Heavy flavour dynamics in event-by-event viscous hydrodynamic backgrounds

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Supported by FAPESP (Brazil)

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**.

✓ Compare **different transport models** with the same background.

✓ Investigate the **effect of initial geometries and fluctuations** on the heavy quarks dynamics through common and **new observables**.

C. Prado, J. Noronha-Hostler, R. K., A. Suaide, J. Noronha and M. Munhoz, Nucl. Phys. A 967 (2017) 664-667 [arXiv:1704.04654]; Phys. Rev. C 96 (2017) 064903 [arXiv:1611.02965]

THE DAB-mod TIMELINE

Heavy quarks...

- **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

Energy loss model

$$\frac{dE}{dx} = -f(T,p,x)\,\Gamma_{\text{flow}}$$

where the chosen parametrizations

$f(T,p,x) = \alpha$ and $f(T,p,x) = \xi T^2$

led to relevant R_{AA} results,

and where the effect of the moving medium on energy loss is given by:

$$\Gamma_{\text{flow}} = \gamma\left[1 - v_{\text{flow}}\cos(\varphi_{\text{quark}} - \varphi_{\text{flow}})\right]$$

Refs: arXiv:1404.6378, arXiv:1609.05171, arXiv:0412346, arXiv:0802.2525

OR

Relativistic Langevin model

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

with the necessary Lorentz boosts and the classic fluctuation-dissipation relation for the diffusion coefficients:

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

Here 2 different parametrizations:
- « M&T »: From Moore and Teaney, QCD+HTL model: $D \propto 1/(2\pi T)$
- « G&A »: From Gossiaux and Aichelin, QCD+HTL collisional model with running coupling and optimized propagator.

Coefficients of proportionality (α, ξ, for D...) are fixed to obtain the best fits to the high p_T D^0 meson R_{AA} for the centrality range 0-10% for T_d=120 and 160 MeV.

Transport

Decoupling temperature: 120 < T_d < 160 MeV encode hadronization large uncertainties.

Fragmentation

With the Peterson frag. function,

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

to obtain the fraction z of the heavy quark E_Q+p_Q taken by the hadron E_H+p_H.

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: 1) thermal factor "exp[-(m_{excited}-m_{ground})/T_d]" => mass hierarchy between the mass states of a hadron type, 2) baryon factor to enhance the baryon/meson ratios (to compensate missing dynamics)

Refs: arXiv:1804.09083v1, Radhakrishnan's talk at QM 2018, arXiv:1505.01413

Hadronization

Decays

Bulk...

Initial fluctuations

- Two possible initial condition models:

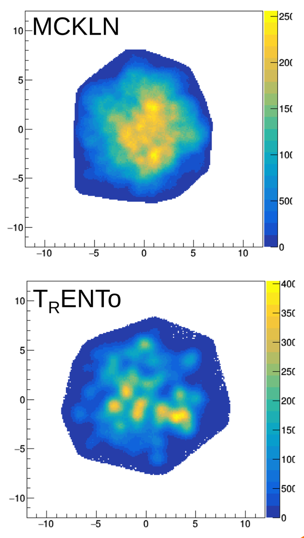
✓ Monte Carlo Kharzeev-Levin-Nardi "**MCKLN**": implementation of a Color Glass Condensate kt-factorization model.

✓ **T_RENTo**: based on eikonal entropy deposition via a "reduced-thickness" function.

- For now: Au-Au at 200 GeV, Pb-Pb at 2.76 and 5.02 TeV, spherical and prolate Xe-Xe at 5.44 TeV (Woods-Saxon parameterization for shaping; β_2 = 0.162)

Refs: arXiv:0707.0249, arXiv:1412.4708, arXiv:1711.08499

Initial density examples (a.u.)



Expansion

- The heavy quark transport equations requires QGP profiles to provide temperature and flow fields.
- QGP evolution with the **v-USPhydro** code: a 2D+1 event-by-event relativistic **viscous** hydrodynamic model. Viscosity is set to η/s = 0.05 and initial time to 0.6 fm/c.
- ~1000 events per centrality 10% range.

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

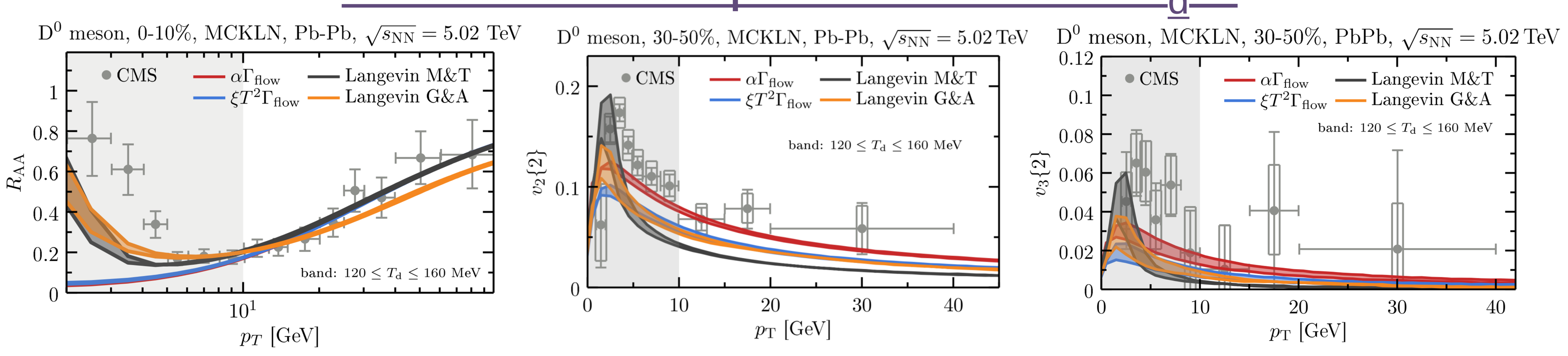
Final stages

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

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

RESULTS

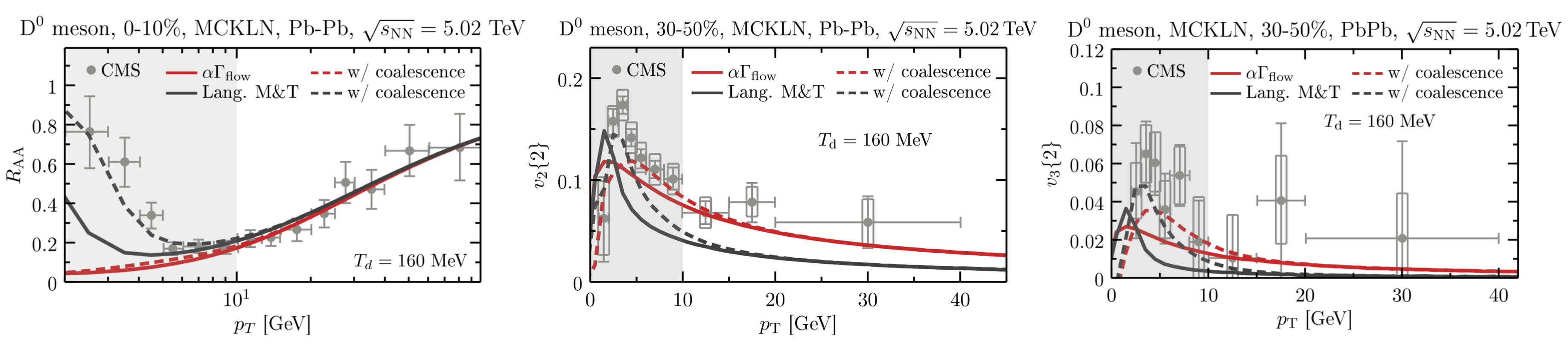
Effects of transport model and T_d ?



- We underestimate a bit the data - Langevin: better at low-p_T - Energy loss: better at higher p_T
- Langevin: need for a radiative component to improve the high-p_T v_n? - Lower T_d gives better results

Refs data: arXiv:1708.04962, arXiv:1708.03497

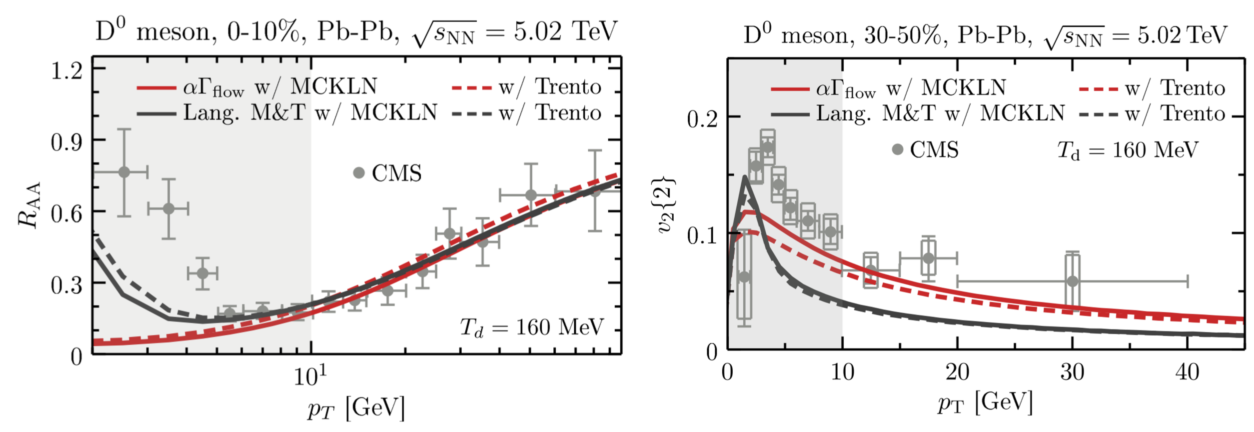
Effect of coalescence ?



Fragmentation: p_{HQ} > p_{D0} ≠ Coalescence: p_{HQ} < p_{D0} (p_T gain from the light quark "thermal" p_T and mass):
=> The low-p_T "lumps" shift towards higher p_T (~3 GeV) => Improvement except for energy loss R_{AA}

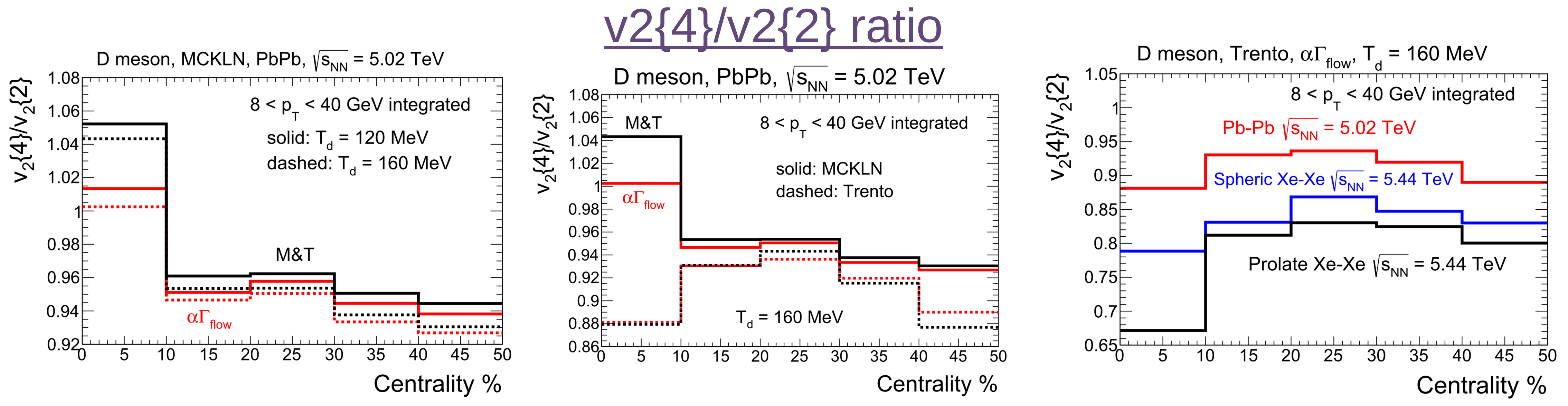
Similar results in refs: arXiv:1503.03039, arXiv:1410.5396, arXiv:1605.06447

Effect of initial state ? MCKLN vs. T_RENTo



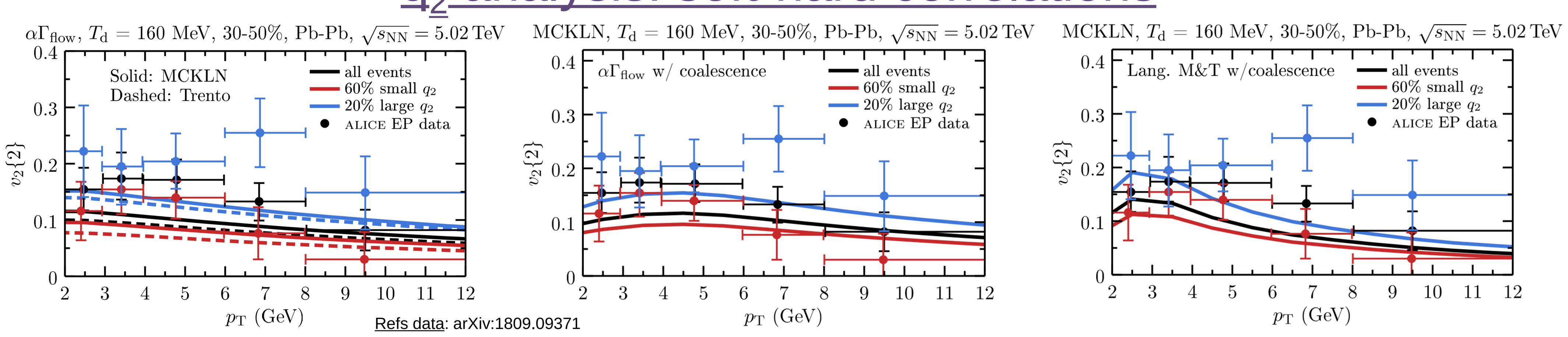
- Type of initial bulk fluctuations has a small impact on HF R_{AA} and $v_n\{2\}$ observables with our mehod to fix the transport model coefficient values.
- T_RENTo leads to a slight increase of the RAA and decrease of v2

v2{4}/v2{2} ratio



- Almost independent of chosen transport model and T_d - Geometry (size & shape) has an important influence
- Type of initial state fluctuations has an impact, especially on the trend => a way to characterize the fluctuations experimentally ?
- Ratio trends with Trento are similar in the soft sectors (see arXiv:1711.08499v2)

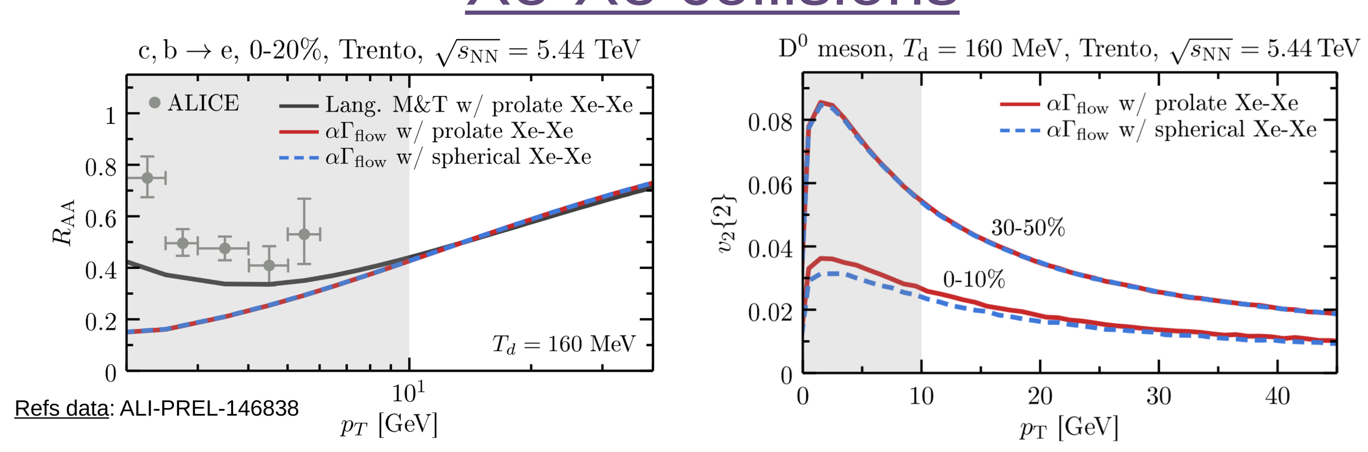
q_2 analysis: soft-hard correlations



Refs data: arXiv:1809.09371

- Globally underestimate the data, though separations ok - Do our q_2 ranges similar to experimental ones ?
- Need to combine lower T_d and coalescence to get better fits

Xe-Xe collisions



Refs data: ALI-PREL-146838

- Prolate & spherical geometries => similar R_{AA} and v_2.
- v_2 (30-50%) a bit smaller than in Pb-Pb - $v_2\{4\}/v_2\{2\}$ more sensitive to shapes

Conclusion:
- « Multiscale » behaviour: Langevin more relevent at low p_T, energy loss at high p_T
- Coalescence required but not sufficient to fit low p_T data
- T_RENTo vs. MCKLN initial states: small effect on common observables
- $v_2\{4\}/v_2\{2\}$ ratio: depends mostly on initial fluct. and syst. geometry

Future: Coalescence at Td=120 MeV and for bottom quarks, Langevin with radiative component, p-Pb collisions, 3D, shadowing...