Measurement of low mass dileptons in ALICE

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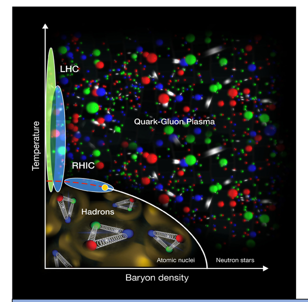
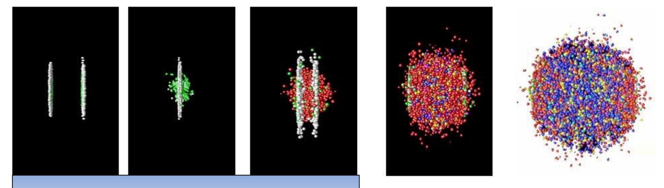
Physics Motivation:

The quark-gluon plasma (QGP) is a state of matter predicted by QCD where quark and gluons are deconfined.

It is possible to recreate the QGP with ultra-relativistic heavy-ion collisions, but only during a short period of time (≈10 fm/c at the LHC) and in a very small volume (≈ 10^4 fm^3 at the LHC)



Phase diagram of matter

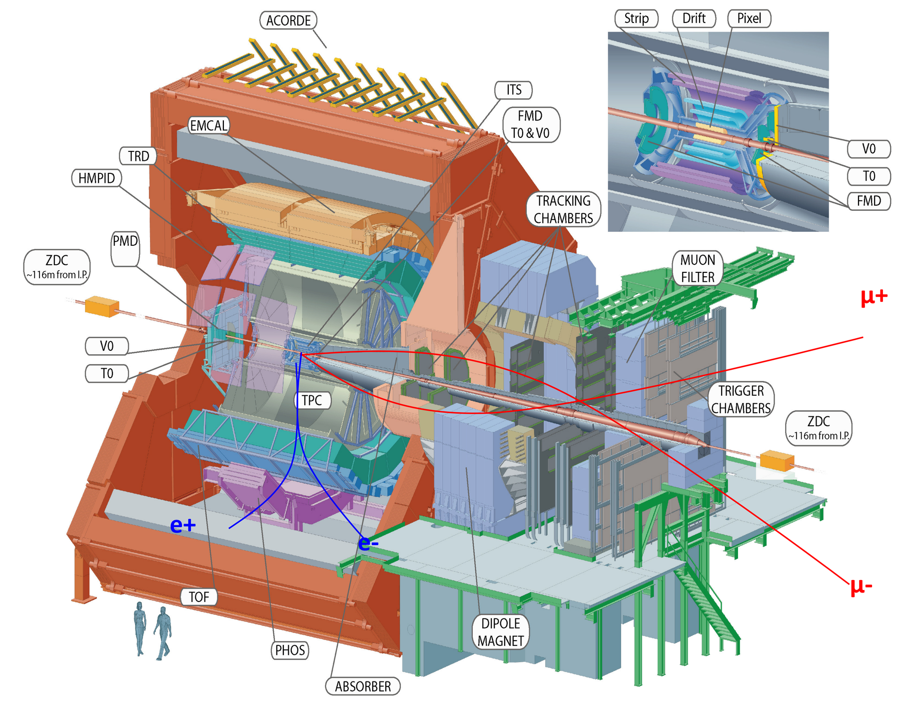


Nuclei collision dynamics

The production of dileptons is a promising tool for the understanding of the chiral symmetry restoration and the thermodynamical properties of the QGP [1].

Studies of dileptons in pp and p–Pb collisions provide reference measurements, as well as an understanding of Cold Nuclear Matter effects in p–Pb collisions.

The ALICE Detector:



- ITS used for vertex determination, tracking and PID, $|\eta| < 0.9$
- TPC used for tracking and PID via dE/dx measurement, $|\eta| < 0.9$
- TOF used for PID via time-of-flight measurement, $|\eta| < 0.9$
- Muon Spectrometer used for muon tracking and triggering, $-4.0 < \eta < -2.5$
- V0 hodoscopes used as trigger and for centrality determination, $-3.8 < \eta < -1.7$ (V0C) and $2.8 < \eta < 5.1$ (V0A)

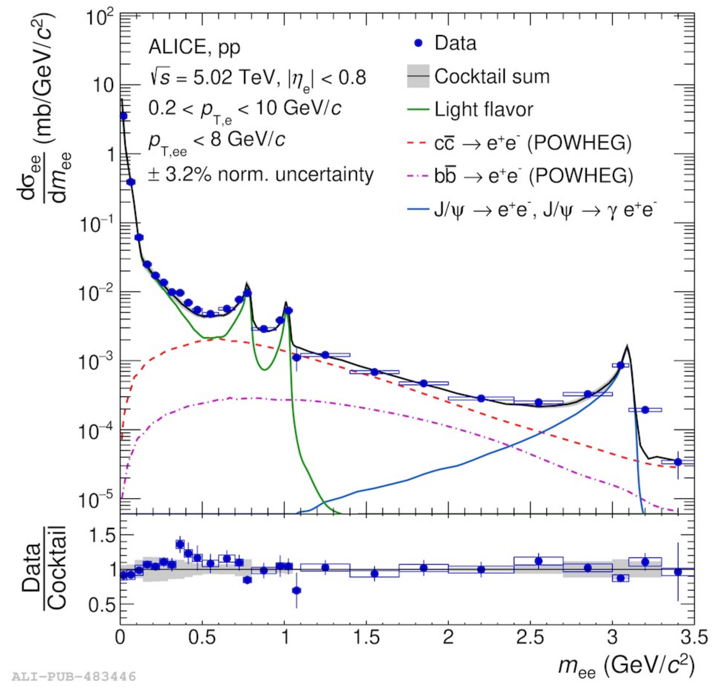
Sources of dileptons :

There are several sources of dileptons.

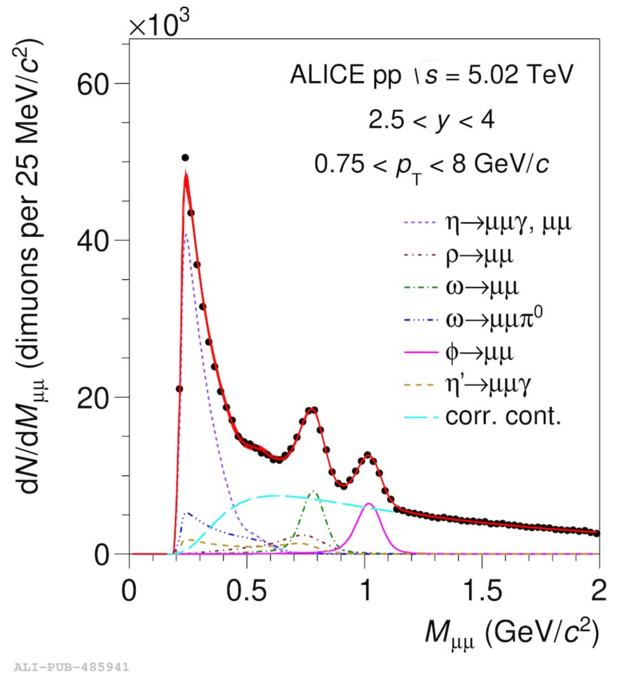
In the low mass range ($0 < m_{ll} < 1.1$ GeV/c^2) : Dalitz decays of pseudo-scalar and vector mesons (**π^0, η, ω, η', ϕ**), and 2-body decays of light-flavor mesons (**ρ, ω, ϕ**). In particular, the $\phi \to l^+l^-$ allows to study the strangeness production and **ρ** is sensitive to the chiral symmetry restoration.

In the intermediate mass region ($1.1 < m_{ll} < 2.7$ GeV/c^2) : dileptons are coming from the decays of correlated heavy-flavor hadrons ($c\bar{c} \to D\bar{D} \to XYl^+l^-$ and $b\bar{b} \to DB\bar{B} \to XYl^+l^-$). This allows to measure $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$.

There is also a contribution due to Thermal Radiation over a broad mass range, that provides insight into the temperature of the medium. However, the measurement of the Thermal Radiation is difficult in the intermediate mass range due to the dominant contribution from charm and beauty hadrons.



Dielectron yield as a function of invariant mass [2]



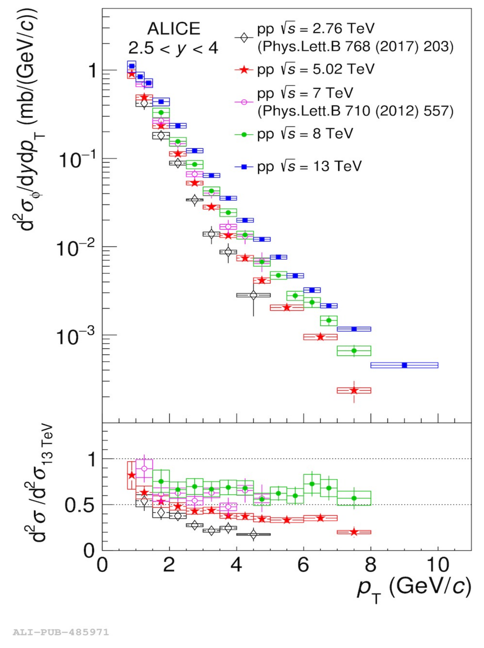
Dimuon yield as a function of invariant mass [3]

Dimuon spectra :

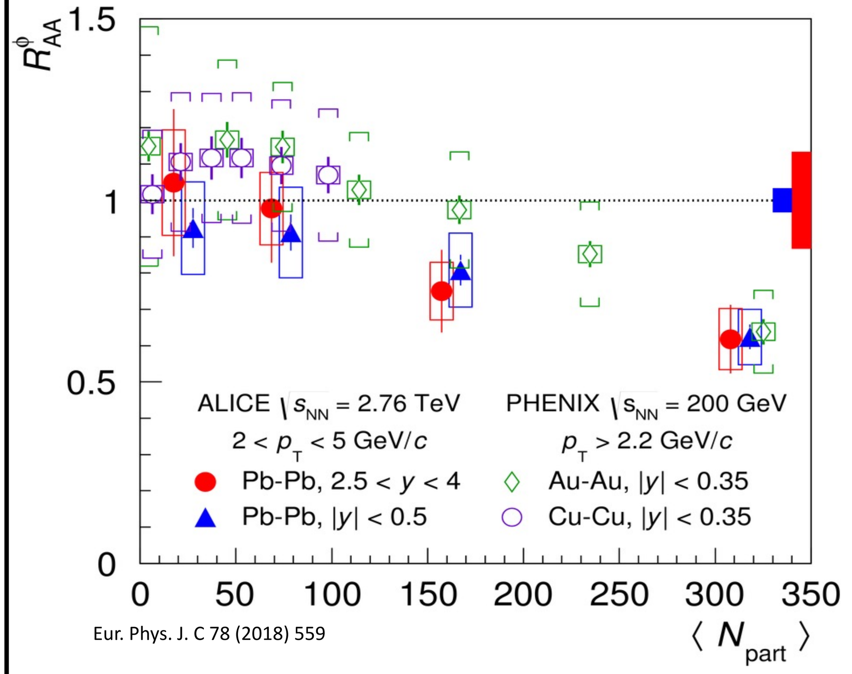
ϕ meson production in pp collisions :

New measurements of the ϕ meson cross section at forward rapidity were performed at $\sqrt{s} = 5.02$, 8 and 13 TeV [2]. The results are compared with measurement at $\sqrt{s} = 2.76$ and 7 TeV.

The differential cross section as a function of p_T shows a hardening of the p_T spectra with increasing collision energy.



Differential ϕ meson cross section as a function of p_T [3]



R_{AA} of the ϕ meson as a function of $\langle N_{part}\rangle$ [4]

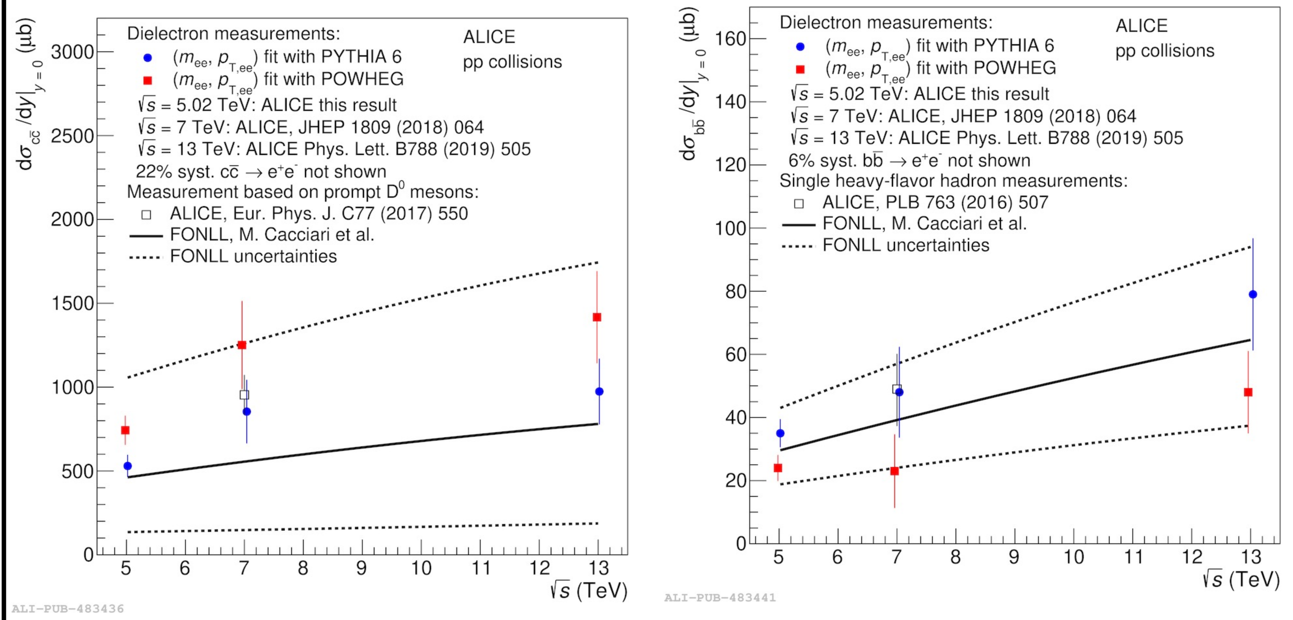
ϕ meson production in Pb–Pb collisions:

The Nuclear Modification factor is defined as $R_{AA} = \frac{1}{N_{coll}} \frac{Y_{PbPb}}{Y_{pp}}$, with Y_{PbPb} and Y_{pp} the production yield in Pb–Pb and pp collisions and N_{coll} the number of binary collisions.

The measurement of the R_{AA} of the ϕ meson at $\sqrt{s_{NN}} = 2.76$ TeV at forward rapidity [3] shows a suppression in central collisions, whereas the R_{AA} is compatible with unity in peripheral collisions.

Results at forward and midrapidity are compatible within uncertainties, which hints towards similar mechanisms driving the interaction of the ϕ meson with the medium, in the two rapidity ranges.

Dielectron spectra :



Cross sections at midrapidity for $c\bar{c}$ (left) and $b\bar{b}$ (right) as a function of $\sqrt{s}$ in pp collisions [2]

Heavy-flavor cross section in pp collisions :

A new measurement of the heavy-flavor cross section at midrapidity was performed at $\sqrt{s} = 5.02$ TeV [4]. The cross section is compared with measurements at $\sqrt{s} = 7$ and 13 TeV [5][6], derived using either PYTHIA or POWHEG generators.

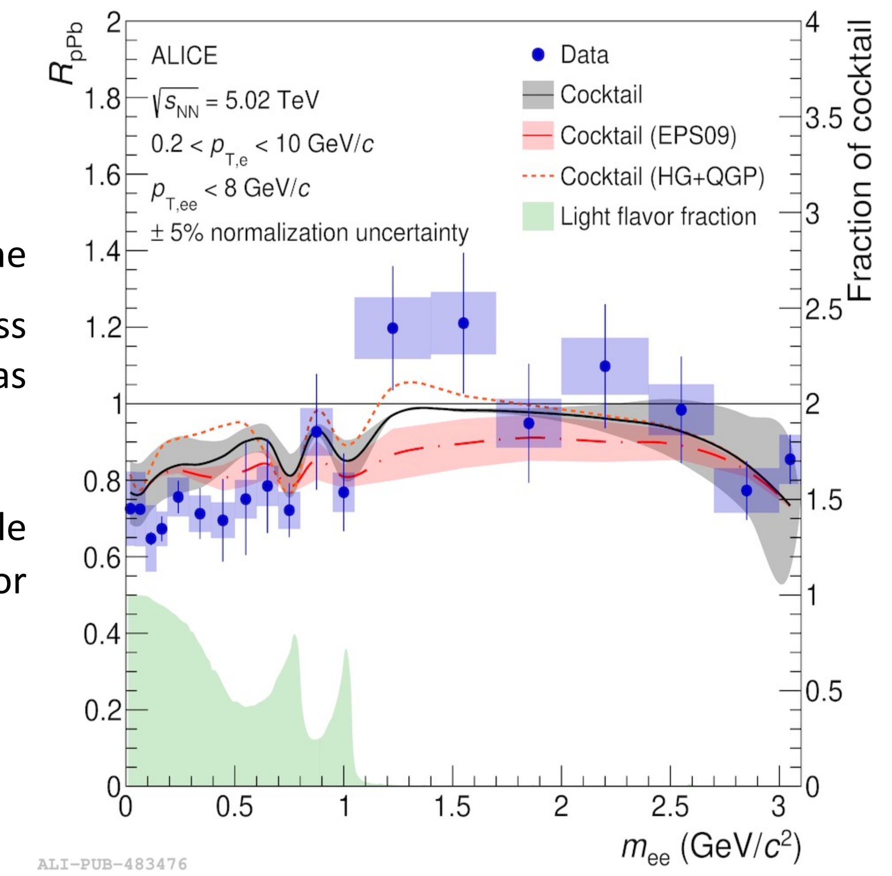
Both measurements derived using either PYTHIA or POWHEG are reproduced by FONLL calculations within uncertainties.

Nuclear modification factor in p–Pb collisions :

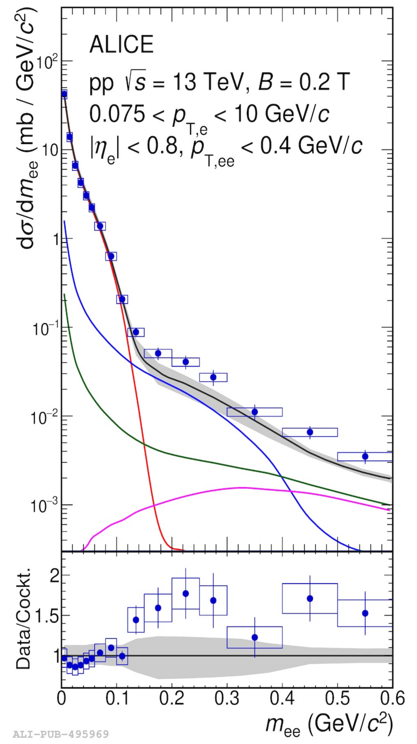
The Nuclear Modification factor is defined as $R_{pPb} = \frac{1}{A} \frac{d\sigma_{ee}^{pPb}/dm_{ee}}{d\sigma_{ee}^{pp}/dm_{ee}}$, with σ_{ee}^{pPb} and σ_{ee}^{pp} the cross section for dielectron production in p–Pb and pp collisions, and A denoting the mass number of the Pb nucleus. A new measurement of the R_{pPb} at $\sqrt{s_{NN}} = 5.02$ TeV was performed [4].

For $m_{ee} < 1.1$ GeV/c^2, R_{pPb}<1 whereas in the intermediate mass region, R_{pPb} is compatible with unity within uncertainties. This suggests a different scaling behavior of the light-flavor production from binary NN collision scaling.

However, with the new measurement of the charm quark fragmentation fractions [8], the value of $\sigma_{c\bar{c}}$ is modified, affecting the previous results, which will be updated accordingly.



Dielectron R_{AA} as a function of invariant mass at $\sqrt{s_{NN}} = 5.02$ TeV [2]



Dielectron cross section as a function of invariant mass [7]

Soft dielectron excess in pp collisions :

A new measurement of the dielectron production at midrapidity was performed at $\sqrt{s} = 13$ TeV with a reduced magnetic field [7], allowing to investigate a low m_{ee} and $p_{T,ee}$ region.

Within the uncertainties, the dielectron cross section and the hadronic cocktail are in good agreement at $m_{ee} < m_\pi$ while an excess over the hadronic cocktail is observed at larger masses, with a significance of 1.6σ. This excess cannot be explained with contributions from known hadronic decays.

Outlooks for Run 3 and 4 :

Upgrade of the ITS and TPC : This will allow to improve vertex resolution and increase the readout rate in Pb–Pb collisions by a factor 100. In particular, it will allow a better separation of prompt sources from heavy-flavor electrons, via DCA studies.

Runs with low magnetic fields : This will allow access to very soft dielectron production at the LHC energies.

Installation of the Muon Forward Tracker: This will add vertexing capability to the ALICE muon spectrometer and improve the dimuon mass resolution as well as reduce the background. Moreover, this will allow to improve the ability to do electron-muon measurements.

References :

[1] R. Rapp, J. Wambach, and H. van Hees, The Chiral Restoration Transition of QCD and Low Mass Dileptons, Landolt-Bornstein 23 (2010) 134
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[3] ALICE, Energy dependence of φ meson production at forward rapidity in pp collisions at the LHC, arXiv:2105.00713
[4] ALICE, φ meson production at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Eur. Phys. J. C 78 (2018) 559
[5] ALICE, Dielectron production in proton-proton collisions at $\sqrt{s} = 7$ TeV, JHEP 09 (2018) 064
[6] ALICE, Dielectron and heavy-quark production in inelastic and high-multiplicity in proton-proton collisions at $\sqrt{s} = 13$ TeV,, Phys.Lett.B788(2019) 505–518
[7] ALICE, Soft-dielectron excess in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. 127, 042302
[8] ALICE, Charm-quark fragmentation fractions and production cross section at midrapidity in pp collisions at the LHC, arXiv:2105.06335