System size scan of D meson R_{AA} and v_n using PbPb, XeXe, ArAr, and OO collisions at LHC

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Collaborators: **Roland Katz, Caio A.G. Prado**, Alexandre A.P. Suaide arXiv:1906.10768 (accepted in PRC) & arXiv:1907.03308

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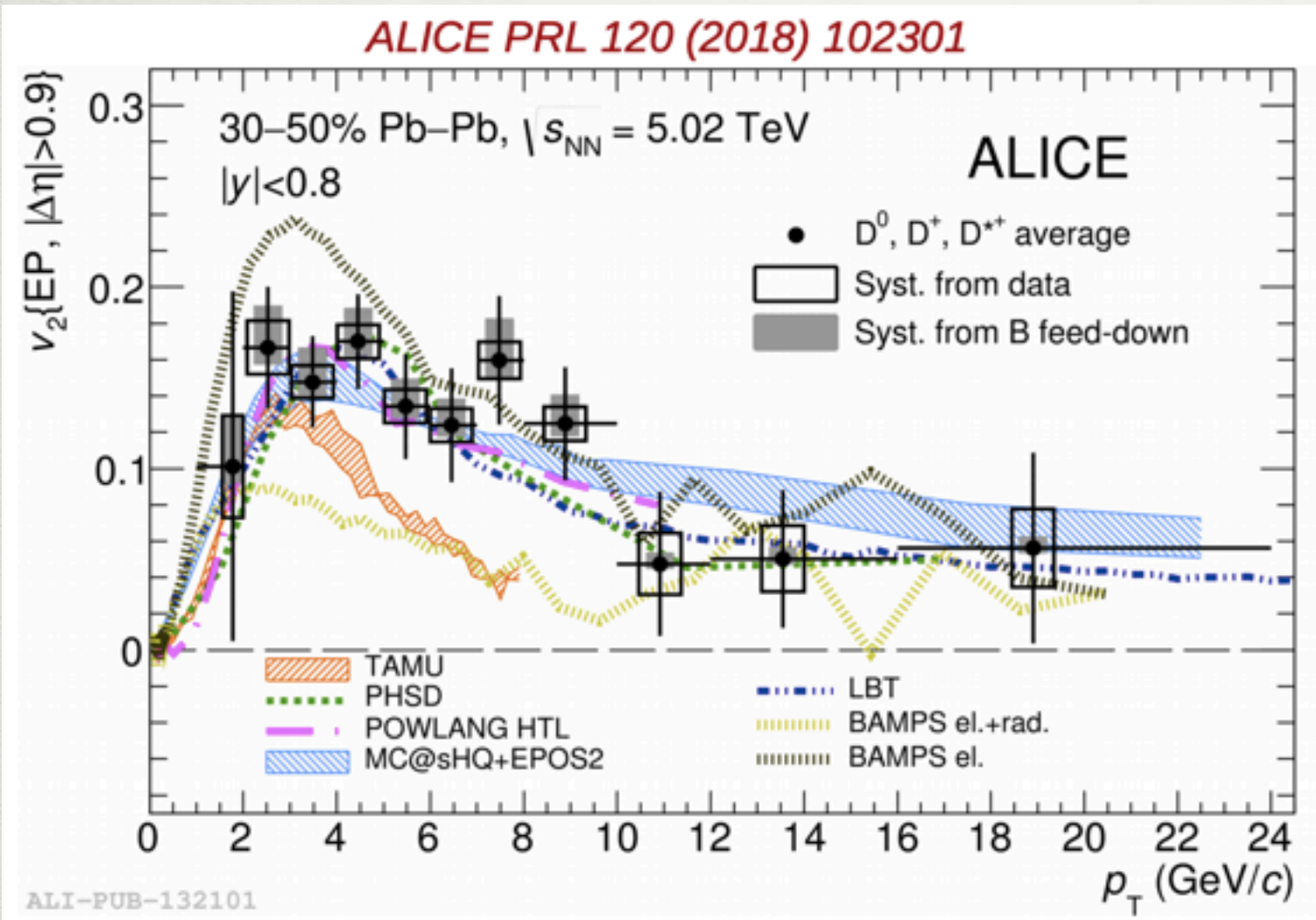
Motivation 1:
What makes theory match data?



What is the data actually telling us?

(Bayesian) Yingru Xe et al, Phys.Rev. C97 (2018) no.1, 014907

DAB-MOD

C. Prado, JNH, R. Katz et al, Phys. Rev. C96, 064903 (2017)

***Roland Katz, Caio A.G. Prado**, et al, arXiv:1906.10768 & arXiv:1907.03308*

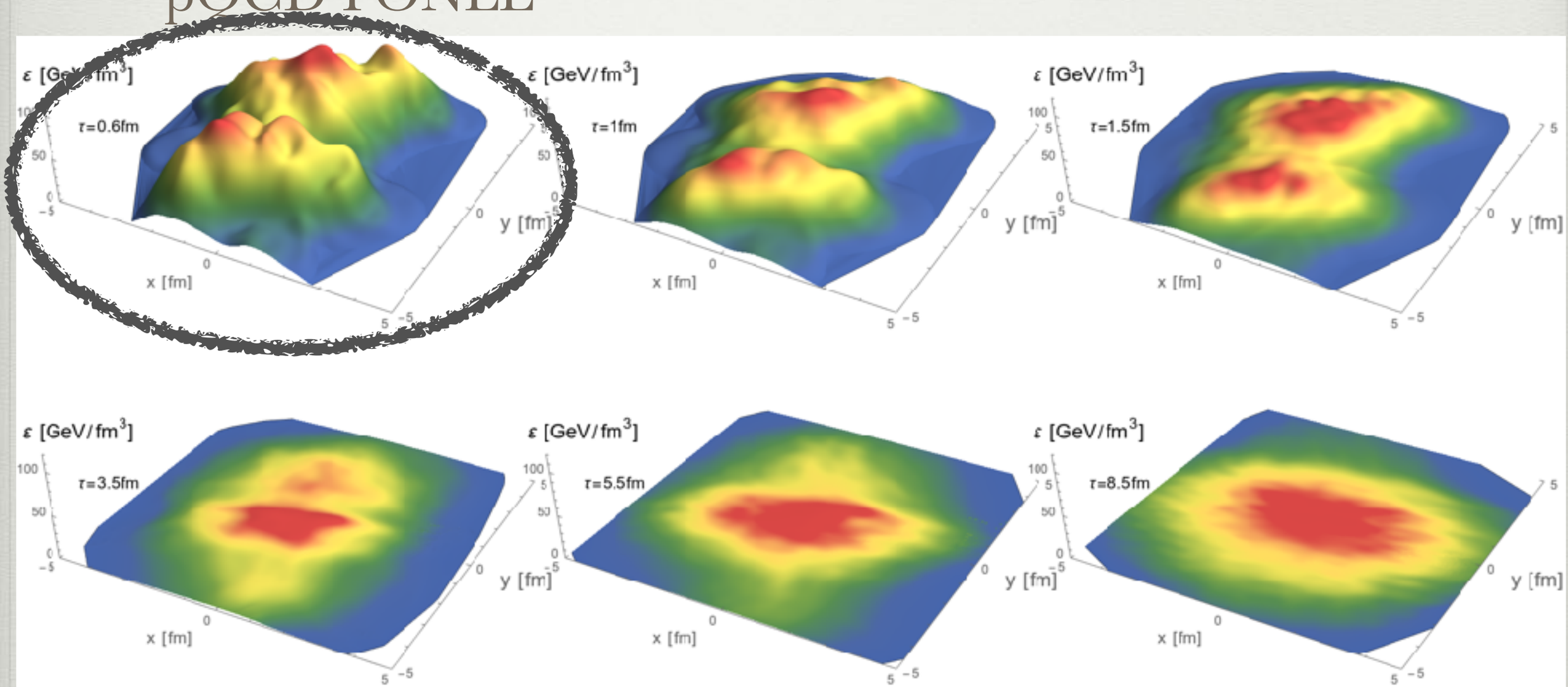
- Heavy flavor (D and B mesons) package that allows for a variety of parameterized energy loss models or *relativistic Langevin models*.
- *Coalescence*

New additions

- Event-by-event relativistic viscous hydrodynamics v-USPhydro JNH et al, PRC88(2013)no.4,044916; PRC90(2014)no.3,034907
- pQCD FONLL calculations for initial quark distributions

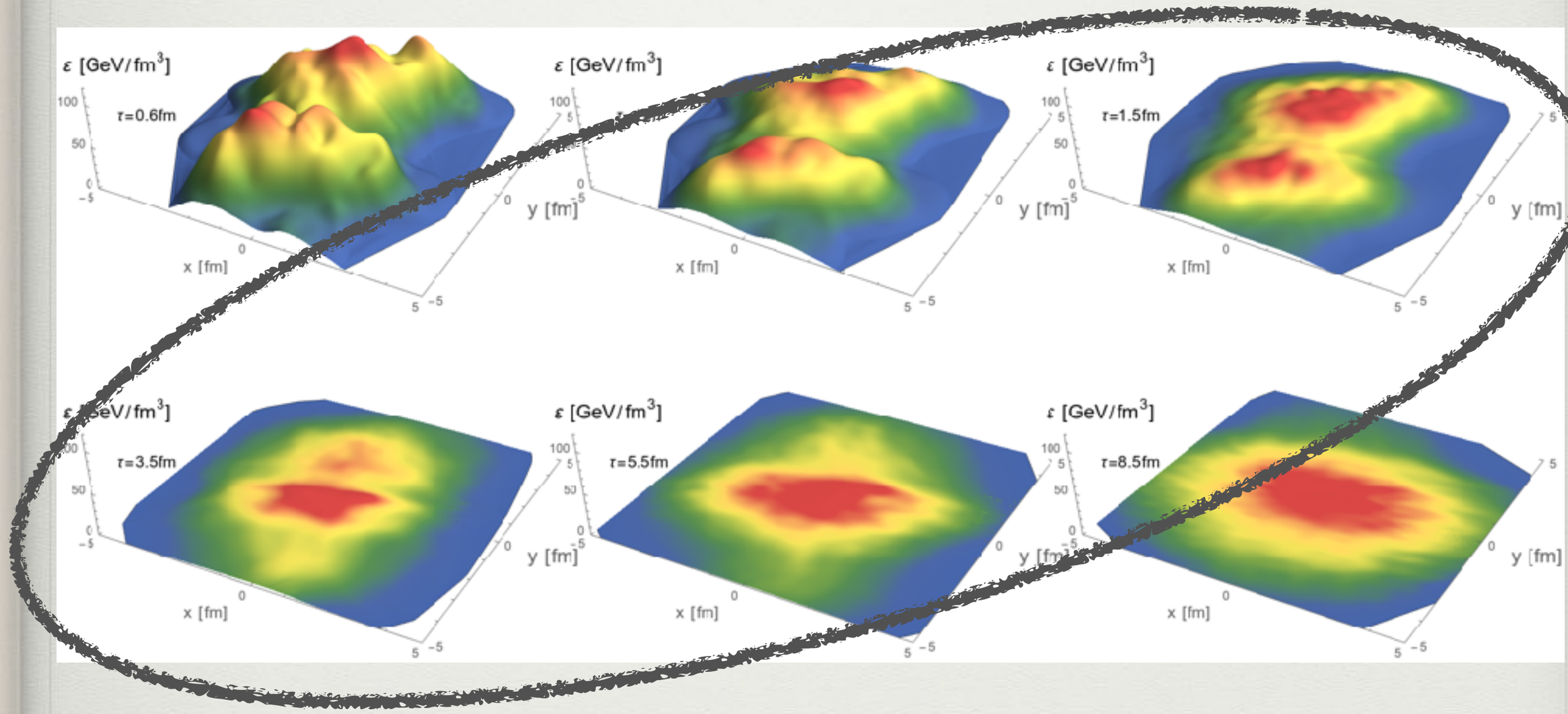
Initial conditions:
Trento/mckln
Heavy Quark Sampling:
pQCD FONLL

Oversampling of heavy quarks
No cold nuclear matter effects or shadowing



Minimum 1000 initial conditions/centrality

Hydro evolution: v-USPhydro
Heavy quark evolution: Either parameterized energy loss or relativistic Langevin model

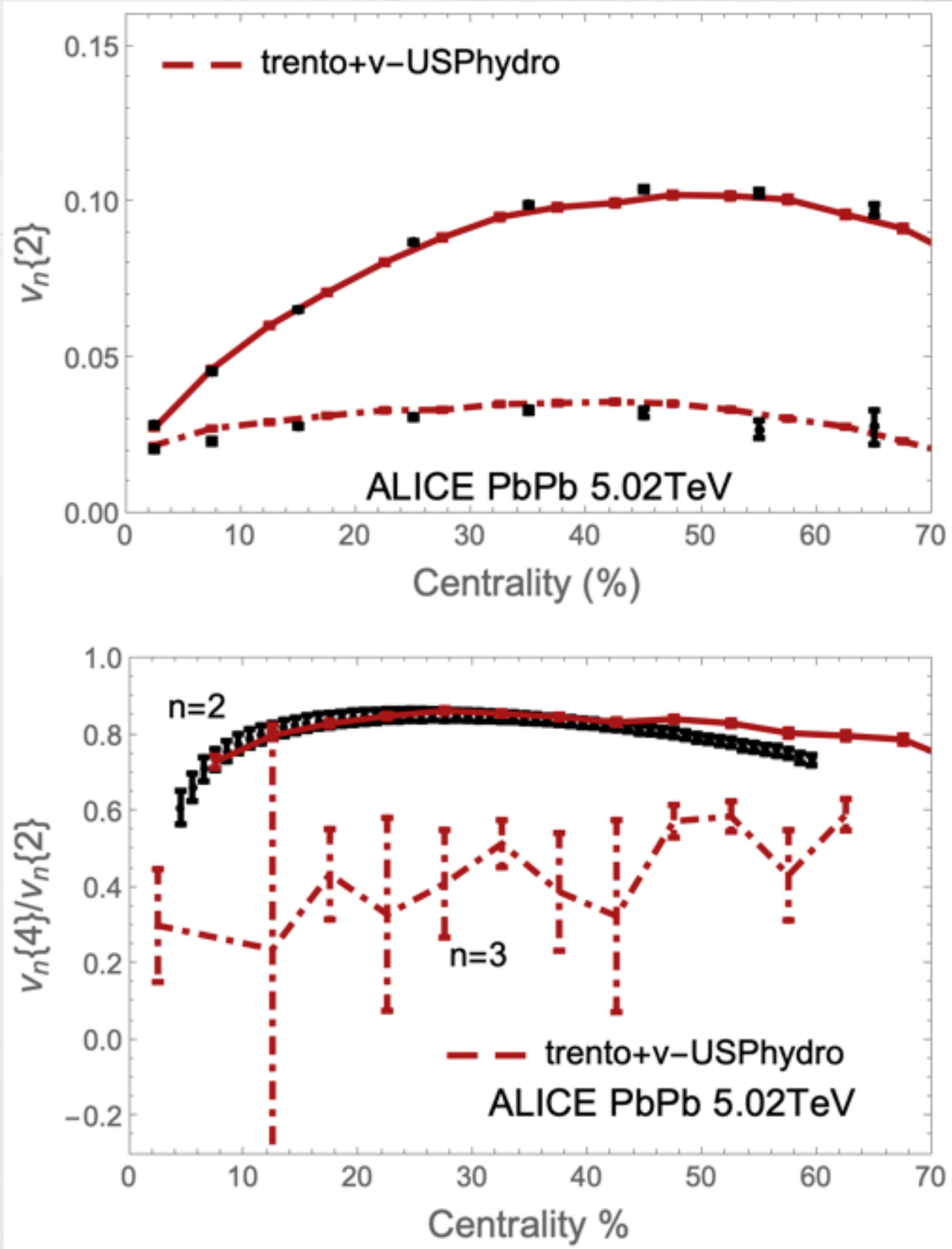


Hydrodynamic parameters tuned to reproduce soft observables

Trento+v-USPhydro

Alba et al, Phys.Rev. D96 (2017) no.3, 034517

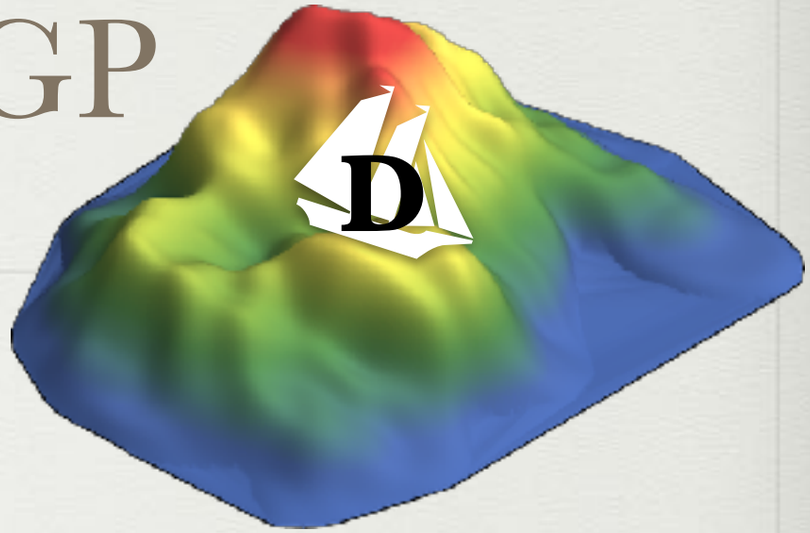
- Trento initial conditions
  - Moreland, Bernhard, Bass Phys.Rev. C92 (2015) no.1, 011901
- v-USPhydro
  - Phys.Rev.C 90 (2014) 3, 034907; Phys.Rev.C 88 (2013) 4, 044916
- Equation of State: EOS2+1 from Lattice QCD
  - [WB] Phys. Lett. B 370 (2014) 99-104
- Viscosity $\eta/s = 0.047$
- Freeze-out $T_{FO} = 150\ MeV$
- PDG16+
  - [WB] Phys.Rev. D96 (2017) no.3, 034517



[Alice] Phys. Rev. Lett. **116**, 132302

Heavy Quarks in a hot QGP

Roland Katz, Caio A.G. Prado, *et al, arXiv:1906.10768 & arXiv:1907.03308*



- Parameterized **Energy loss** model

$$\frac{dE}{dL} = -f(T,p,L)\zeta\Gamma_{flow}$$

- Parameterized Energy loss fluctuations ζ

Betz&Gyulassy JHEP 1408 (2014) 090

- Medium contribution

$$\Gamma_{flow} = \gamma\left[1 - v_{flow}\cos(\phi_q - \phi_{flow})\right]$$

- **Langevin Model** (QCD+HTL)

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

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

Diffusion coefficients from:

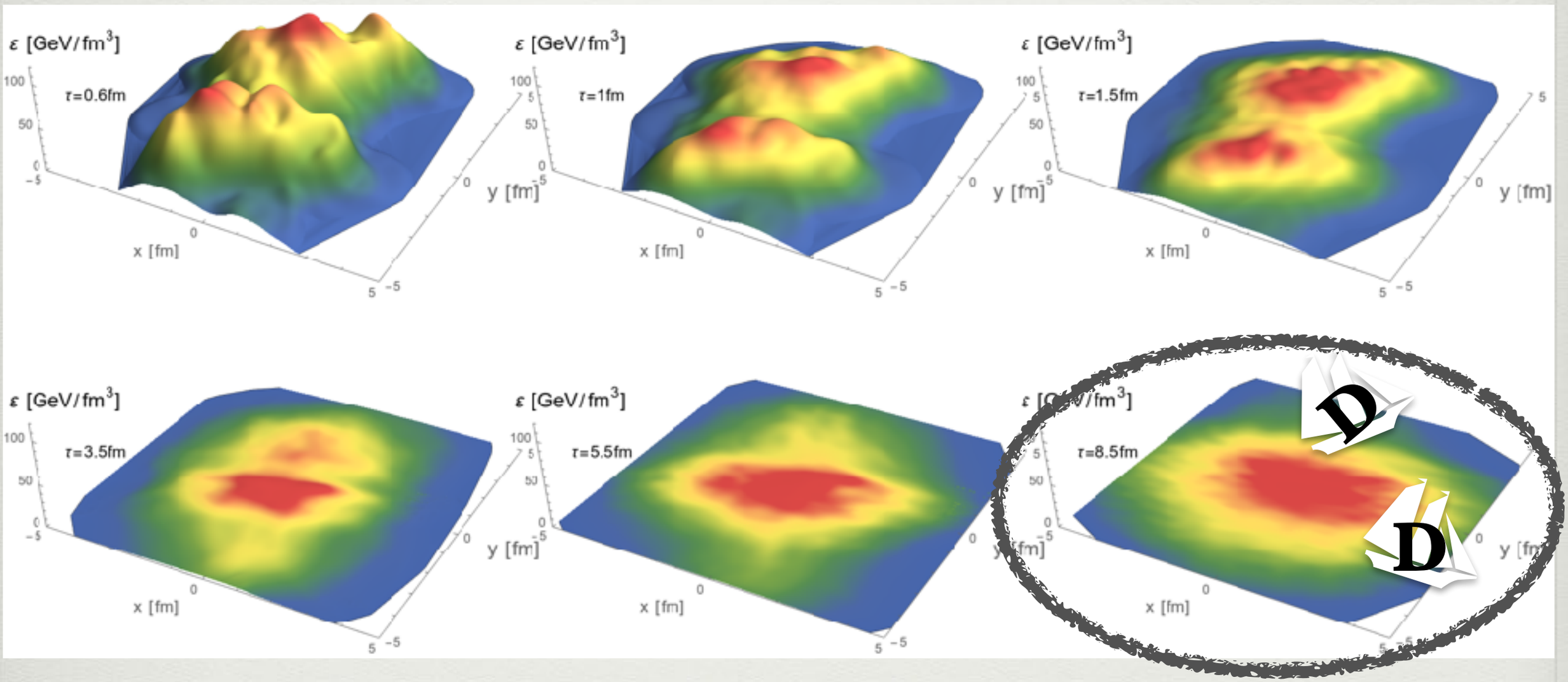
- M&T $D \propto 1/(2\pi T)$

Moore & Teaney Phys. Rev. C71, 064904 (2005)

- G&A running coupling

Gossiaux & Aichelin, Phys. Rev. C 78, 014904 (2008)

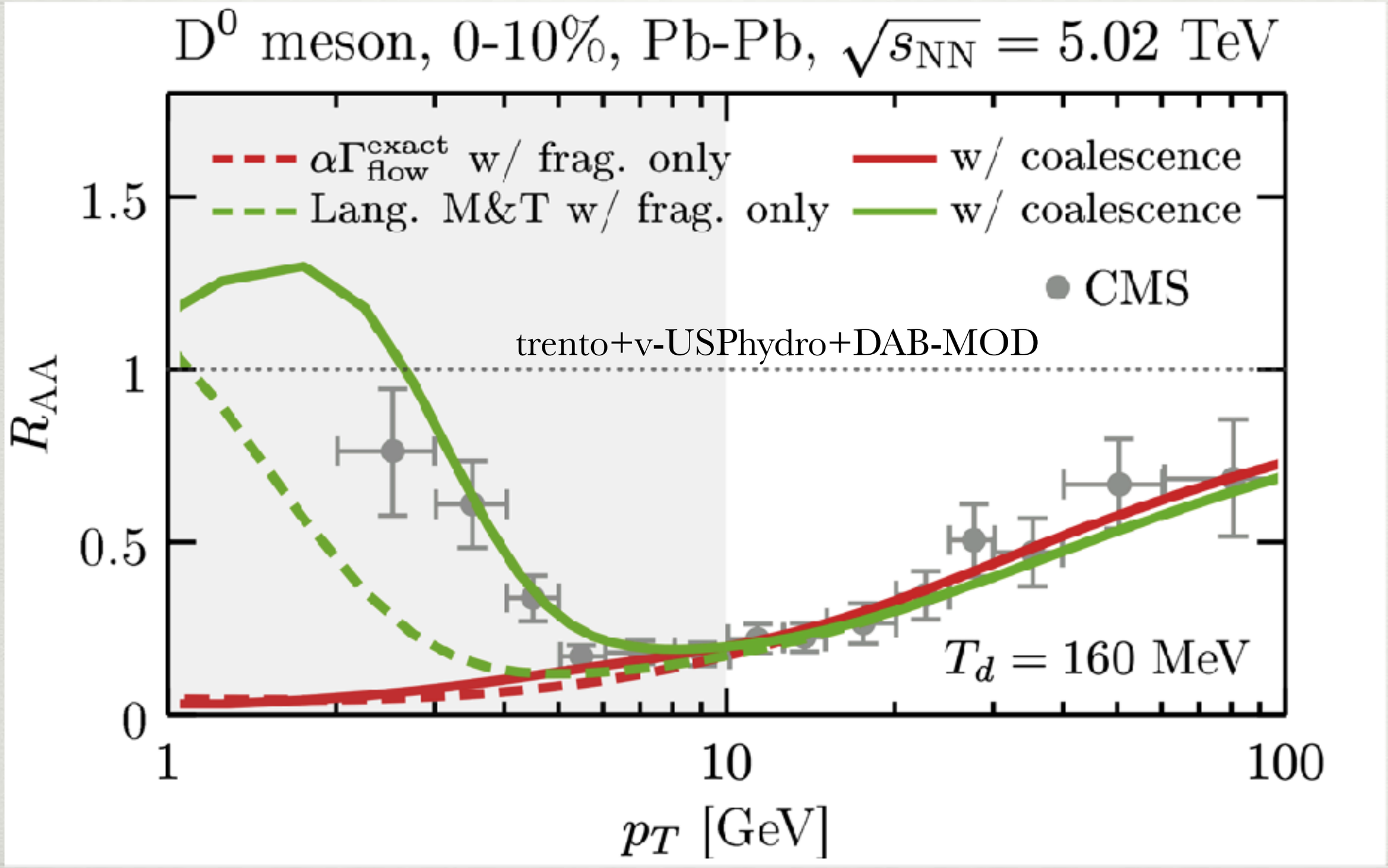
Hydro particlization: Cooper-Frye+decays
Heavy quark fragmentation: Petersen fragmentation function+light/heavy quark coalescence



Semi-leptonic decays done in Pythia8

R_{AA}:"Best Fit" PbPb 5.02 TeV results

***Roland Katz, Caio A.G. Prado**, et al, arXiv:1906.10768*



Azimuthal anisotropies (hard/heavy)

Scalar Product [1]- 1 soft+1 hard particle correlation

$$v_n\{SP\}(p_T) = \frac{\langle v_n^{soft}\, v_n^{hard}(p_T) \cos\left(n\left[\psi_n^{soft} - \psi_n^{hard}(p_T)\right]\right)\rangle}{\sqrt{\left\langle \left(v_n^{soft}\right)^2 \right\rangle}}$$

Rapidity gap to suppress non-flow

Averaging over events [2] ($\sim$ 5% effect theoretically [3])

- Calculated in 0.5% centrality bins
- $\langle \cdots \rangle \rightarrow$ multiplicity weighing
- 0.5% rebinned into 5% or 10%

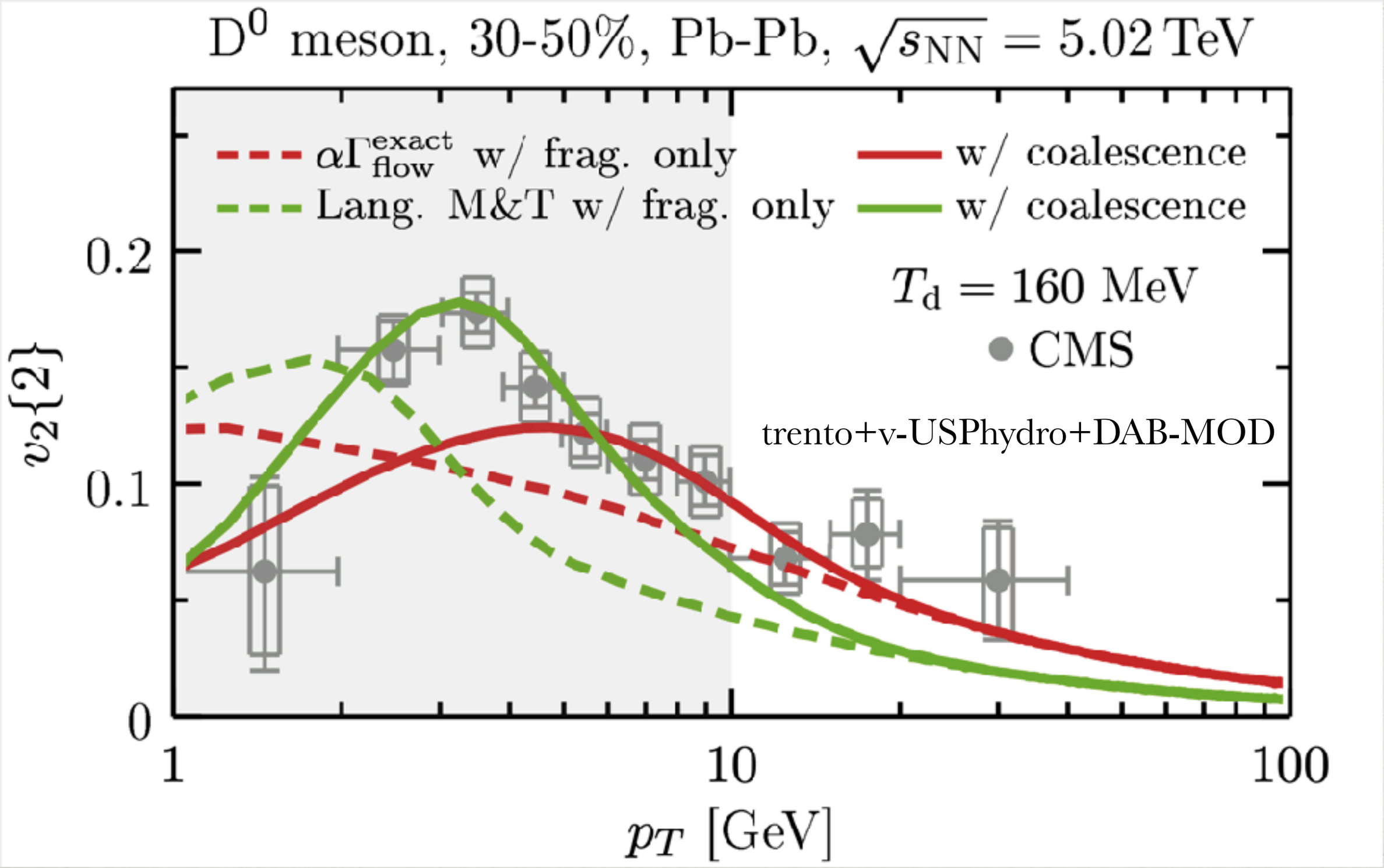
[1] Luzum and Ollitrault PRC87 (2013) no.4, 044907; JNH, Betz, Noronha, Gyulassy Phys.Rev.Lett. 116 (2016) no.25, 252301

[2] Bilandzic et al, PRC83(2011)044913; PRC89(2014)no.6,064904

[3] Gardim, Grassi, Luzum, Noronha-Hostler, Phys. Rev. C 95, 034901 (2017); JNH, Betz, Gyulassy, Luzum, Noronha, Portillo, Ratti Phys. Rev. C 95, 044901 (2017)

$v_2\{2\}$:"Best Fit" PbPb 5.02 TeV

***Roland Katz, Caio A.G. Prado**, et al, arXiv:1906.10768*

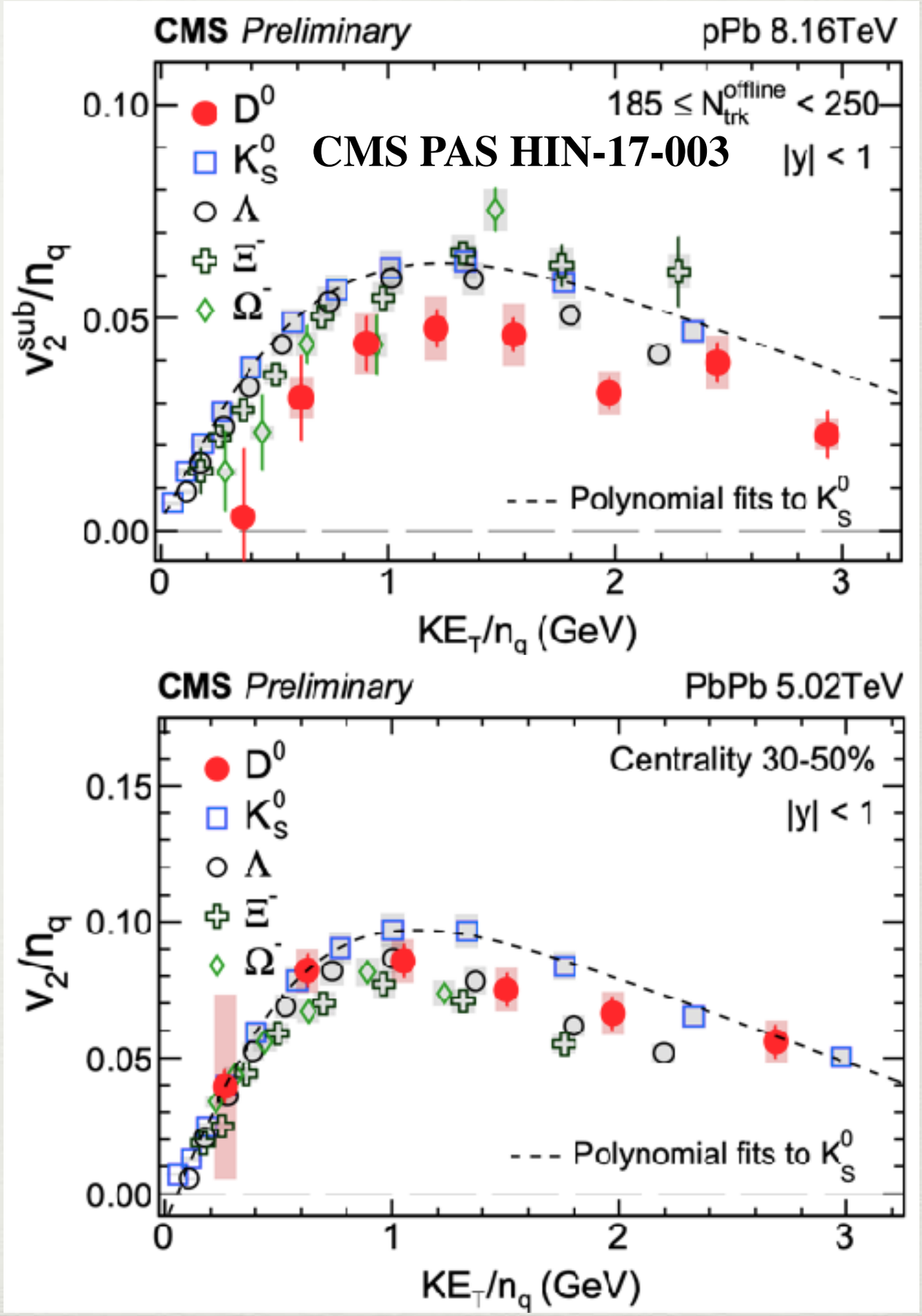


Motivation 2:

D meson scaling with system size

Can we understand system size dependence of energy loss?

Comparisons between soft and hard sector?



PROPOSAL FOR COLLISIONS

$^{40}Ar^{40}Ar$ $^{16}O^{16}O$

arXiv:1812.06772

CERN-LPCC-2018-07
December 18, 2018

Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams

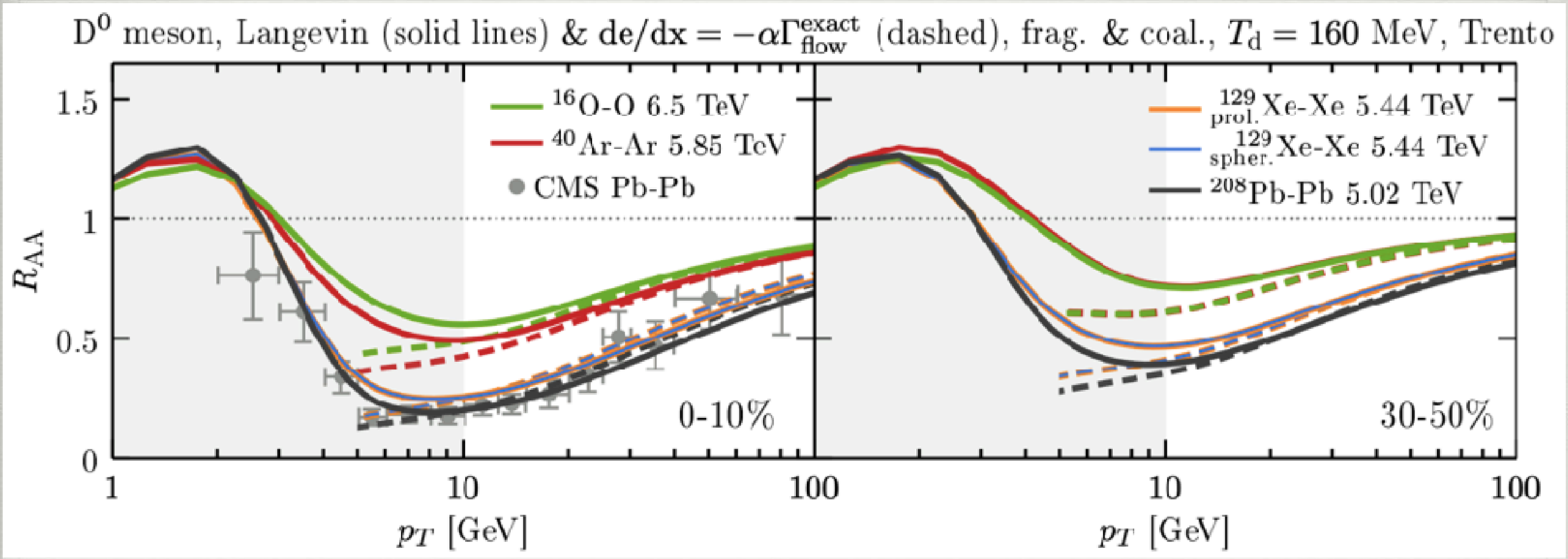
Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

Hydro already worked well with XeXe collisions

Giacalone, JNH, Phys.Rev. C97 (2018) no.3, 034904

R_{AA} across system size

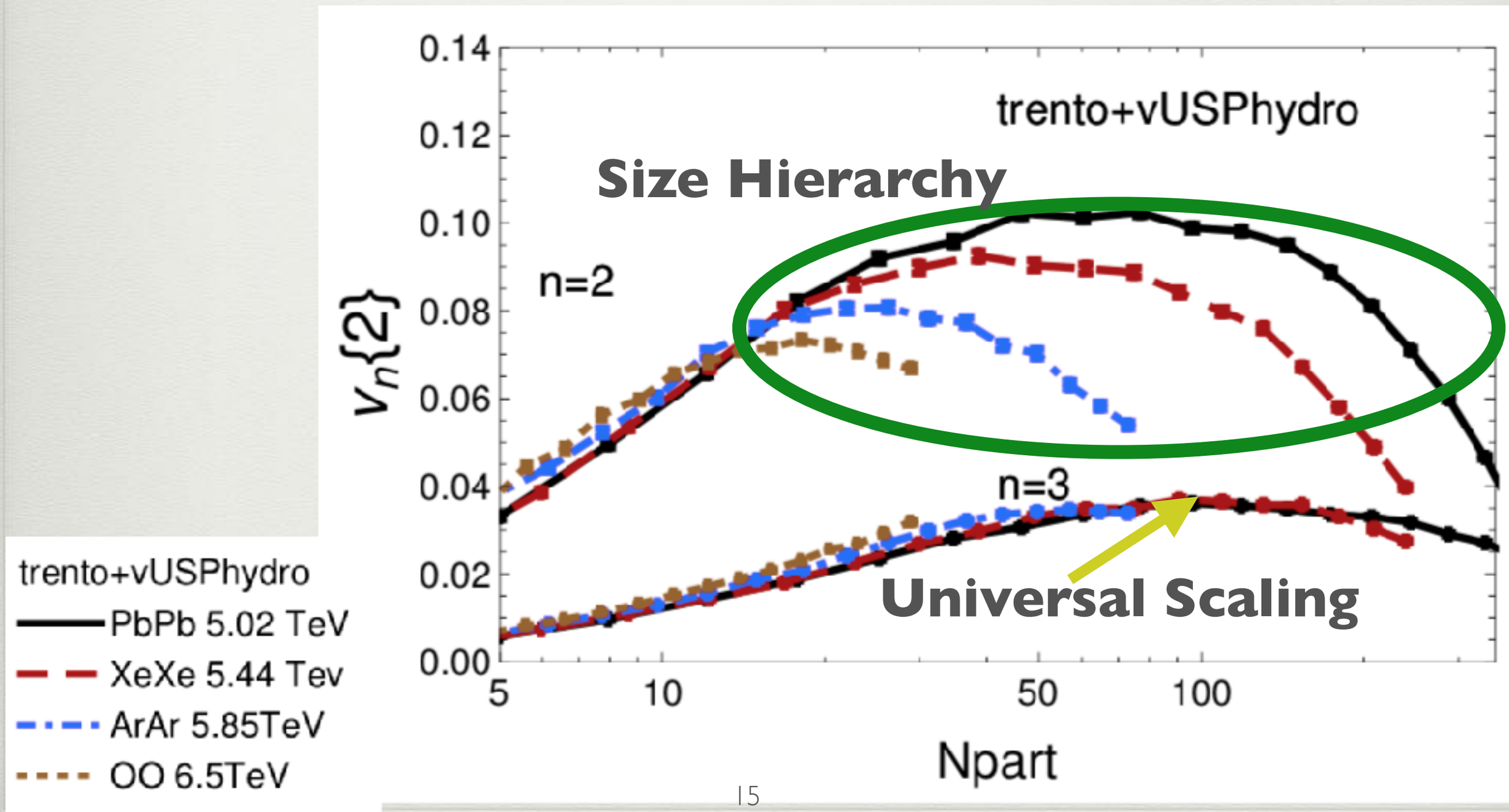
R. Katz, JNH et al, arXiv:1907.03308



- $R_{AA} \to 1$ as the system size decreases
- R_{AA} from energy loss less than from Langevin

SOFT SECTOR: UNIVERSAL SCALING VS. HIERARCHY

Sievert, JNH, *Phys.Rev.C* 100 (2019) 2, 024904



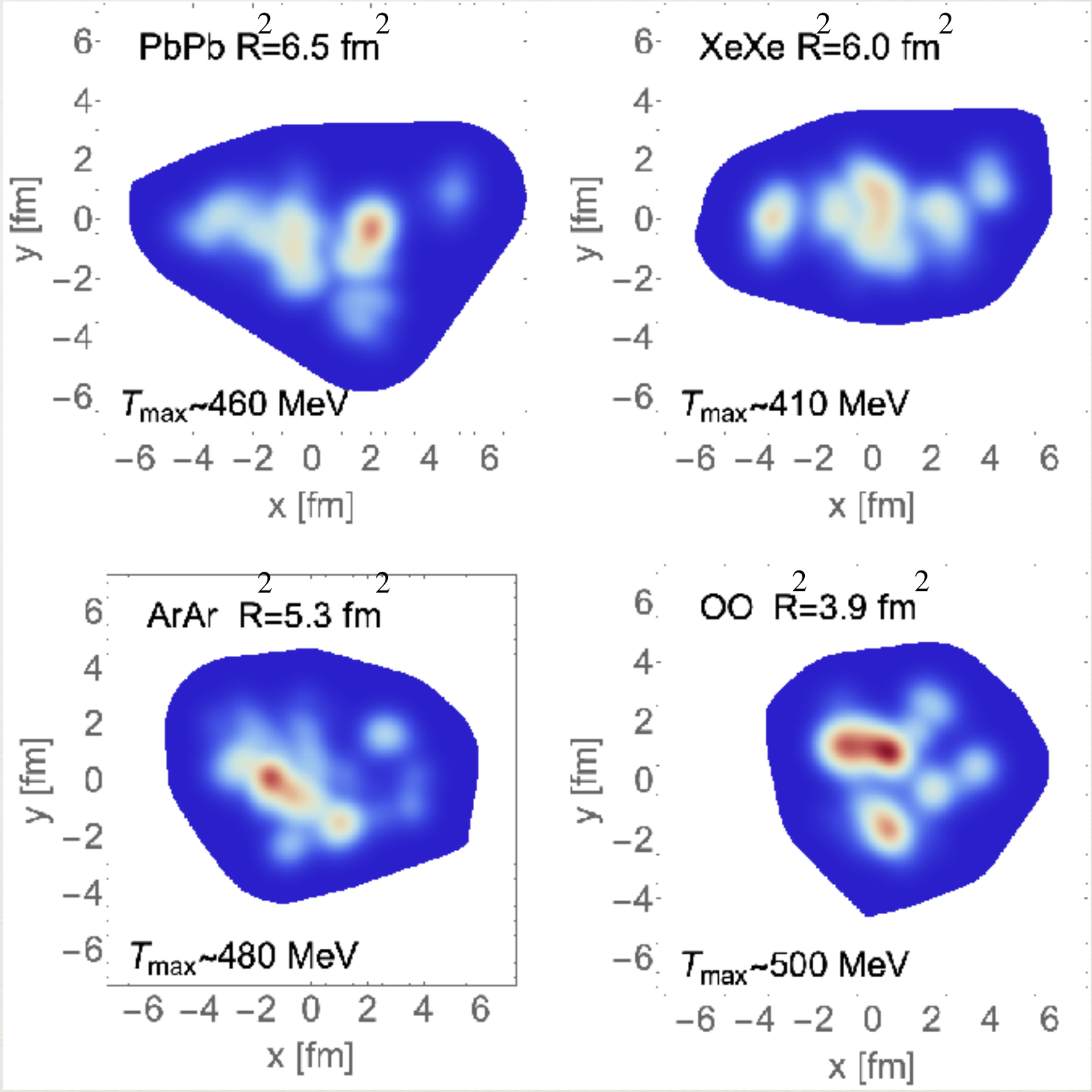
TYPICAL EVENTS

PbPb and XeXe events larger, more elliptical.

ArAr and OO smaller and rounder.

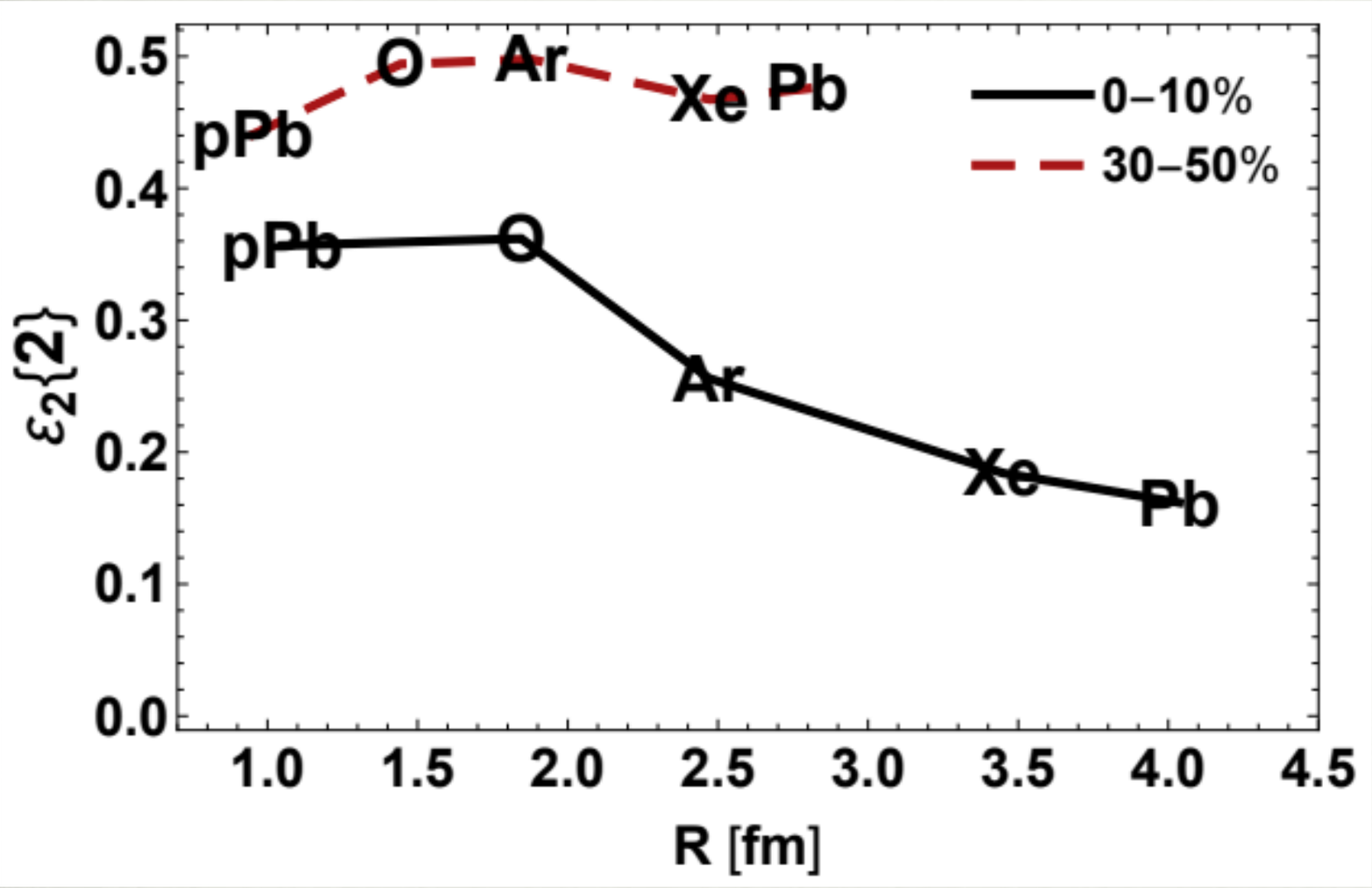
Small systems are hotter

Sievert, JNH, *Phys.Rev.C* 100 (2019) 2, 024904



Geometry and system size

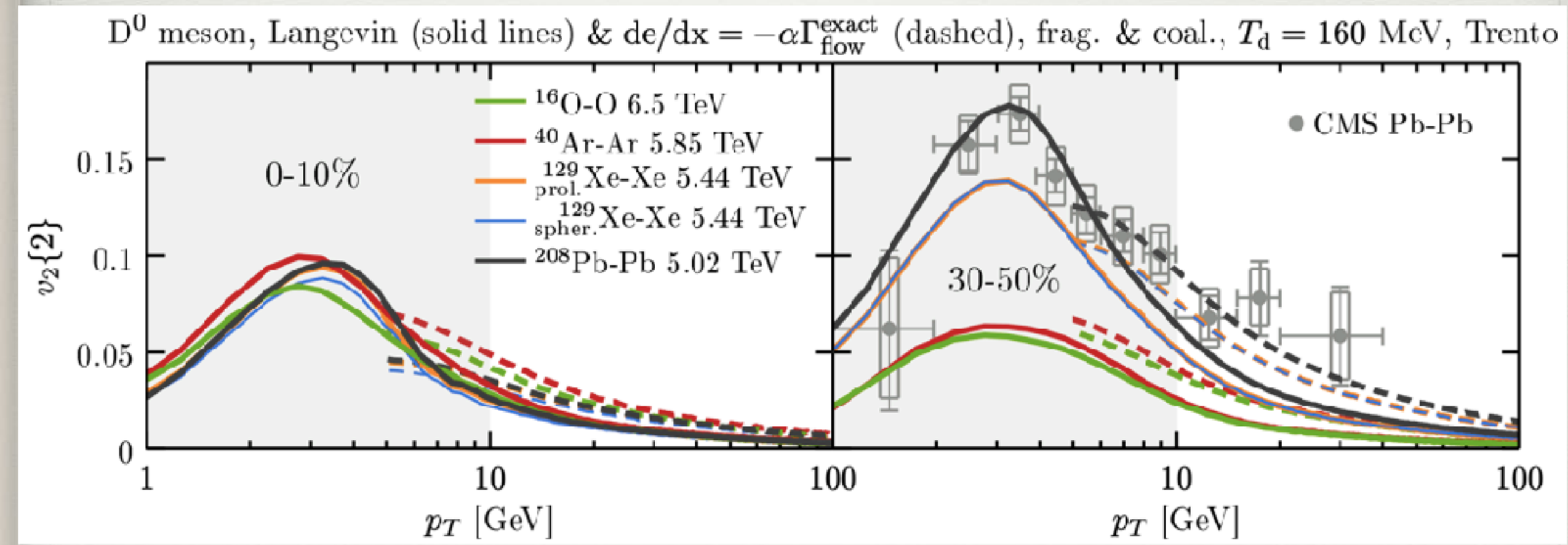
R. Katz, JNH et al, arXiv:1907.03308



- Central collisions: as size ⇓ system is more elliptical
- Mid-central collisions: as size ⇓ system , shape is nearly constant

Mid-Central collisions

R. Katz, JNH et al, arXiv:1907.03308



- **0-10% centrality**: $v_2 \sim$ *const* across system size ($\Uparrow$ in ε_2 with $\Downarrow$ R)
- **30-50% centrality**: $v_2 \Downarrow$ with $\Downarrow$ system size ($\varepsilon_2 \sim$ const.)

Sources of uncertainty

- **Soft sector:** overall normalization constant tuned to dN/dy
- **Heavy flavor sector:** overal normalization constant tuned to R_{AA}

Here we assume both remain constant across system size, but we really need experimental data to be sure!!

Conclusions and Outlook

- DAB-MOD is a modular heavy flavor code that can compare energy loss vs. Langevin directly with the same hydrodynamic backgrounds
  - Langevin works best at low pT and Energy loss at high pT
- Comparing PbPb, XeXe, ArAr, OO collisions:
  - v_2 of D mesons ~const in 0-10% and sensitive to system size in 30-50%
  - More suppression of D mesons from Energy loss than Langevin
- More RHIC/sPHENIX results to come.

BACKUP