The D-meson nuclear modification factor as measured with ALICE

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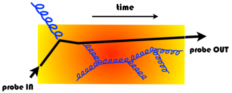
The importance of measuring heavy-flavour particles.

- Charm and Beauty quarks are primarily produced in hard scattering processes in the early stage of collisions.
- Traverse the Quark-Gluon Plasma created in heavy-ion collisions and lose energy via radiative gluon emission and elastic collisions.
- Heavy quarks are expected to lose less energy than light quarks and gluons due to the color-charge and dead cone effects.



  - The color charge dependence leads to the expectation that $E_{\mathrm{loss}}(\mathrm{gluons}) > E_{loss}(\mathrm{quarks})$ (casimir factor).
  - The dead-cone effect leads to the expectation of a mass-dependent radiation suppression ($\theta < m_Q/E_Q$).

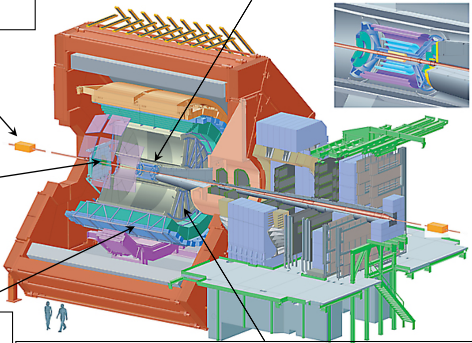
Expectation: $E_{loss}(g) > E_{loss}(\mathrm{light\ quarks}) > E_{loss}(c) > E_{loss}(b)$

Phys. Rev. D71 (2005) 054027 & Y. Dokshitzer & D. Kharzeev PLB 519(2001)199

ALICE Detector

Zero-Degree Calorimeter (ZDC):
Centrality determination.

Inner Tracking System (ITS): Tracking, vertexing and PID via dE/dx



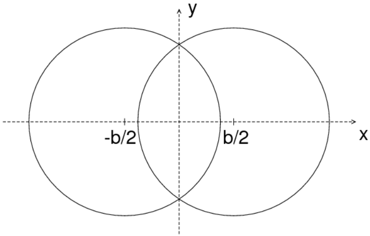
V0 detector: trigger, centrality and multiplicity.

Time-of-Flight (TOF): PID via time of flight

Time Projection Chamber (TPC): tracking, PID via dE/dx.

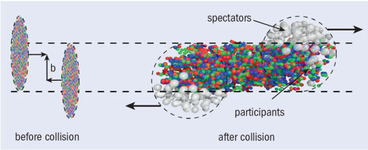
Centrality

- In Pb-Pb collisions **centrality** is defined by the impact parameter b, in which we differentiate between central (small b) and more peripheral (larger b) events.



- The notion of centrality is used such that 0-10% centrality implies the 10% most central events.

- Experimentally one can also discuss the **average number of nucleons participating** (N_{part}) in a collision, or the number of hard-nuclear collisions (N_{coll}), which can be calculated via a Glauber fit.



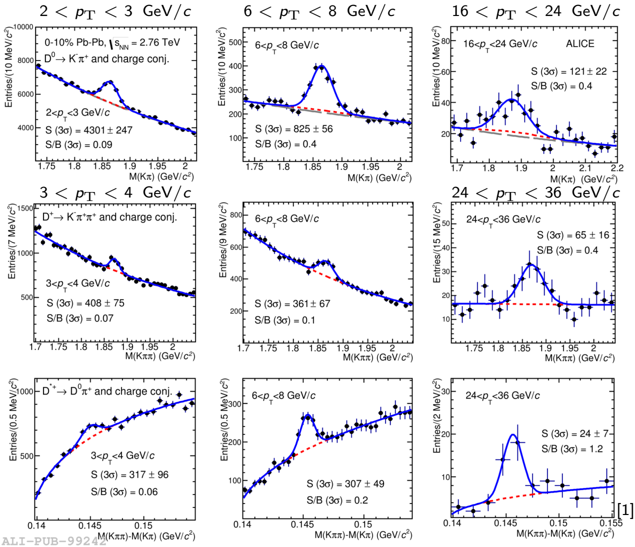
D-meson production

- The reconstruction is done for the following hadronic decays at mid-rapidity:
  - $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ (Branching ratio: $3.88 \pm 0.05\%$)
  - $\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$ (Branching ratio: $9.13 \pm 0.19\%$)
  - $\mathrm{D}^{*+} \to \mathrm{D}^0\pi^+$ (Branching ratio: $67.7 \pm 0.5\%$)

  And the respective charge conjugates.
- Analysis based on decay vertex topologies displaced from the primary vertex and PID of the decay products.
- Signal extraction via an invariant mass analysis.

K.A. Olive et al (Particle Data Group), The review of particle physics, Chin. Phys. C **38** (2014) 090001.

Inv. Mass distr. for $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV Pb-Pb collisions



The invariant mass distribution in the 0-10% centrality class in three p_{T} bins for

(K, π) (D^0),

(K, π, π) (D^+)

and mass difference:

$\Delta M = M(\mathrm{K}\pi\pi) - M(\mathrm{K}\pi)$ (D^{*+})

[1] [ALICE Collaboration], JHEP 01 (2012) 128

Nuclear Modification Factor (R_{AA})

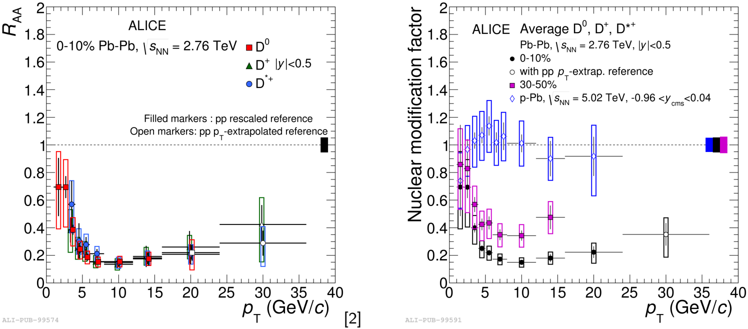
- Comparison of the particle yields in Pb-Pb collisions and binary-scaled pp collisions (R_{AA}).

$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \cdot \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}, \tag{1}$$

  $\langle T_{\mathrm{AA}} \rangle$ is the average nuclear overlap function (Glauber model).
- Thus if no nuclear effects are present $R_{\mathrm{AA}} = 1$ (expected for high p_{T}).
- Similarly for the p-Pb collisions we define:

$$R_{\mathrm{pPb}} = \frac{1}{A} \cdot \frac{\mathrm{d}\sigma_{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}, \tag{2}$$

R_{AA} & R_{pPb} vs p_T



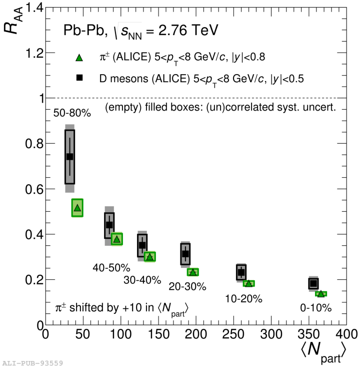
[2] [2]

- D^0, D^+ and D^{*+} results are compatible within uncertainties, so averages can be used.
- Large suppression of D mesons at $4 < p_T < 24$ GeV$/c$.
- R_{pPb} is consistent with unity while the R_{AA} is significantly below 1 for $p_T > 3$ GeV$/c$:
  $\rightarrow$ Suppression of the D-meson yield in Pb–Pb collisions is due to in-medium effects.

[2] [ALICE Collaboration], arXiv:**1509.06888** [nucl-ex],

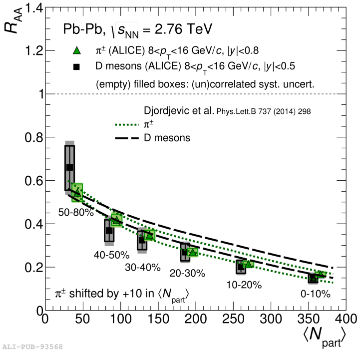
R_{AA} vs centrality

$5 < p_T < 8$ GeV/c



[3]

$8 < p_T < 16$ GeV/c

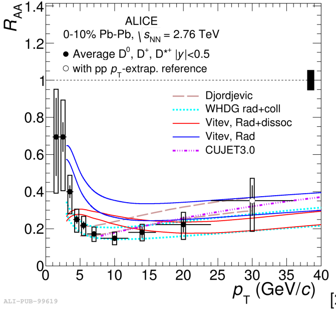


[3]

- A centrality-dependent suppression pattern of the R_{AA} is observed for D mesons, which is very similar to the one observed for pions.
- The suppression reaches a factor of 5-6 in the highest p_T interval for the 0-10% centrality class.

[3] [ALICE Collaboration] JHEP 1511 (2015) 205. Model: Djordjevic: PRL 737 (2014) 298.

Comparison with model calculations



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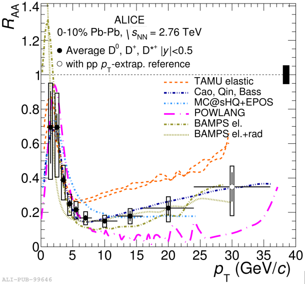


[2]

models from:

- Djordjevic: Phys. Lett. **B737**(2014) 298-302
- WHDG: Nucl. Phys. A 872 (2011) 256
- Vitev: Phys Rev **C80** (2009) 054902
- CUJET3.0 Chin. Phys. Lett. **32** no.9, (2015) 092501
- POWLANG: Eur. Phys.J. **C71** (2011) 1666 Eur. Phys. J. **C75** (2015) 3
- TAMU: Phys. Lett. **735** (2014) 445-450
- MC@HQ+EPOS: Phys. Rev. **C89** (2014) 014905
- BAMPS: Phys. Lett. **B717** (2012) 430
- Cao, Qin, Bass: Phys. Rev **C88** no. 4 (2013) 044907

Interaction of heavy quarks with medium computed considering:

- Only Coll. $E_{\rm loss}$: POWLANG and TAMU, BAMPS (scaling in regime where rad. is dominant) (I)
- Rad. and Coll. $E_{\rm loss}$: Djordevic, WHDG, CUJET3.0, MC@sHQ+EPOS, BAMPS(II), Cao Qin Bass.
- Vitev has only Rad. $E_{\rm loss}$ (I) and for II it includes in-medium dissociation heavy-flavour hadrons.

Comparison to several models gives a good agreement with the data.

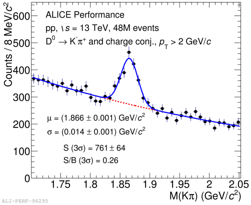
[2] [ALICE Collaboration], arXiv:**1509.06888** [nucl-ex],

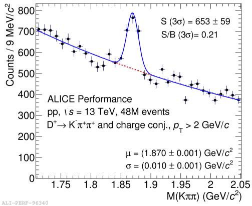
Conclusion

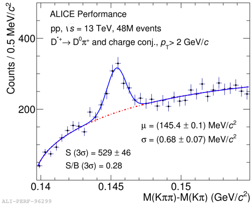
- The nuclear modification factor for D mesons shows a p_{T} and centrality-dependent suppression of the D-meson yield, up to a factor of 5-6 for central events with $8 < p_{\mathrm{T}} < 12$ GeV/c.
- The measured R_{pPb} is consistent with unity which indicates that the suppression of the D-meson yield in Pb–Pb collisions is due to in-medium effects.
- Comparison to models gives good agreement for several models, both for models that do and do not include a hydrodynamical medium expansion. Stronger constraints on the models can be found when combining R_{AA} and elliptic flow measurements.

Future prospects for D mesons

- Run I: the D^0 is under study at very-low p_T (< 1 GeV/c) in pp and p-Pb collisions. (Improvement of total open-charm cross section)
- Run II has an increased luminosity and centre of mass energy.
- First look at Run II data in pp collisions at $\sqrt{s} = 13$ TeV: already high statistical significance for D mesons for $p_\mathrm{T} > 2$ GeV/c in first 48M events.







- Pb-Pb run at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV has finished just before Christmas.

Questions?

Thank you for listening!

Backup

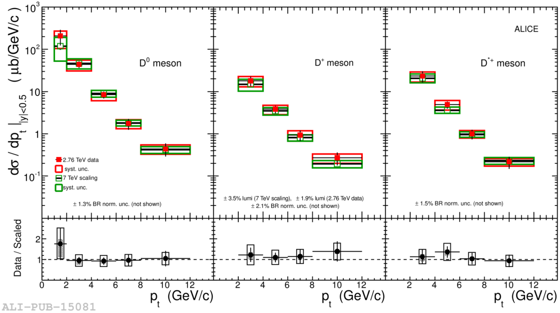
Explicit gluon radiation casimir

Casimir effect: $\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$

- α_s QCD coupling constant
- C_R Casimir coupling factor 4/3 for quarks and 3 for gluon.
- $\hat{q}$ transport coefficient dependent on the medium (average p_{T} kick per unit path length of probe (prop to gluon density))
- L length traversed in medium

Rescaling

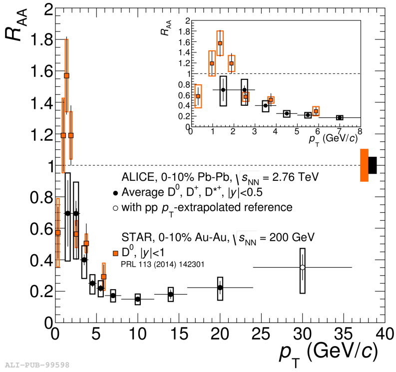
Done with pQCD based energy scaling (FONLL), checked with available $\sqrt{s} = 2.76\,TeV$ measurements:



[4]

[4] ALICE Collaboration, JHEP **1207** (2012) 191.

Comparison to STAR and R_{pPb} models



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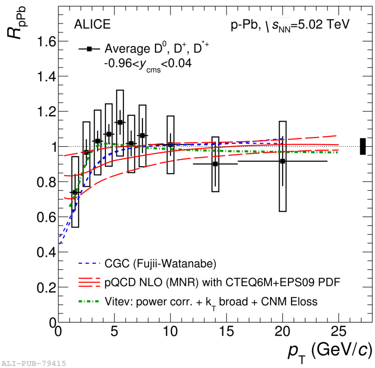


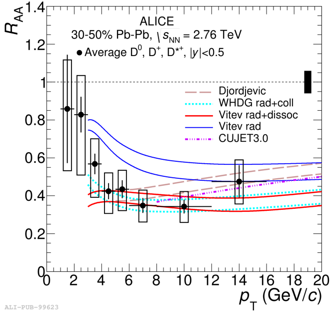
[5]

- For a $p_{\mathrm{T}} > 2$ GeV/c the D-meson results are compatible with the $\mathrm{D}^0\mathrm{R}_{\mathrm{AA}}$ at lower energies.
- Within the current uncertainties all the models that include initial-state effects describe the data well.

[5] ALICE Collaboration, Phys.Rev.Lett. **113** (2014), 232301.

STAR: PRL113 (2014) 142301

Comparison with model calculations, more peripheral



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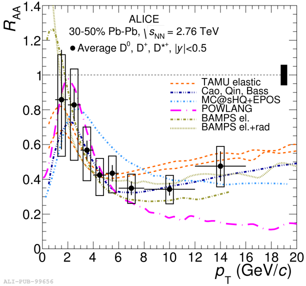

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- BAMPS: Phys. Lett. **B717** (2012) 430;
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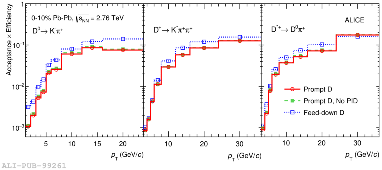
Description of the medium

- No medium, Glauber model nuclear overlap: Djordevic, WHDG and Vitev.
- Hydrodynamical medium expansion: CUJET3.0, MC@sHQ+EPOS, BAMPS, Cao Qin Bass, POWLANG and TAMU.

Efficiency and Feeddown



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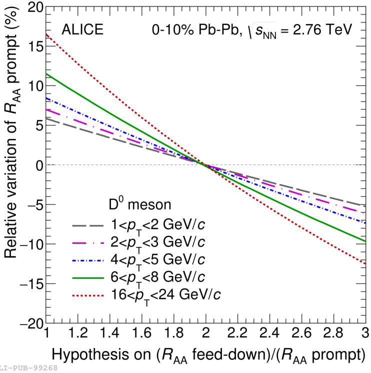

[2]

- The results are corrected for the acceptance of our detector (including rapidity interval) and for the efficiency of the chosen cuts on the data.
- Relative systematic uncertainties on the prompt D-meson production yields in Pb–Pb collisions for selected p_T intervals.