# System size scan of D meson using PbPb, XeXe, ArAr, and OO collisions at LHC


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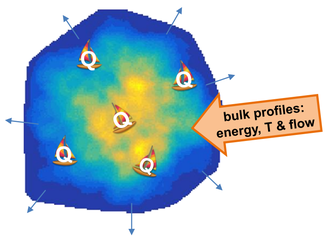
**Supported by FAPESP (Brazil), Region Pays de la Loire (France), NFSC and MOST (China), Alfred P. Sloan Foundation and US-DOE Nuclear Science (USA)**


## Motivations

- ✓ **Develop a modular simulation "DAB-MOD"** to study the production of open heavy mesons in heavy ion collisions and describe simultaneously the $R_{AA}$ and $v_2$.
- ✓ Study the heavy flavour azimuthal anisotropies through the more rigorous **cumulant method**.
- ✓ Experimental observations of D mesons in p-Pb collisions: $R_{AA} \sim 1$ but significant $v_2$ => **Is the common framework still valid in small systems ?**
- ✓ Investigate **how D mesons scale with system size and structure** => Explore various colliding systems toward p-A collisions [arXiv: 1812.06772]

C. Prado, J. Noronha-Hostler, R. Katz, A. Suaide, J. Noronha and M. Munhoz, Phys. Rev. C 96 (2017) 064903 [arXiv:1611.02965], arXiv:1906.10768 [nucl-th] and **arXiv:1907.03308 [nucl-th]**

## THE DAB-MOD TIMELINE




**Heavy quarks... / Bulk...**

- **Large oversampling** of the heavy quarks.
- Distributed spatially following initial QGP energy density.
- Transverse momentum distribution given by **FONLL spectra** and with random azimuthal direction.
- **No shadowing or cold nuclear matter** effects.

**Initial condition / Initial fluctuations**

**Relativistic Langevin model**

$$dp_i = -\Gamma(\vec{p})p_i dt + \sqrt{dt}\sqrt{\kappa}\rho_i$$

with the necessary Lorentz boosts between global and local frames. The diffusion coefficients are given by the classic fluctuation-dissipation relation:

$$\kappa = 2E\Gamma T = 2T^2/D$$

and the parametrization from Moore and Teaney QCD+HTL model: $D = 2.2/(2\pi T)$

Scaling constant fixed to obtain the best fit to the $D^0$ meson $R_{AA}$ data in 0-10% centrality Pb-Pb collisions. *Same constant for all colliding systems.*

Refs: arXiv:0412346, arXiv:1906.10768

**Transport / Expansion**

**Decoupling temperature**: $T_d$ = 160 MeV

**Fragmentation**

With the Peterson frag. function, to obtain the fraction $z$ of the heavy quark $E_Q+p_Q$

$$f(z) \propto [z(1-1/z-\epsilon_Q/(1-z))]^{-1}$$

**Light-heavy quark coalescence**

- Inspired by Dover et al.: instantaneous projections.
- Coalescence probabilities as a function of $p_Q$, the local flow and the angle between them.
- To fit the observed heavy hadron ratios, we include new thermal factors "exp[-($m_{excited}$-$m_{ground}$)/$T_d$]" => mass hierarchy between the energy states of a hadron type.

Refs: arXiv:1804.09083v1, arXiv:1906.10768 , arXiv:1505.01413

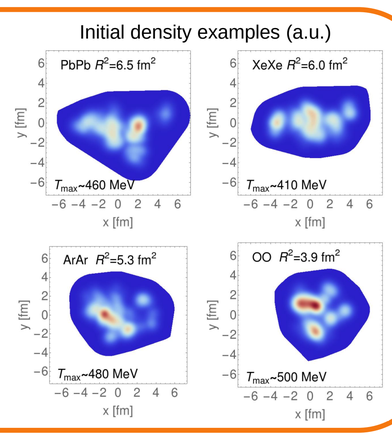
**Hadronization / Decays**

- **No re-scattering** considered in the final hadronic phase.
- Focus on **semi-leptonic decays** performed with Pythia 8.

**Initial fluctuations**

- **Initial condition** models: **$T_R$ENTo** Based on eikonal entropy deposition via a "reduced-thickness" function.
- For Pb-Pb 5.02 TeV, spherical and prolate Xe-Xe 5.44 TeV (Woods-Saxon parameterization for shaping; $\beta_2$ = 0.162), Ar-Ar 5.85 TeV and O-O 6.5 TeV collisions.

Refs: arXiv:1412.4708, arXiv:1901.01319




**Expansion**

- The heavy quark transport equations require QGP profiles w/ temperature and flow fields.
- QGP evolution with the **v-USPhydro code**: **2D+1 event-by-event relativistic viscous hydrodynamic** model. Viscosity is set to η/s = 0.05 and initial time to 0.5 fm/c.
- *Same constants for all colliding systems.*
- ~1000 events per centrality 10% range.

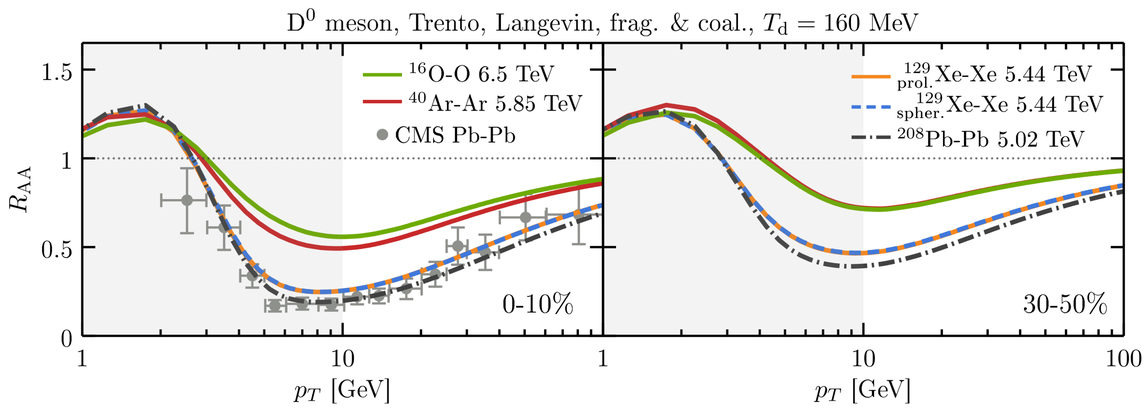
Refs: arXiv:1305.1981, arXiv:1508.02455, arXiv:1307.6130, arXiv:0707.0249

**Final stages**

- **Cooper-Frye freeze-out** with viscous corrections (included in v-USPhydro).
- It describes Pb-Pb experimental data in the soft sector, such that all the hydrodynamic parameters are fixed.

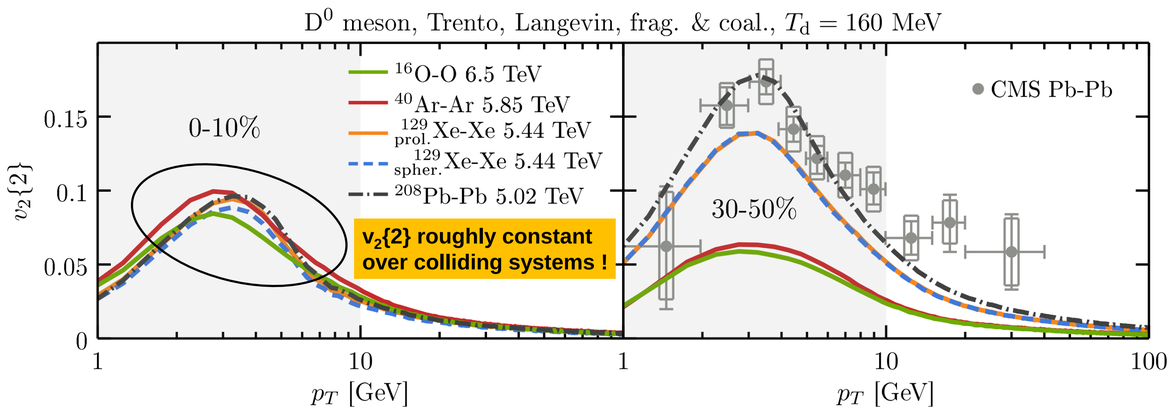
## RESULTS

### Nuclear modification factor $R_{AA}$? ①




$R_{AA} \rightarrow 1$ gradually as system size decreases
$(1 - R_{AA})$ is roughly proportional to the system initial radius $\sim A^{1/3}$
=> heavy quarks lose less energy as the path length decreases

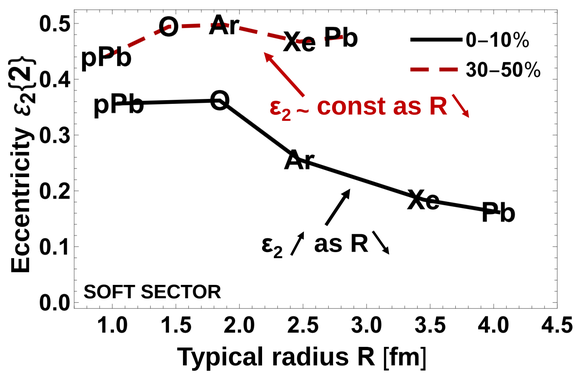
### Elliptical azimuthal anisotropies $v_2\{2\}$ ? ②



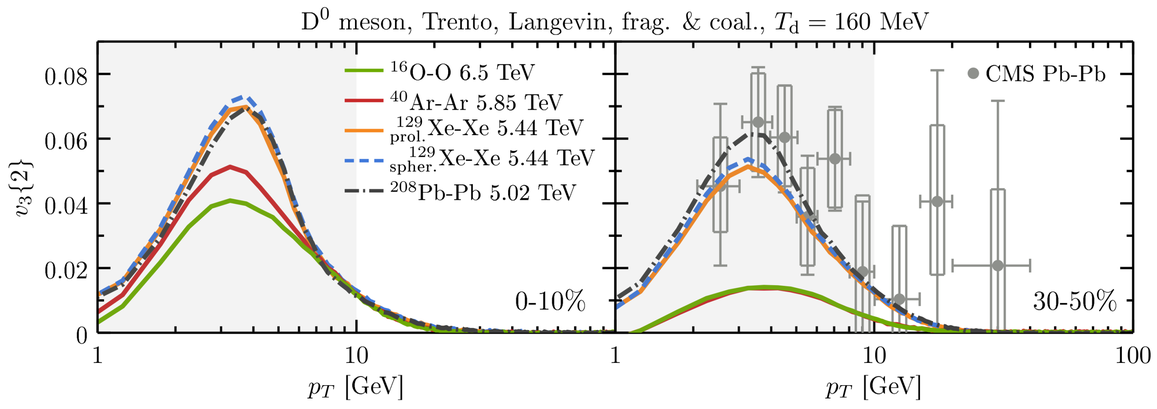

** Mid-central collisions 30-50% **
$v_2\{2\}$ hierarchy with colliding system
=> whereas eccentricities $\varepsilon_2 \sim$ const, system size plays an important role for $v_2\{2\}$ !

** Central collisions 0-10% **
$v_2\{2\} \sim$ independent of the colliding system
=> balance between $v_2$ suppression from R ↘ and enhancement from $\varepsilon_2$ ↗

- Larger $v_2$ of Ar-Ar and O-O in 0-10% than in 30-50%
- $D^0$ $v_2\{2\}$ sensitive to deformed Xe in 0-10%

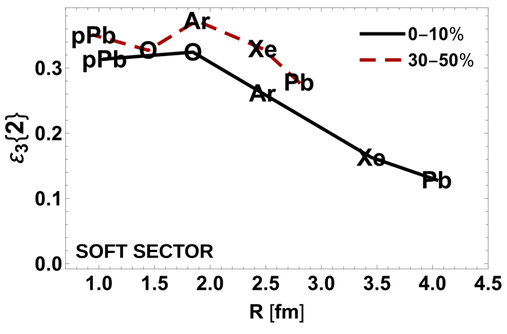



### Triangular azimuthal anisotropies $v_3\{2\}$ ? ③



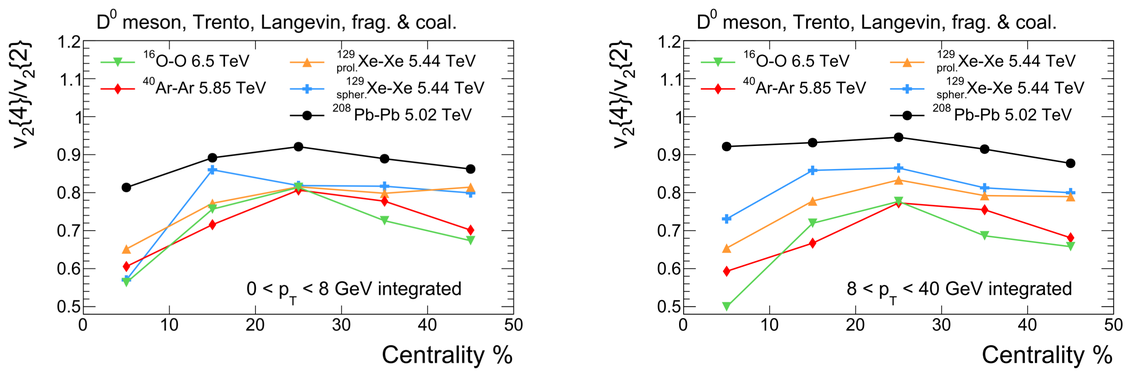

- More suppressed in small systems, even with $\varepsilon_3$ ↗
- At the ≠ of Pb-Pb, in smaller systems no ~ universality with centrality: $v_3^{0\text{-}10\%} >> v_3^{30\text{-}50\%}$

=> Approx. universality in Pb-Pb can be explained by a balance between the variations in typical system size and $\varepsilon_3$ with centrality




Refs CMS data: arXiv:1708.04962, arXiv:1708.03497

### $v_2\{4\}/v_2\{2\}$ ratio ④




- At high $p_T$: strong dependence on system size of the average value
- $v_2\{4\}/v_2\{2\}$ ↘ with size ↘ : more distinct than in the soft sector

**Conclusion:**
- First predictions for the D meson observables for the potential system size scan at LHC
- $R_{AA} \rightarrow 1$ gradually as systems size decreases; but will it reach 1 in pPb ?
- $v_n\{2\}$ arise from a non trivial interplay between typical sizes & eccentricities.
- $v_2\{2\} \sim$ independent of the colliding system in 0-10% ! due to balance between these effects

**Future:** p-Pb collisions, 3D, shadowing...