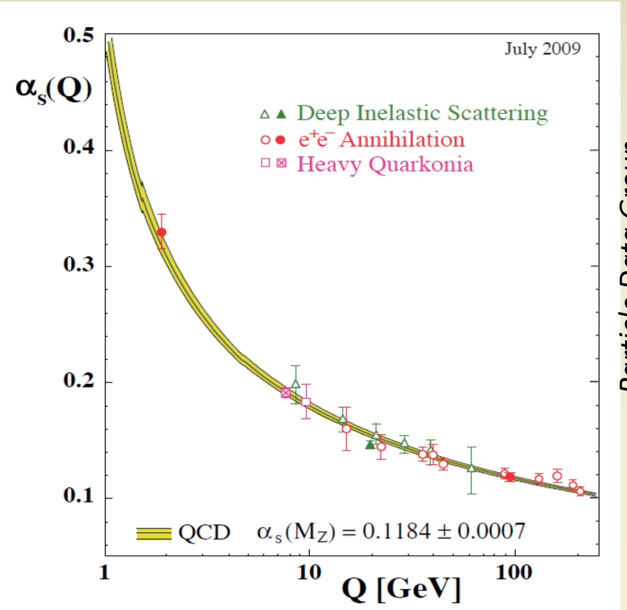
From the nucleon to the Quark Gluon Plasma (QGP)



Interaction between quarks and gluons is characterised by the *running coupling constant* α_s.

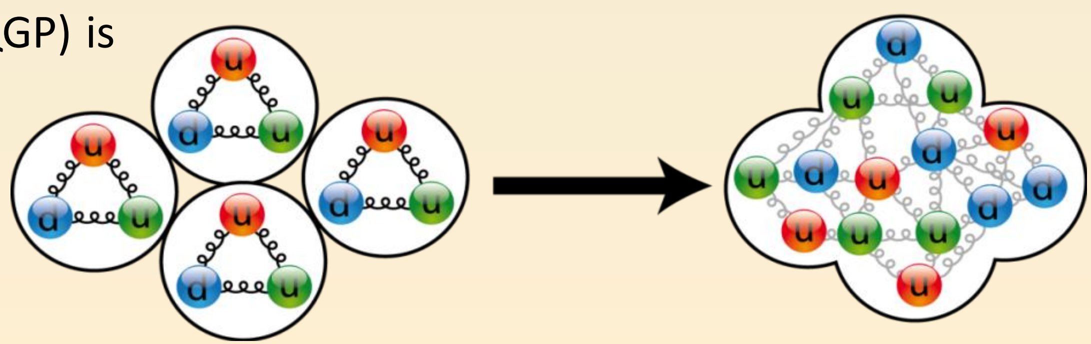
Low energies → confinement

High energies → Asymptotic freedom



As a consequence, for high energies and densities a phase transition, at a given critical temperature T_c, from ordinary nuclear matter to a deconfined state (QGP) is expected.

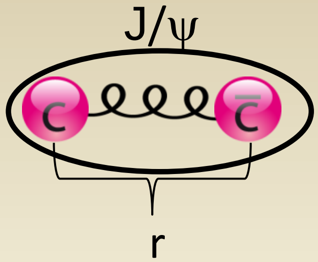
High-energy heavy-ion collisions will allow to achieve the necessary conditions to create the QGP in a laboratory.

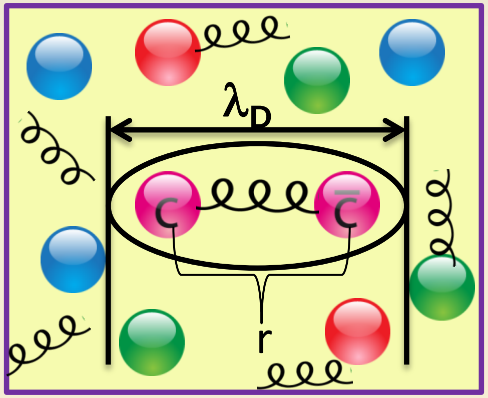


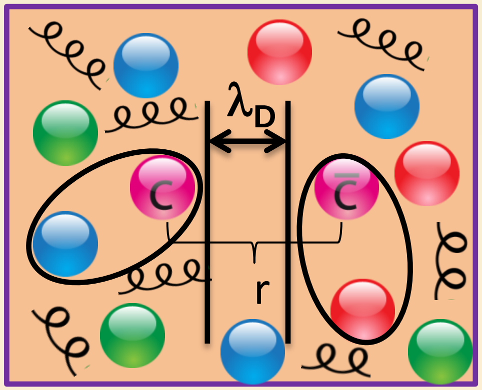
Ordinary nuclear matter

QGP

How can we probe the QGP?







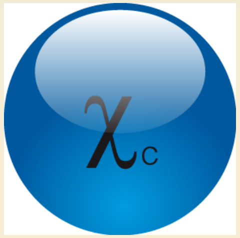
Quarkonia (bound states of $q\bar{q}$) have been proposed as a tool to characterize the QGP [1]:

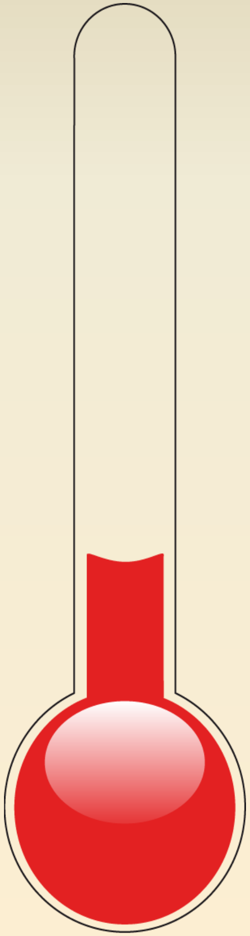
- Created in the first instants of the collision.
- Color screening → Debye radius (λ_D) decreases with temperature.
- Quarkonium production is suppressed.

Suppression depends on the binding energy of quarkonia states:

- Binding energy decreases with charmonium's ($c\bar{c}$) mass.
- Excited states melt down at different temperatures (T_{Melt}).

Quarkonia family can be used as a thermometer for the QGP!





$T_{Melt} < T_c$

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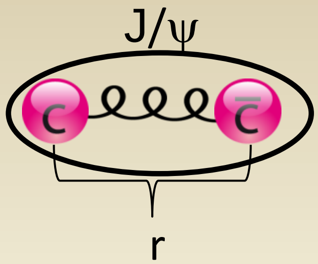

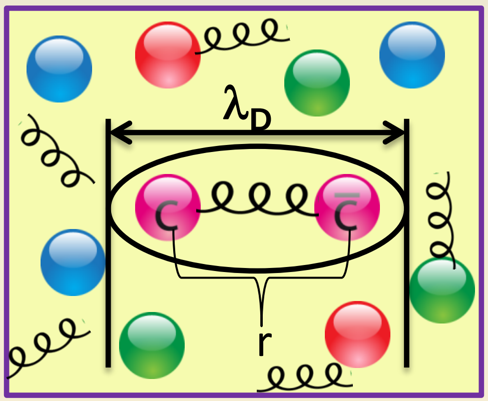

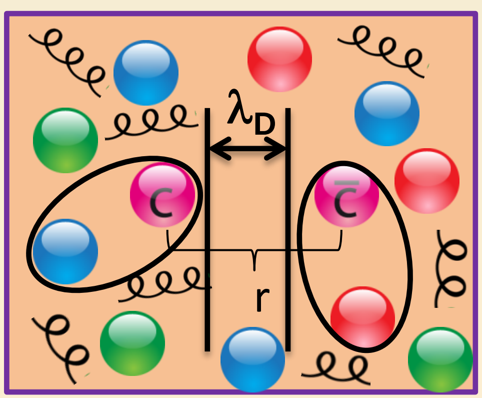

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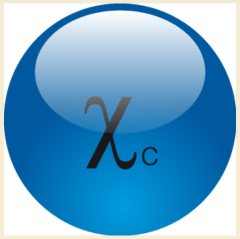

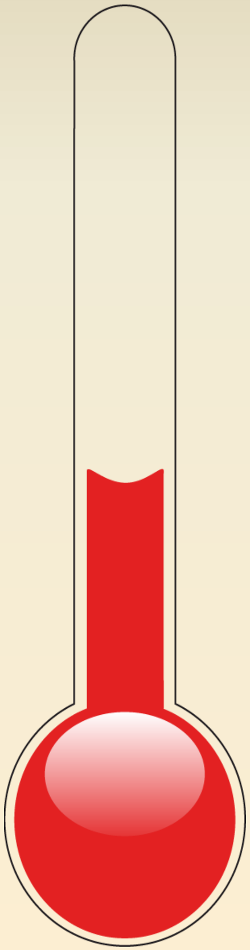

$T_{Melt} \approx T_c$

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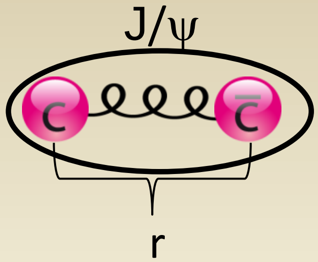

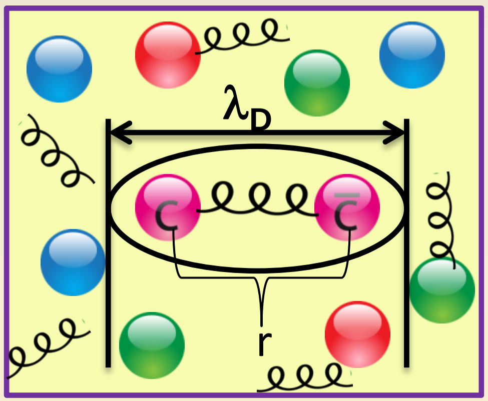

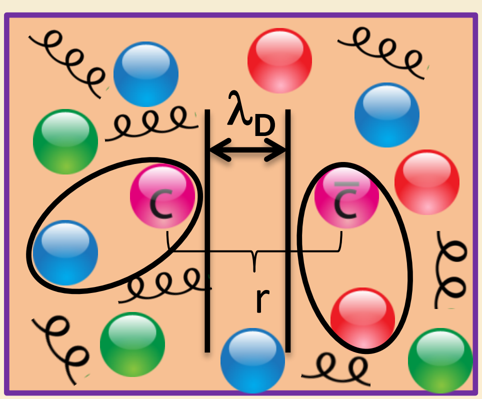

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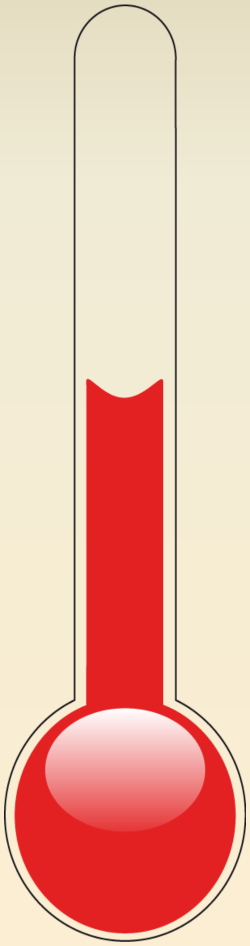

$T_{Melt} \approx 1.1\ T_c$

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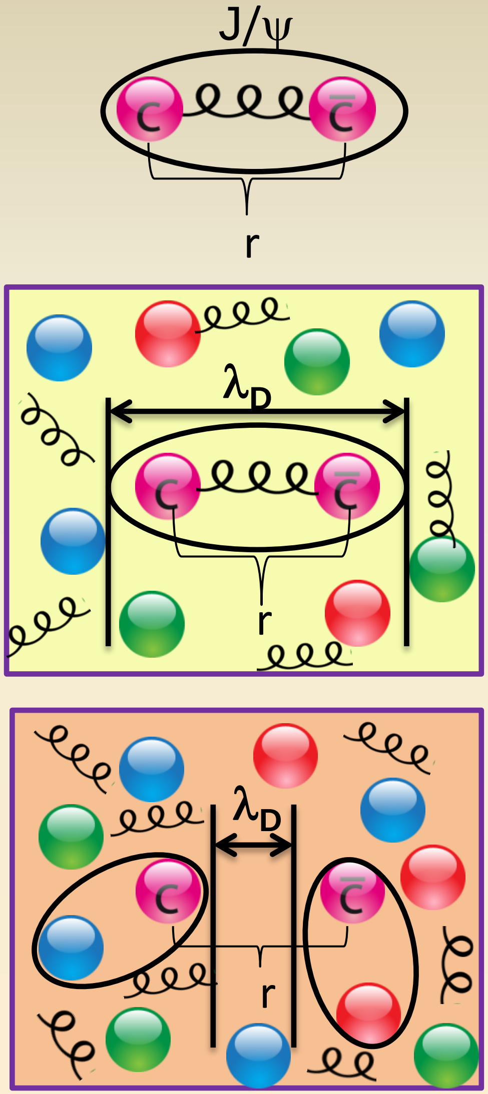

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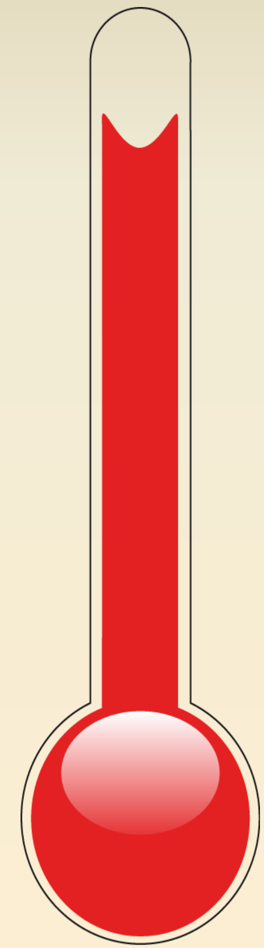


$T_{Melt} \approx 2.1\ T_c$

[1] T. Matsui and H. Satz, J/Ψ Suppression by Quark-Gluon Plasma Formation, Phys. Lett. B178, 416 (1986).

Nucleus-nucleus vs proton-proton collisions

Nucleus-nucleus collisions are compared to proton-proton collisions using the Nuclear Modification Factor:

$$R^{i}_{A+A} = \frac{(d^2N^i/dp_T dy)_{A+A}}{<N^i_{coll}>(d^2N/dp_T dy)_{p+p}}$$

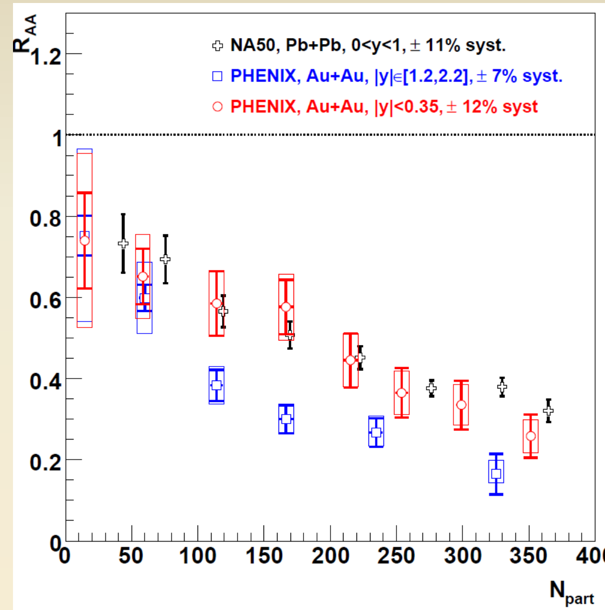
- $R_{A+A} \approx 1$ → No difference between the production in A+A and in p+p collisions.

- $R_{A+A} \neq 1$ → Medium induced effects

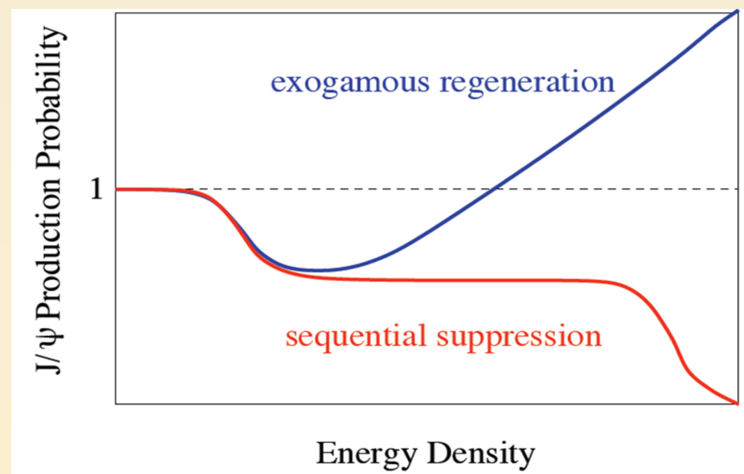
✓ Clear suppression observed in RHIC and SPS.

Collision energy at LHC > RHIC and SPS
 ⇒ larger suppression?

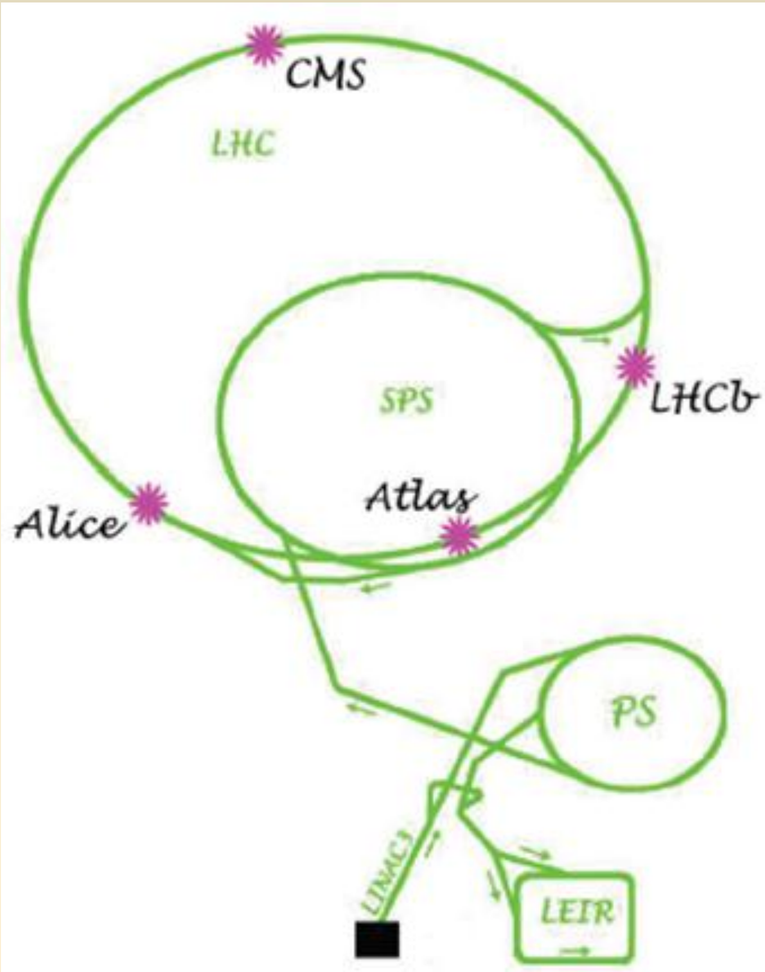
10 times more $c\bar{c}$ pairs produce in the LHC than in RHIC ⇒ regeneration?



Quarkonia Production in Hot and Cold Matters, R. Granier de Cassagnac, J. Phys. G, 2008 35, 104023.



The LHC and the Pb–Pb collisions



Path followed by Pb nucleus

✓ Largest particle accelerator in the world.

✓ Smaller accelerators are used as pre-injectors.

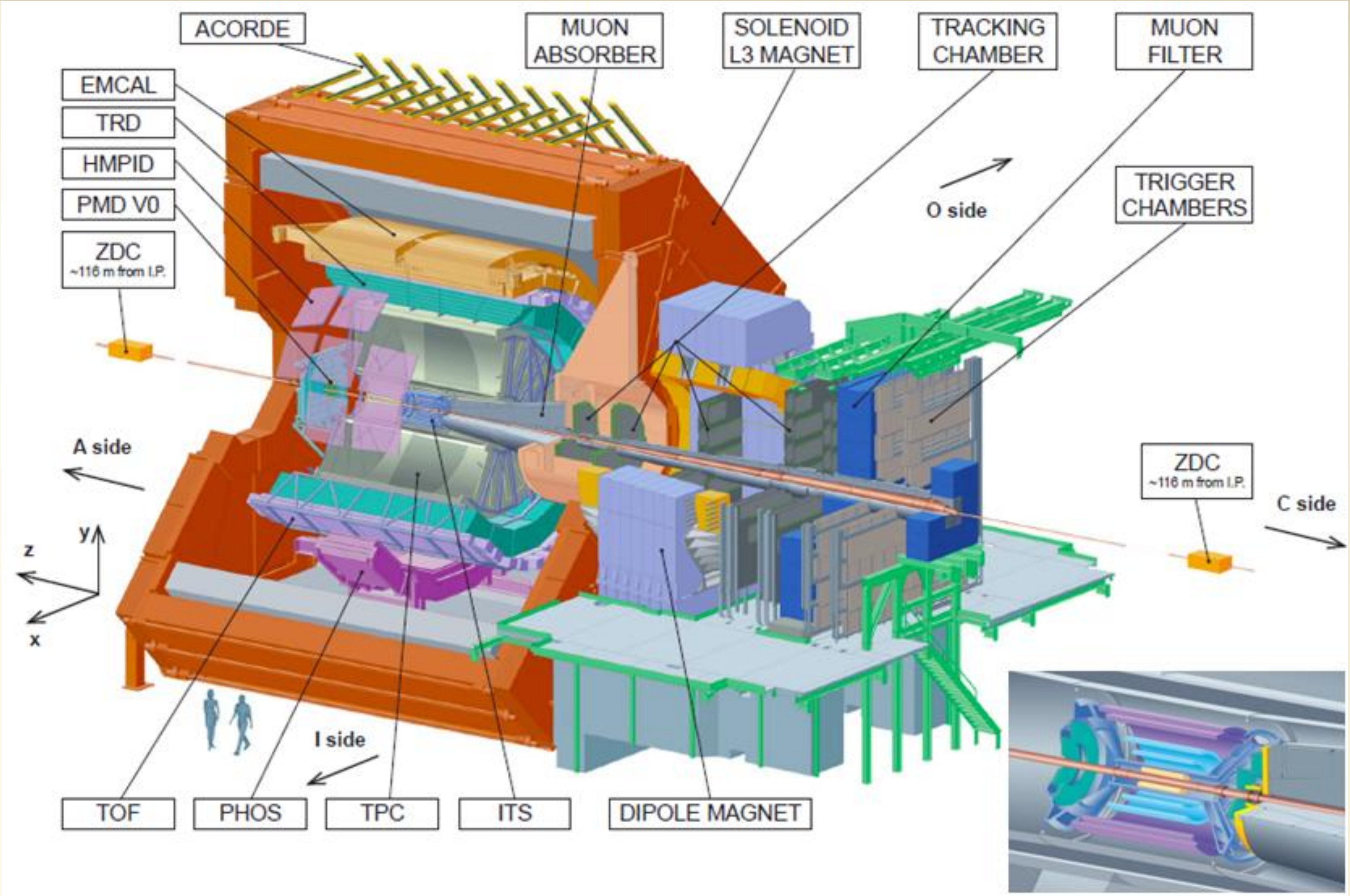
✓ $\sqrt{s_{NN}} =$ 2.76 TeV Pb-Pb collisions (x14 RHIC energy).

✓ Data taking: 8 Nov – 6 Dec 2010.

✓ In particular, for the J/Ψ analysis, approximately 22 million minimum-bias collisions were used

$\boldsymbol{L}_{int} = 2.8\ \mu b^{-1}$

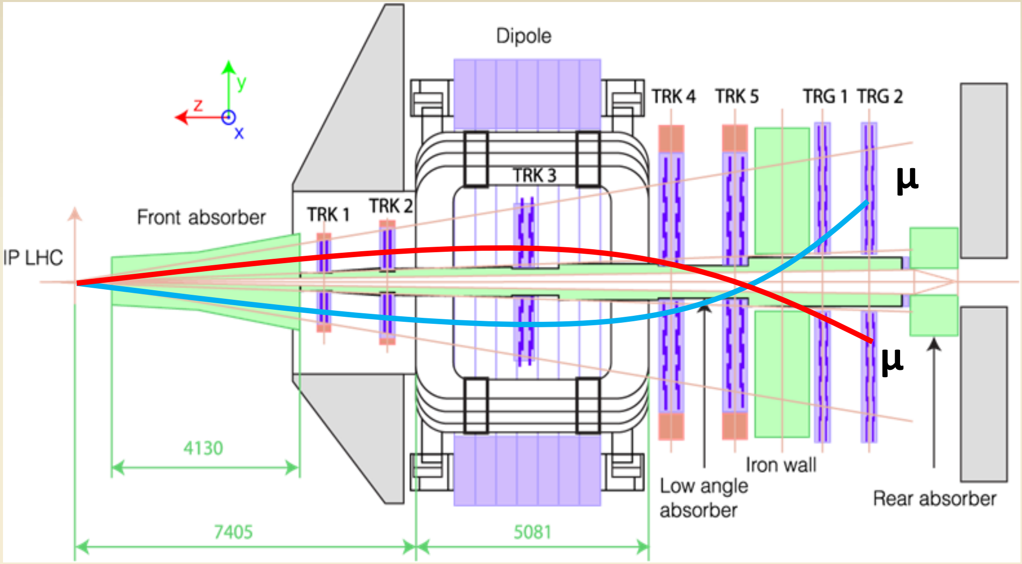
The ALICE experiment



Minimum bias for Pb-Pb collisions: V0A and V0C and SPD
V0 (V0A & V0C) is a multiplicity detector made out of plastic scintillator.
SPD are the two inner most layers of the ITS.

The Muon Spectrometer

Located in the forward rapidity region and with a full azimuthal coverage, it is composed by:



• Absorbers:

a) Front absorber.- Absorbs hadrons, photons and electrons.
b) Beam shield.- Protects from particles produced at large *y*.
c) Iron wall.- Absorbs hadrons that punch-through the frontal absorber.

• Magnetic dipole.- 3 T·m integrated magnetic field, bends charged particles allowing to extract the sign of their electric charge and momentum.

• Tracking chambers.- Spatial resolution, in bending coordinate, better than 100 μm in order to identify and disentangle the ϒ family (100 MeV resolution).

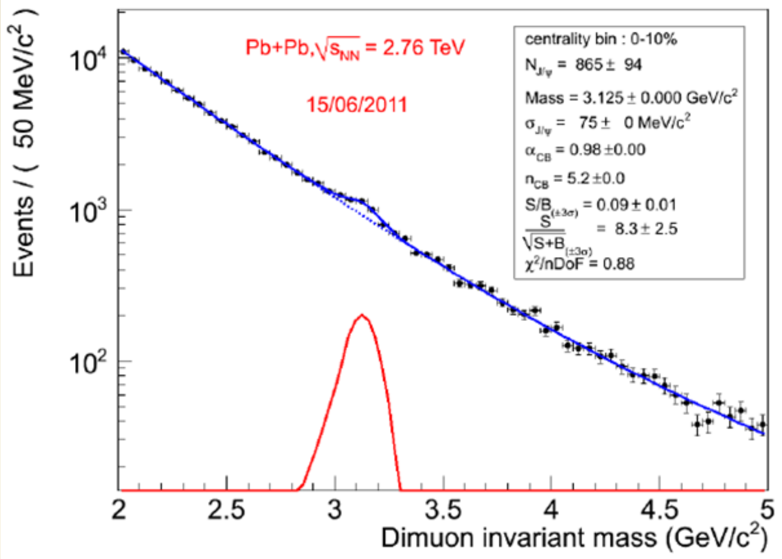
• Trigger chambers.- Timing resolution of 1-2 ns and latency of 700 ns (LØ trigger), can trigger likesign and unlikesign events.

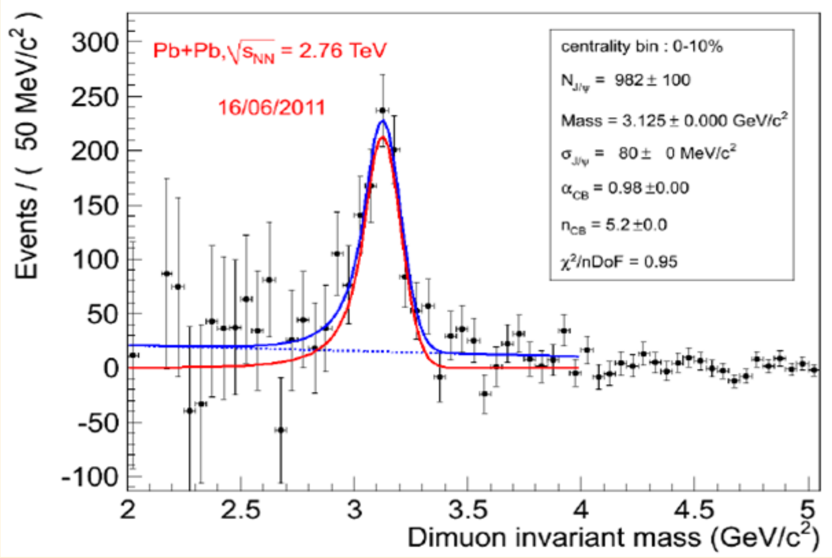
The 2010 analysis

To extract the R_{AA} we need to calculate the yield of J/Ψ in a given centrality range *i*

$$Y^{i}_{J/\psi} = \frac{N^{i}_{J/\psi}}{B.R. \times N^{i}_{MB} \times AccEff}$$

The term in the numerator is the raw number of J/Ψ obtained after fitting the invariant mass distribution. It has also been computed after background substraction (modeled using the event-mixing technique).





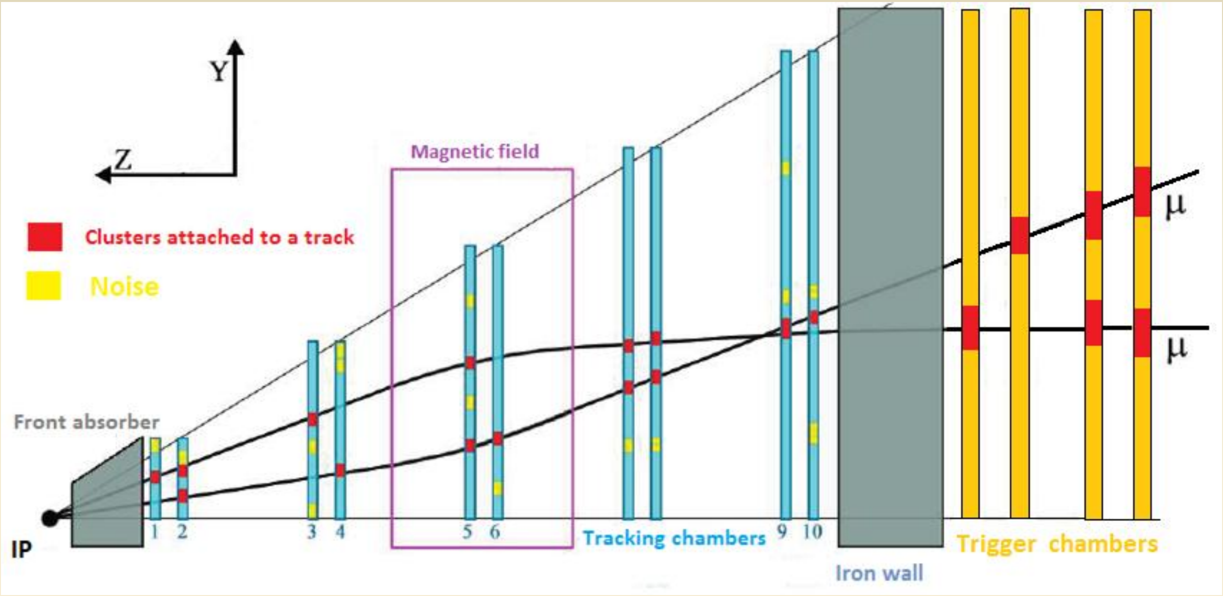
B.R. is the branching ratio decay of a J/Ψ into two muons.

N^{i}_{MB} is the number of mimum-bias events used for the analysis.

Last term in the denominator is the acceptance times efficiency correction.

The following slides will focus on the efficiency calculations of the tracking chambers

The tracking reconstruction method



In order to be reconstructed, a particle crossing the Muon Spectrometer must:

✓ Leave at least one cluster in each one of the first three stations.

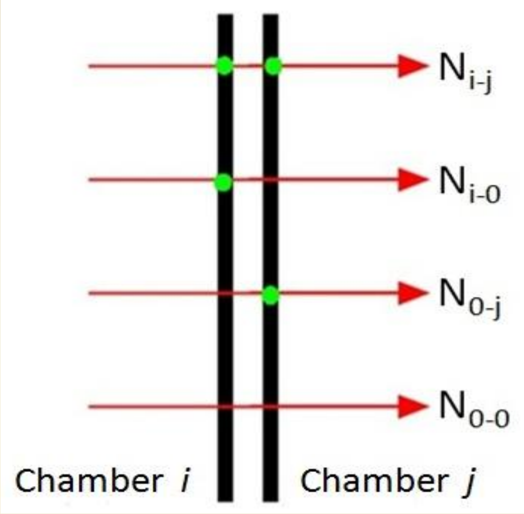
✓ And at least 3 clusters in the last 2 stations.

The general tracking algorithm is the following:

✓ Build primary track candidates using clusters on stations 4&5 making all combinations of clusters between the two chambers and then extrapolating to the other station.
✓ Propagate tracks to stations 3, 2 and 1.
✓ Match tracking tracks with trigger tracks.
✓ Extrapolate reconstructed tracks to the vertex of the collision correcting for energy loss and multiple scattering in the front absorber.

The Tracking Efficiency Algorithm

Due to the redundancy of the detector, a particle crossing a Muon Tracking station can leave:



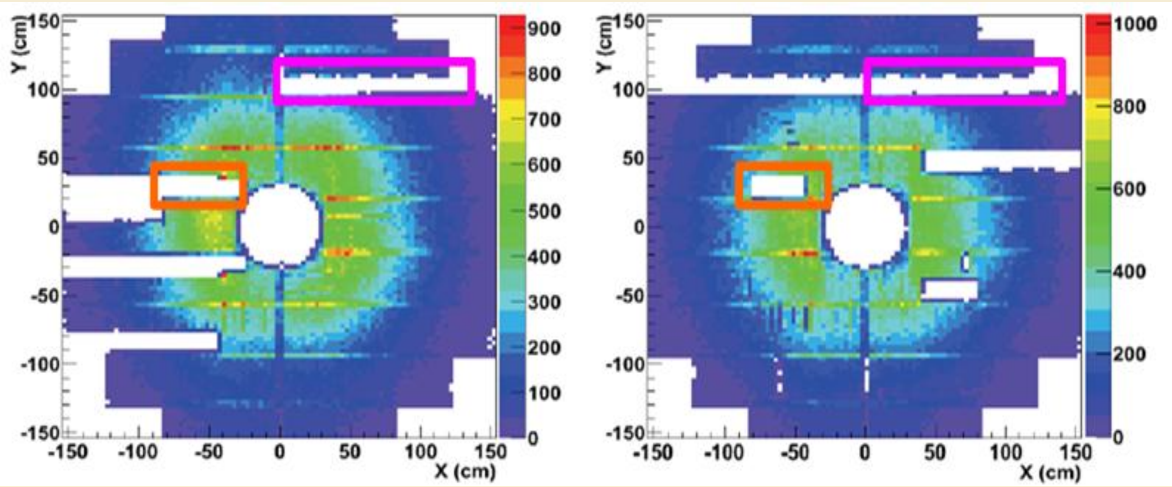
a) A cluster in both chambers (N_{i-j}).
b) A cluster only in chamber *i* (N_{i-0}).
c) A cluster only in chamber *j* (N_{0-j}).
d) Leave no cluster (N_{0-0}).

$N_{Tot} = N_{i-j} + N_{i-0} + N_{0-j} + N_{0-0}$

$\varepsilon_i \varepsilon_j N_{Tot} = N_{i-j}$

Uncorrelated efficiency

$$\varepsilon_j = \frac{N_{i-j}}{N_{i-j} + N_{i-0}}$$



Chamber occupancy (Station 3) during 2010 Pb-Pb runs

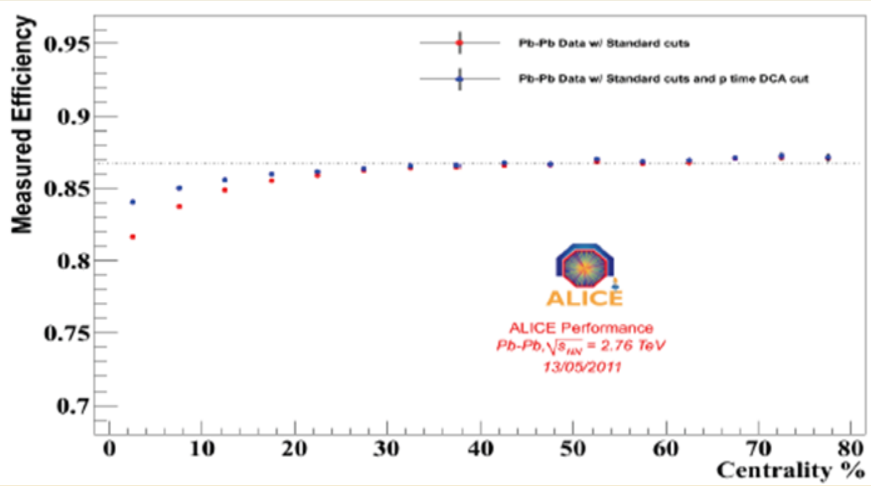
Parts of the detector are removed when not fulfilling the quality requirements (voltage trip, high occupancy, missing pedestal, etc).

Approximately 12 % of the electronic channels were discarded during Pb-Pb runs.

Correlated Dead Areas: $N_{0-0} \neq 0$

$\Rightarrow \varepsilon_j$ overestimated.

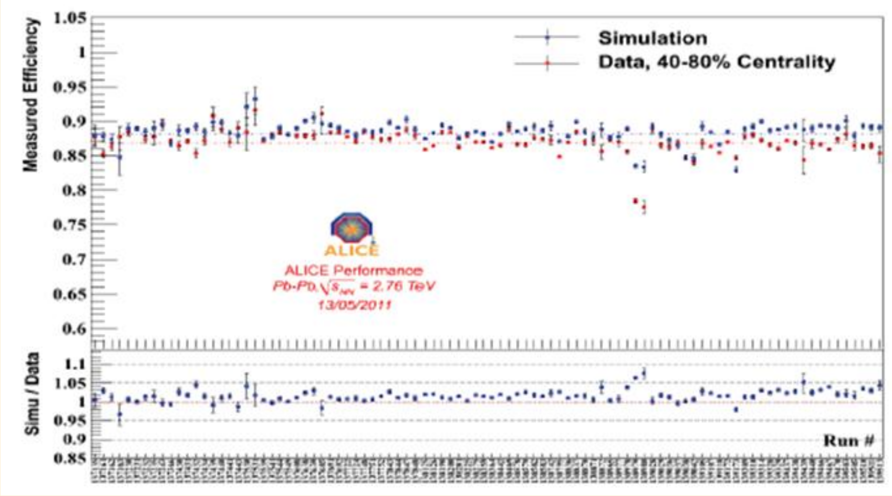
Uncorrelated efficiency



In heavy-ion physics it is important to measure the efficiency of the detector as a function of the event centrality.

Decrease by 3% in efficiency for most central events relative to events with centrality of 40-80%.

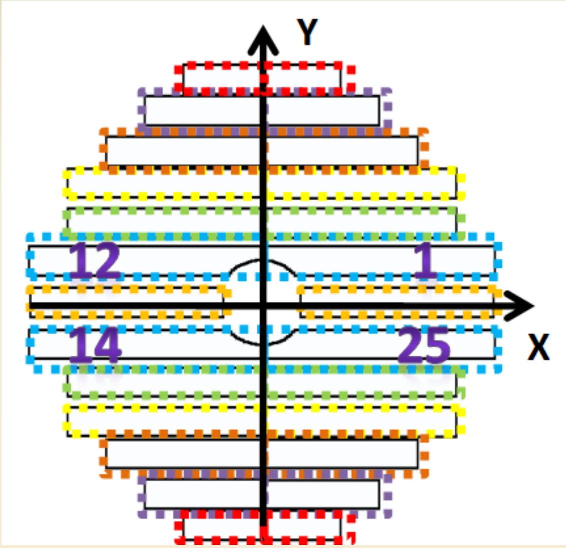
The systematic uncertainties on the uncorrelated efficiency is computed by comparing the efficiency from real data to the efficiency from a pure J/Ψ simulation: the tracking efficiency is quite stable in both cases.



The value of the uncorrelated systematics is estimated as 1.5 %

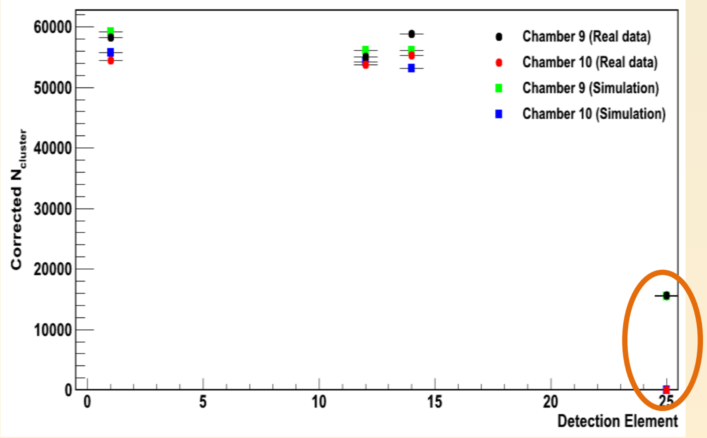
In search of Correlated Dead Areas (CDA)

- X-Y symmetry of the Detection Elements (DE) in each chamber.
- Each symmetric group of DEs should, approximately, detect the same number of tracks after uncorrelated efficiency correction.
- Lower number of tracks detected by a DE is the signal of a CDA.

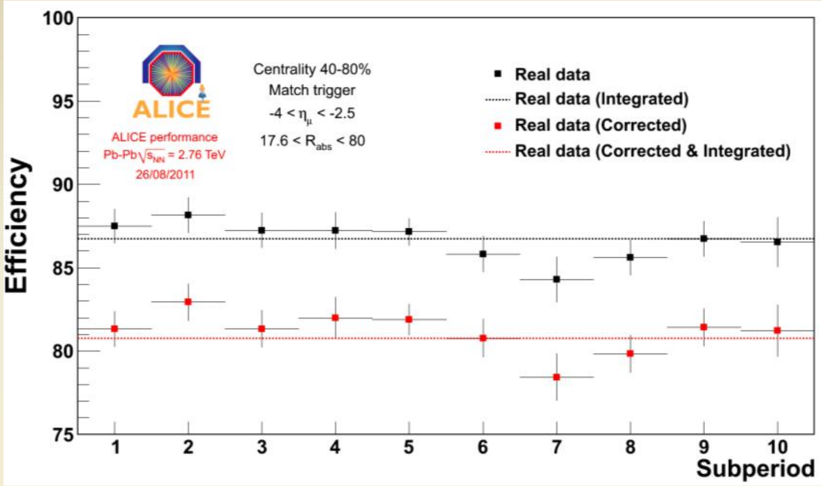


Systematic uncertainties are assessed by comparing the difference between real data and simulation.

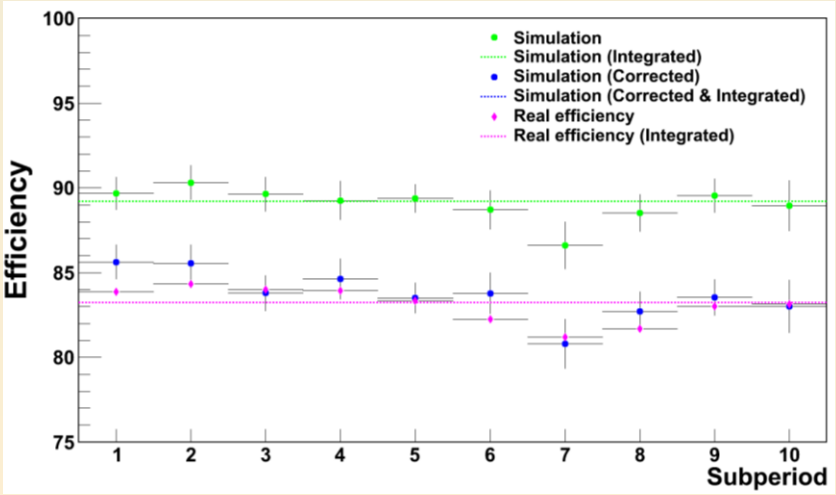
As the method to spot CDAs relies on the cluster occupancy distribution of the chambers, the MC generator was tuned to reproduce this distribution.



Correlated effects



- Pb-Pb data divided in 10 small subperiods.
- Right plot shows the efficiency of real data before and after correction of CDAs.
- ΔEfficiency ≈ 6%.



- Left plot shows the results for MC.
- Very good agreement between real and corrected efficiency →The method is working.
- Real efficiency = reconstructed/reconstructible.
- Good agreement between corrected data and real efficiency → MC used to correct the data.

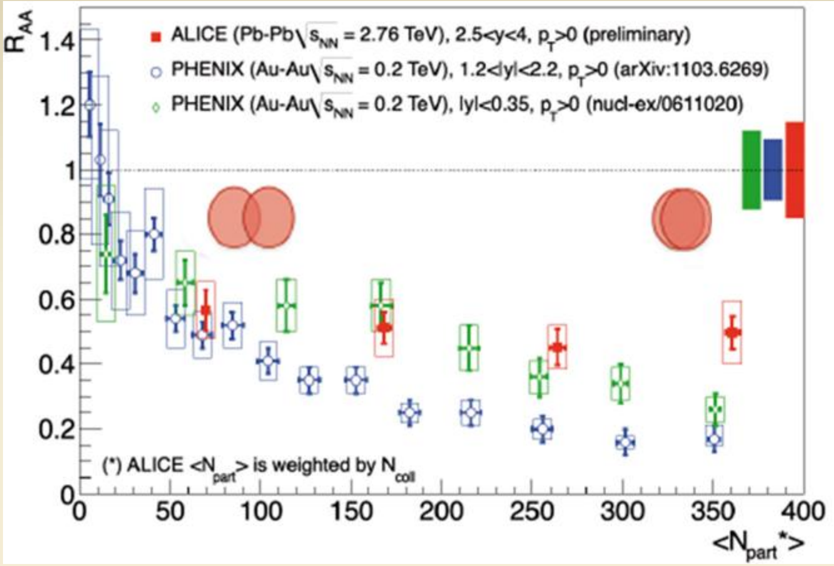
Systematic uncertainty for correlated tracking inefficiency = 1%

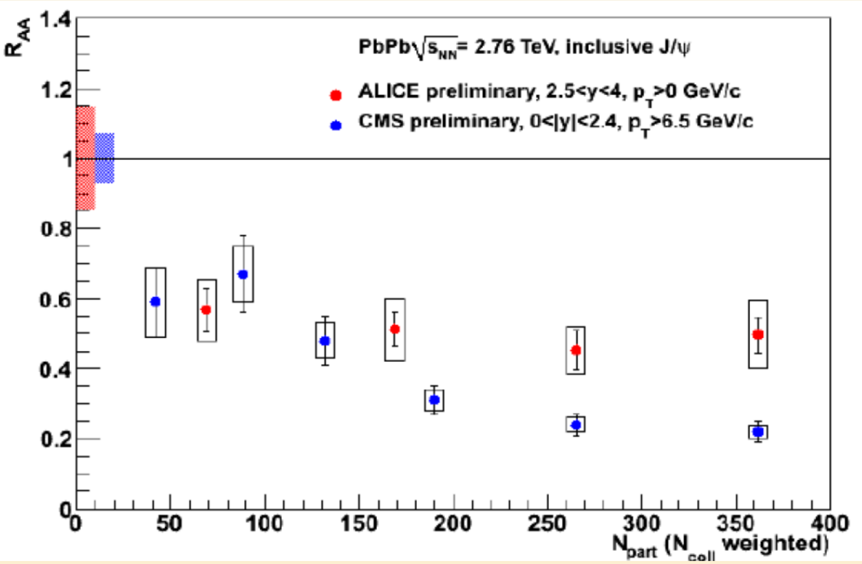
2010 analysis results

- R_{AA} vs $< N_{part} >$ for ALICE & PHENIX (RHIC): clear suppression is observed in both experiments.

- PHENIX: suppression depends on centrality and is steeper at forward rapidity.

- ALICE: R_{AA} is almost flat.





- ALICE compared to CMS: the former observes less J/Ψ suppression in most central collisions than the later.

⟶ But p_T and *y* ranges are separated (no overlap at all)!

First indications of regeneration at the LHC?

Measurement of p-Pb reference is needed for a definitive answer!

Conclusions and outlook

- The QGP is created in high energy heavy-ion collisions: quarkonium family can be used as a thermometer for the QGP.

- The correlated and uncorrelated efficiencies of the tracking chambers of the Muon Spectrometer have been computed.

- Systematic uncertainties have been measured by comparing real data vs simulation.

- First results on J/Ψ R_{AA} in Pb-Pb collisions at LHC have been presented: higher R_{AA} than at RHIC, the Nuclear Modification Factor has a flat dependence with centrality and the suppression is higher at large p_T.

- 2011:
  - ❑ Expected 20 times more data.
  - ❑ R_{AA} vs more centrality bins, p_T and rapidity.
  - ❑ $\langle p_T^2 \rangle_{Pb-Pb} / \langle p_T^2 \rangle_{p-p}$
  - ❑ Ψ’, ϒ
  - ❑ …

Backup

Correcting efficiencies

Compute

$$N^{i}_{Cluster} = N_{i-j} + N_{i-0}$$

and the efficiency of each Detection Element (DE): $$\varepsilon_i = \frac{N_{i-j}}{N_{i-j} + N_{0-j}}$$

Then proceed to correct $N^{i}_{Cluster}$ by the efficiency of the DE

$$\text{Corrected } N^{i}_{Clusters} = \frac{N^{i}_{Cluster}}{\varepsilon_i}$$

	Chamber	Station
Original efficiency	$\varepsilon_i = \frac{N_{i-j}}{N_{i-j} + N_{0-j}}$	$\varepsilon_k = 1 - (1-\varepsilon_m)(1-\varepsilon_n)$
Corrected efficiency	$\varepsilon'_{Ch} = \frac{N_{i-j}}{N_{i-j} + N_{0-j} + N_{0-0}}$	$\varepsilon'_{St} = \varepsilon_{St}\left(\frac{\varepsilon'_{Ch}}{\varepsilon_{Ch}}\right)$

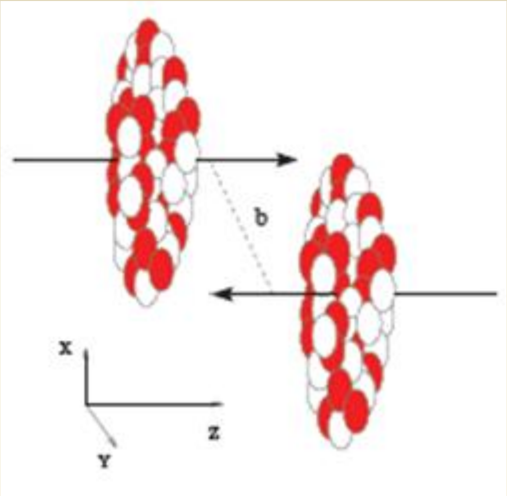
Centrality

Extreamly important observable in heavy-ion collisions.

Impact parameter (*b*): distance between geometrical centers.

N_{part}: nucleons in the overlaping region of two nuclei.

N_{coll}: number of binary nucleon-nucleon collisions.



Can't be measured directly → need indirect techniques.

In ALICE it is measured by the V0, ZDC, TPC and SPD.

In this work the V0 amplitude + a Glauber fit is used to estimate the centrality percentile.