

Influence of the latest hadronic resonances on lattice QCD comparisons, thermal models, and SMASH



Jordi Salinas San Martín, R. Hirayama, J. Hammelmann, J. M. Kartheim, P. Parotto, J. Noronha-Hostler, C. Ratti, and H. Elfner

Idea

- State-of-the-art EoS of nuclear matter, hydrodynamical simulations, freeze-out and sampling codes, and hadronic transport approaches all use **hadronic lists**.
- Hadron lists in hybrid approaches to heavy-ion collisions **must be the same across all stages of the evolution to remain fully consistent**.
- We constructed a new list, the **PDG2021+** with the latest information on light and heavy resonances.
- We developed a pipeline to quickly update the list and use as input for other frameworks, such as SMASH.

Introduction

- Experiments have observed **more and more massive resonances** over the years.
- Heavy resonances can have an **important impact on the thermodynamics and other observables**.
- Hadronic transport approaches usually have conservative particle lists.

Figure 1 shows the baryon mass spectra from the new PDG2021+, the preceding PDG2016+, and the default list included in SMASH 2.2. Newly observed states are found on the spectra for all families. Mass, width, decay channels, and branching ratios have been updated.

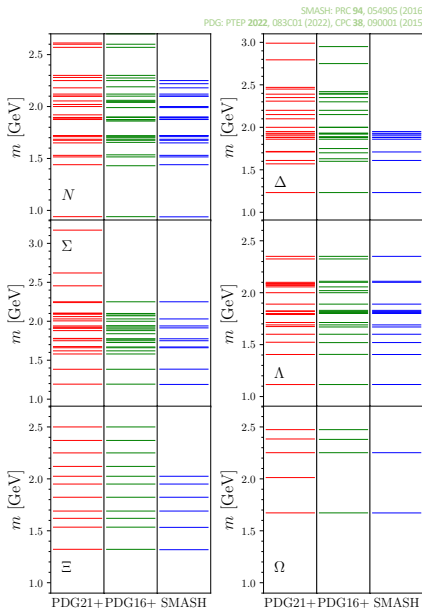


Figure 1

Results

Partial pressures

- Thermodynamics can be tested by **comparing against lattice QCD results**.
- Using the hadron resonance gas (HRG) model, we compute the total pressure of the gas, as well as the individual contributions per particle family, or **partial pressures**.

In Fig. 2, we show the partial pressures from N 's and Δ 's, as well as Ω 's. Up to the range of validity of the HRG model ($T \sim 150$ MeV), all hadronic lists considered describe lattice data well for non-strange baryons. **Recently discovered Omega states improved partial pressure comparisons to lattice QCD.**

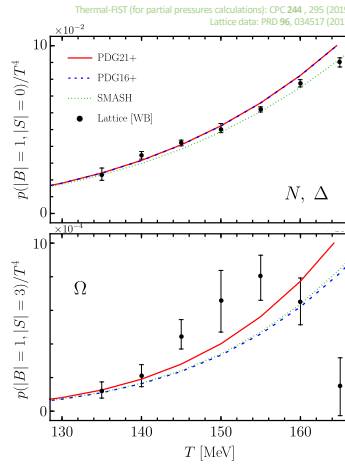


Figure 2

Susceptibilities

- Susceptibilities of conserved charges and their ratios are sensitive to the flavor content of hadrons.**
- $\chi_{11}^{BQ} / \chi_2^B$ susceptibility ratio is particularly sensitive to the proportional content of charged baryons with respect to the total baryons.

Figure 3 shows the $\chi_{11}^{BQ} / \chi_2^B$ susceptibility ratio for three different hadronic lists and lattice results. **The extended lists are consistently better at describing the data and agree with the results from lattice, up to the limiting T of the HRG.**

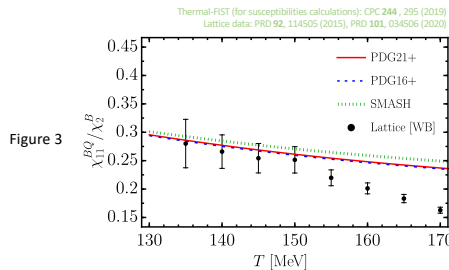


Figure 3

Thermal models

- HRG model is also used to **fit the hadron yield data** assuming thermal and chemical equilibrium at freeze-out.
- With a χ^2 -minimization, the **best fitting chemical freeze-out parameters T , μ_B , and V are extracted**.

In Fig. 4 we used Thermal-FIST to calculate the yield for 0-10% Pb-Pb at $\sqrt{s} = 5.02$ TeV for the PDG2021+ in the 1FO and 2FO scenarios. In the former, all particles freeze-out at the same temperature, whilst on the second strange particles freeze-out at a higher temperature. **Compared to other lists, the PDG2021+ improves the fit to experimental data.**

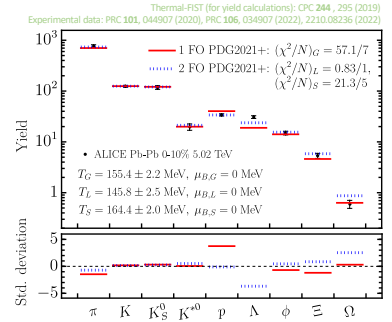


Figure 4

Momentum spectra

- The p_T spectra for identified particles can also be affected by using a different list.
- This is important when extracting the bulk viscosity from hydrodynamic simulations.
- We use a blast-wave model to show the effect on spectra.
- Hadronic transport approaches often only allow $1 \rightarrow 2$ -body decays, and hadronic lists must be adapted.**

In Fig. 5, the p_T spectra after a blast-wave model with direct decays is shown for two different lists: the PDG2021+ and SMASH. We include the cases of $1 \rightarrow 2$ -body and complete decays. **A noticeable change in slope can be observed, particularly for pions. Consequently, $\langle p_T \rangle$ also changes.**

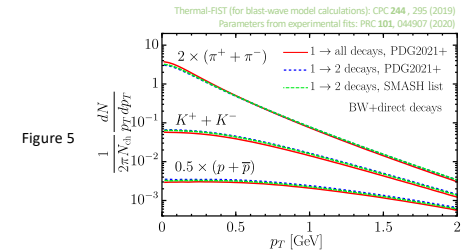


Figure 5

Conclusions

A complete and updated hadronic list that is used at all stages of the evolution of a heavy-ion collision is needed to be **fully consistent**. Including more resonances can have a **significant impact** on thermodynamics, particle yields, and p_T spectra.