

## INTRODUCTION

It is commonly accepted that nuclear matter undergoes a transition to the *Quark-Gluon Plasma* (QGP) for very high energies: simulations on lattice establish that for small densities this is a smooth crossover, but starting at the *Critical End Point* (CEP), this should turn into a first-order transition at high densities.

In order to localize the position of the CEP, and to extract signals for QGP properties, it is important to have a perfect control on the effective models of QCD through which experimental measurements are analyzed.

## THE HRG MODEL

The *Hadron-Resonance Gas* (HRG) model describes the system of strong-interacting hadrons as a non-interacting gas of hadrons and resonances, where resonance formation mediates the attractive interactions among hadrons.

This model has been extremely successful in describing both the particle production of *Heavy-Ion Collisions* (HIC) at the *chemical freeze-out* (FO), and observables calculated on lattice; it can also provide the equation of state of QCD matter which can be used within hydrodynamical simulations.

The HRG model gives a naive description of the degrees of freedom in the confined phase, and it is therefore relatively easy to implement physical effects in order to test new physics and/or to approach the constraints imposed by the experimental setup. Through these implementations one can thus describe: final state re-interaction (isospin randomization), finite acceptance of detectors, canonical suppression due to small sizes of the system and *repulsive interactions*.

## PARTICLE LIST

The main input for the HRG model is the hadronic spectrum; particles are observed by experiments and then listed by the *Particle Data Group* (PDG). The list is updated every year, but it can be extended with predictions from the *Quark Model* (QM). The large abundance of predicted states makes the difference in the description of key observables [1], especially in the less known strange sector. However the wild inclusion of states can easily spoil the description of other observables.

Here I list the number of states present in the PDG and QM lists, classified by families. It should be noted that most of the QM states have very high masses, and that the peculiar configurations would make them very difficult to be measured.		PDG	QM
	$\pi$ (1)	136	329
	N (4)	28	48
	$\Delta$ (8)	22	27
	K (4)	23	42
	$\Lambda$ (2)	19	48
	$\Sigma$ (6)	22	51
	$\Xi$ (4)	11	47
	$\Omega$ (2)	4	15
	Total	738	1525

## EXCLUDED VOLUME EFFECT

Repulsive interactions are neglected in the *ideal* version of the HRG model, but their relevance has been recently pointed out [2, 3]. These can be easily implemented in the HRG through the so called *Excluded Volume* (EV) approach, whose net effect is to balance the "attraction" due to the presence of resonances.

Below I show results for the simultaneous description of particle yields [4] *AND* lattice calculations (including pressure, interaction measure and 7 that the description of the FO surface among fluctuations of conserved charges).

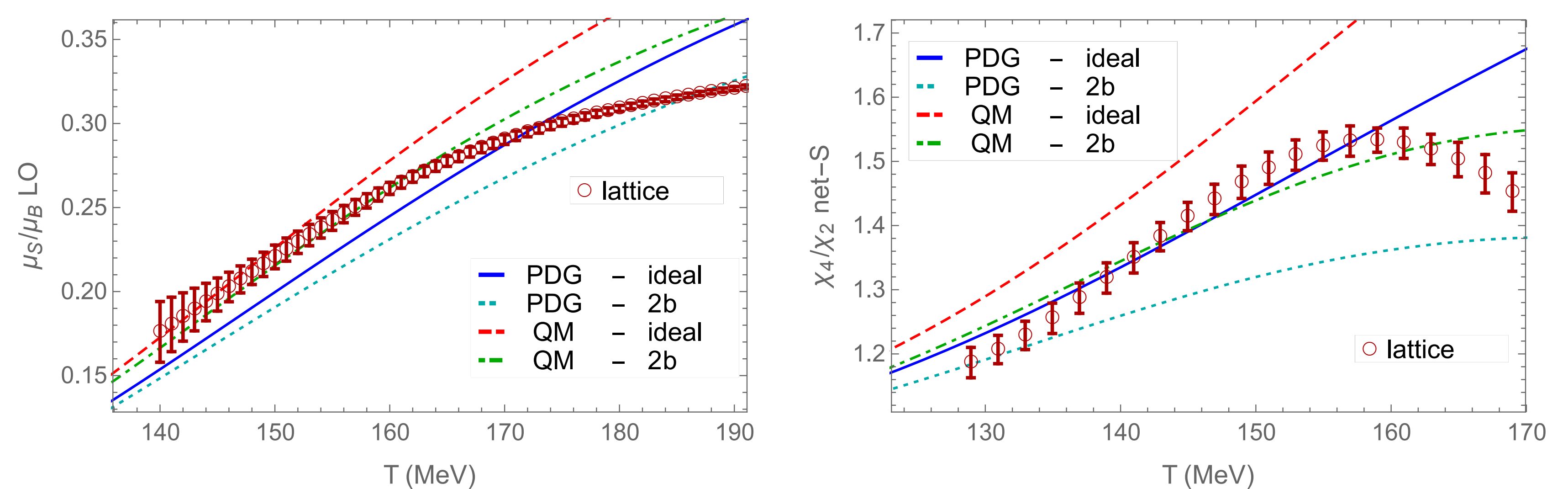
With the EV is possible to parametrize particles' effective size; it can be shown that the description of the FO surface among fluctuations of conserved charges can be improved considering a volume which is directly proportional to the particle mass, and/or with smaller strange states with respect to light ones with the same mass; here I scale volumes accordingly to  $r_p = 0.36$  and  $r_\Lambda = 0.27$  (2b).

	$\chi^2_{yields}$	$T$ (MeV)	$V$ (fm <sup>3</sup> )	$\chi^2_{lattice}$
PDG id	2.81	154.14	5047	9.49
PDG 2b	1.96	157.64	5734	14.07
QM id	1.45	148.39	6227	15.905
QM 2b	2.24	149.27	7483	1.705

## STRANGE OBSERVABLES

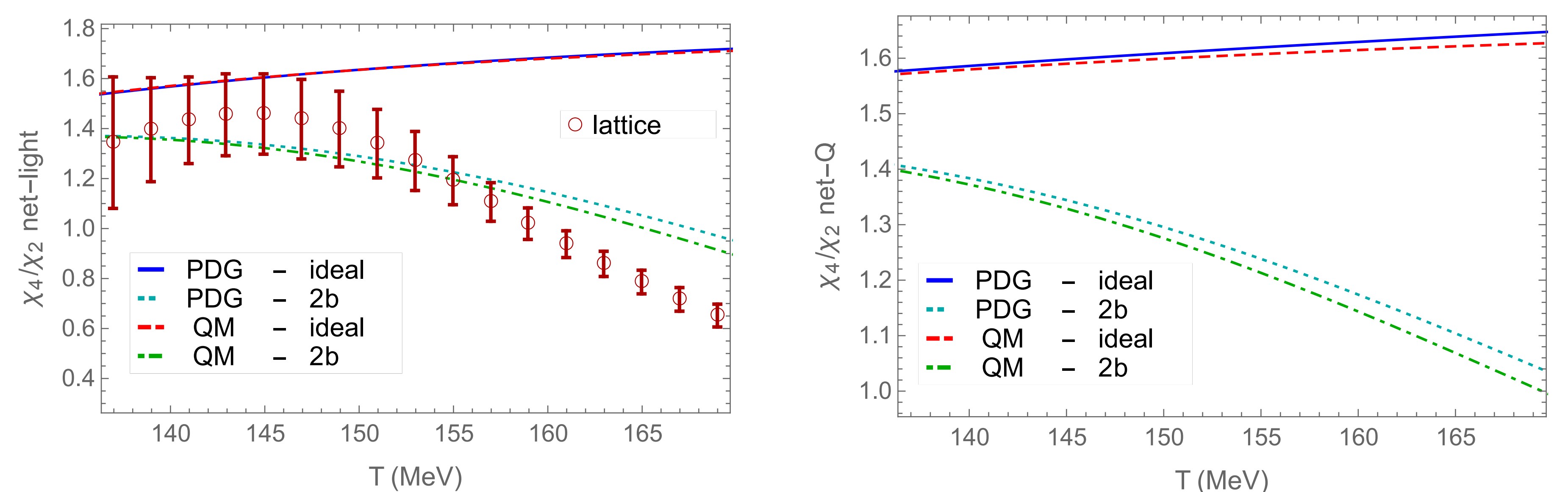
For every particle species it is possible to extract the properties of the corresponding decay channels listed by the PDG; these can then be applied to QM states in order to fit data on particle yields, improving the  $\chi^2$  roughly by a factor 2.

But only with the simultaneous inclusion of QM states and repulsive interactions it is possible to have a good description of both lattice and experimental results. This can be understood observing that EV effects do not spoil the improvement due to QM states for the  $\mu_S/\mu_B$ , and nicely counteract the effect of multi-strange baryons in the  $\chi_4/\chi_2$  for net-strangeness.



## EV SUPPRESSION

One of the major consequences of EV is the suppression of 4th-order cumulants with respect to 2nd-order ones, which is manifest for all quantum numbers like the net-number or light quarks. Observables dominated by light quarks are mostly unaffected by extensions of the particle list, and the available lattice calculations suggest the presence of EV effects; future results on net-charge fluctuations could help to clarify this issue.



## CONCLUSIONS: EV vs CEP

Studies on lattice calculations in the pure gauge sector [5] confirm the need for the EV mechanism. A systematic analysis on the experimental measurements performed by STAR [6] on fluctuations of conserved charges, could give significant insights in this direction: indeed the observed dip in the net-proton kurtosis could be an effect due only to repulsive interactions [7], concealing or making disappear the signal for the CEP.

## REFERENCES

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- [4] P. Alba *et al.*, arXiv:1606.06542 [hep-ph].
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- [7] V. Vovchenko *et al.*, arXiv:1609.03975 [hep-ph].