UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

muses

smash

Illinois Center for Advanced Studies of the Universe

Influence of the latest resonances from PDG on thermal models and lattice QCD comparisons

In collaboration with: R. Hirayama, J. Hammelmann, J. Karthein, P. Parotto, J. Noronha-Hostler, H. Elfner, C. Ratti, MUSES Collaboration

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Roadmap to a new lattice-based EoS

HRG with the latest experimental data

PDG: pdg.lbl.gov

Compare thermodynamics with lattice results

see A. Acuña Nava's talk

Export hadron list to CMF

see N. Cruz's talk

Adapt hadronic list to SMASH

Calibrate SMASH

see R. Hirayama's talk

Merge with lattice

J. Noronha-Hostler, P. Parotto, J. Karthein, C. Ratti, 1902.06723

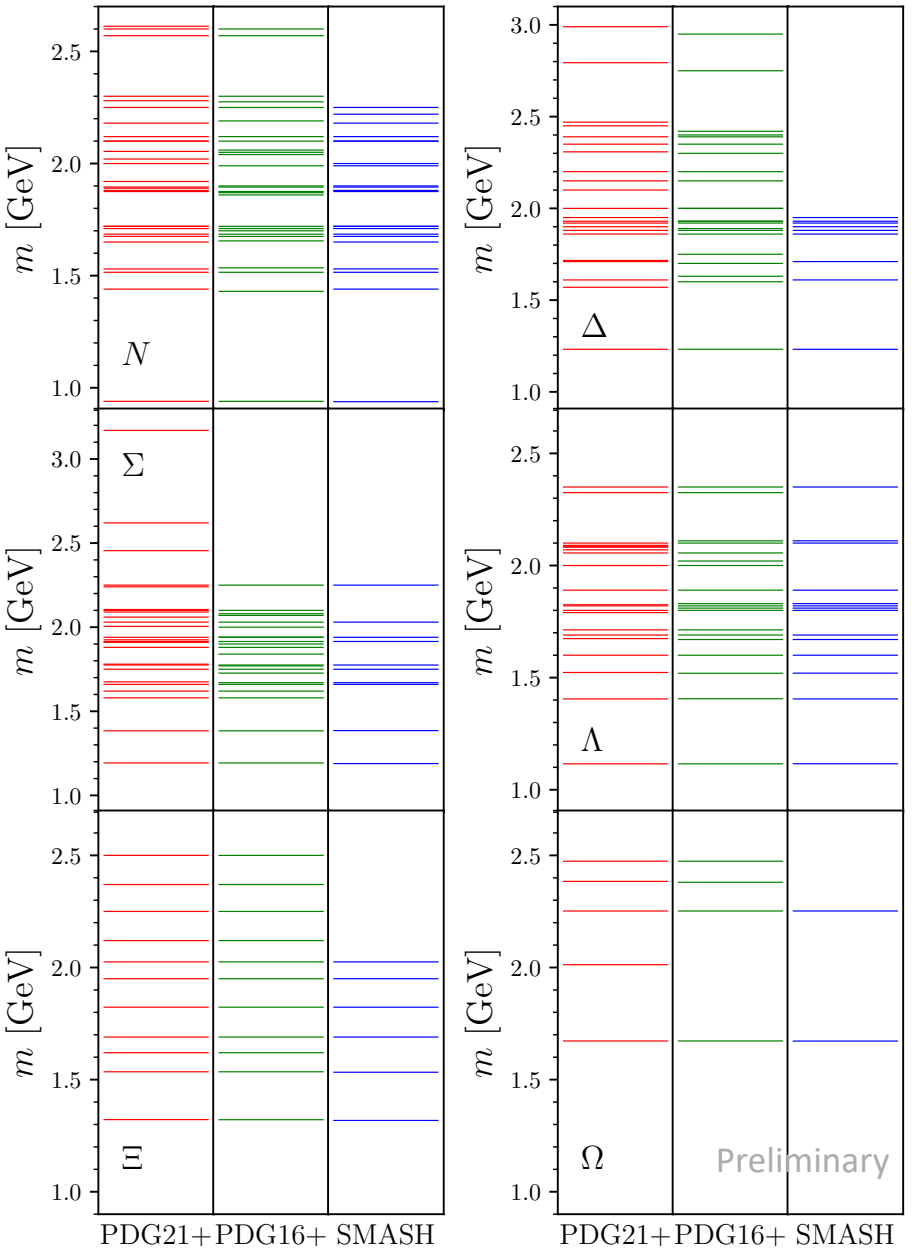
P. Parotto, D. Mroczek, J. Noronha-Hostler, C. Ratti et al., 1805.05249

J. Karthein, D. Mroczek, A. Acuña Nava, J. Noronha-Hostler, P. Parotto, C. Ratti et al., 2103.08146

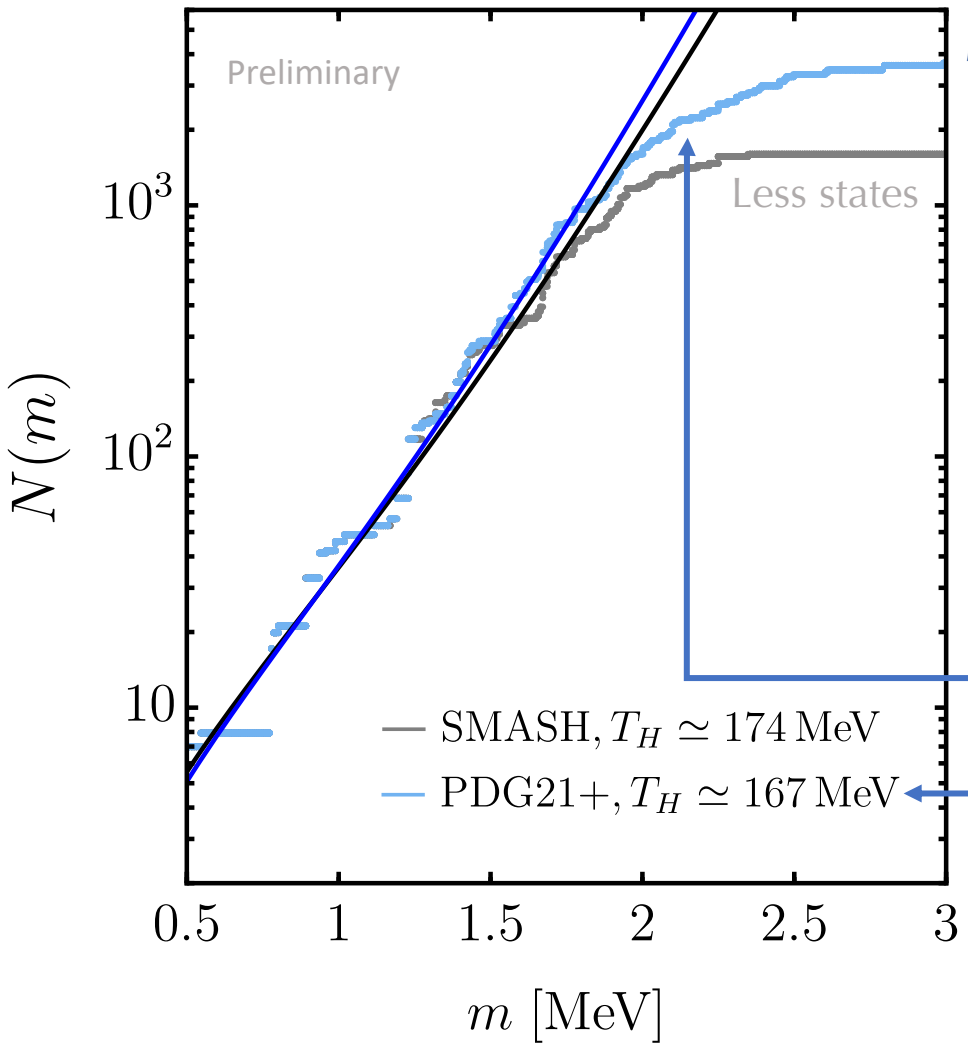
Goal: construct a consistent new EoS that can be used troughout a HIC simulation

Latest PDG data

- Centralized hadronic database based on the PDG
- Tracks several particle properties, e.g., mass, width, isospin, etc.
- Has all hadrons and their reported branching ratios
- 760 particles
- Updated branching ratios vs. PDG16+
- Contains *–**** particles



A lower limiting temperature



Hagedorn observed an exponentially rising spectrum which led to the conclusion there was a limiting hadron temperature

$$N(m) = \int_0^m \rho(m')dm'; \quad \rho(m) \sim m^{-a} e^{m/T_H}$$

Adding more hadronic states supports the exponentially rising spectrum

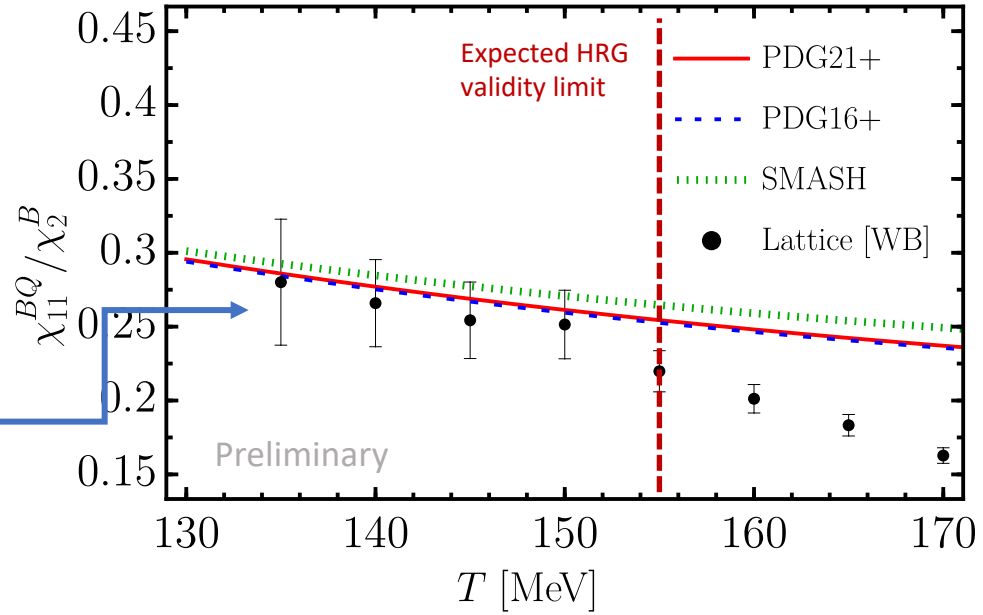
The extracted temperature becomes closer to the pseudo-critical temperature from LQCD

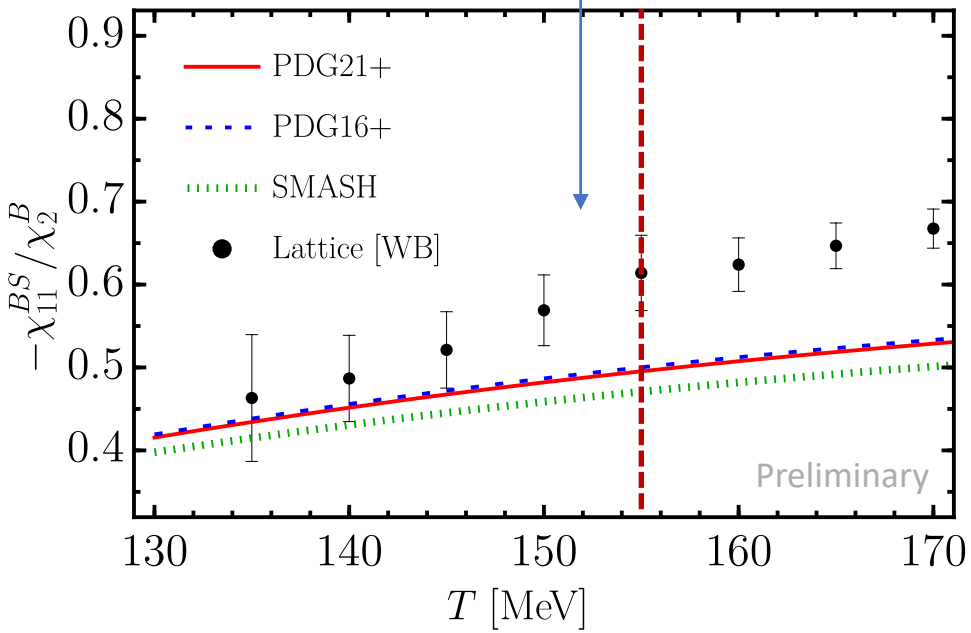
HRG susceptibilities vs LQCD

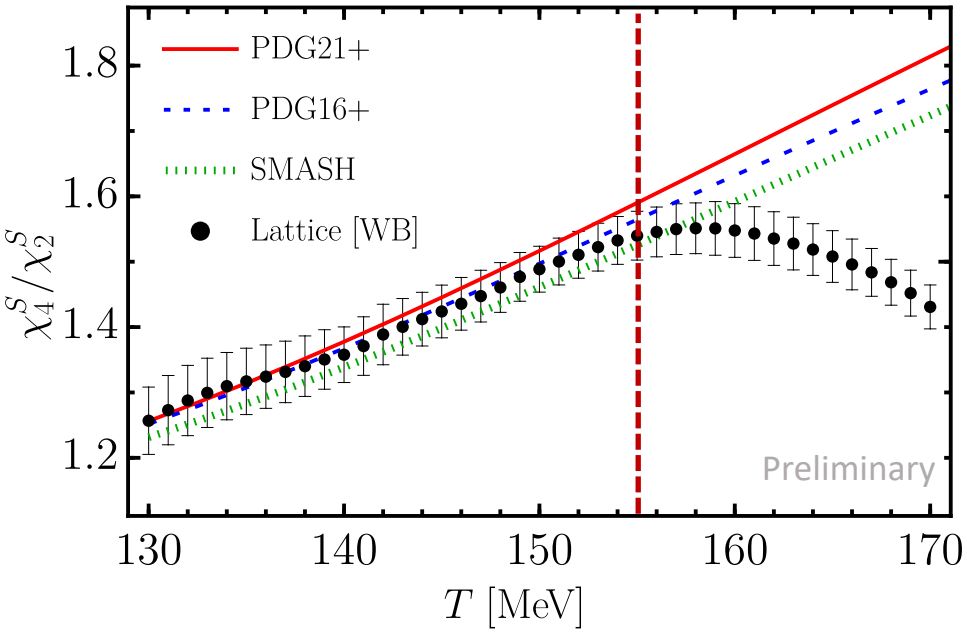
Disagreement with lattice data hints at missing strange resonances (Λ, Σ, Ξ, Ω)

A flavor-dependent excluded volume could improve this comparison; see 2107.00588

The new list is consistent with both the previous PDG2016+; more strange particles could improve this too

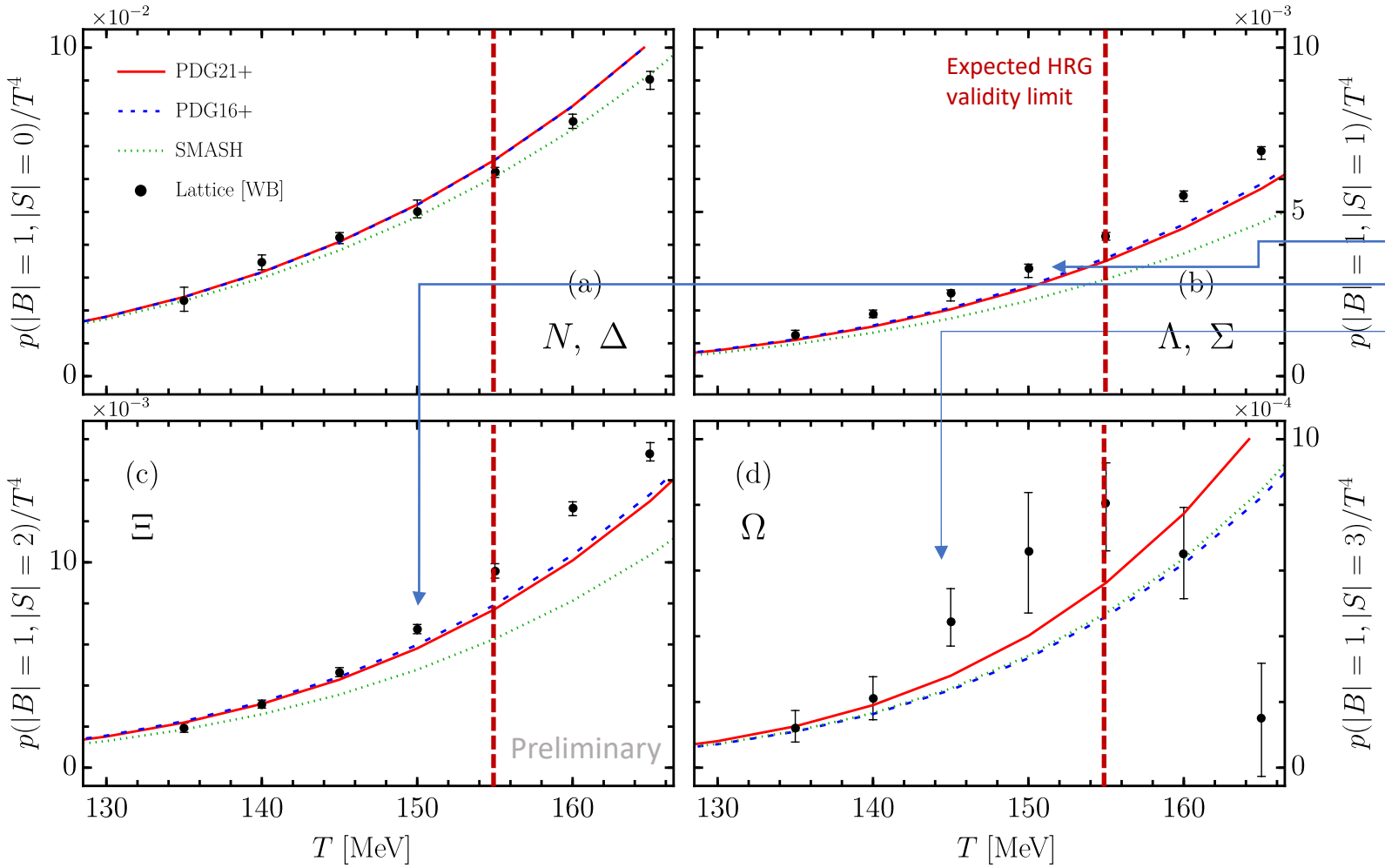






Excluded volume can capture the drop; see 2107.00588

HRG partial pressures vs LQCD



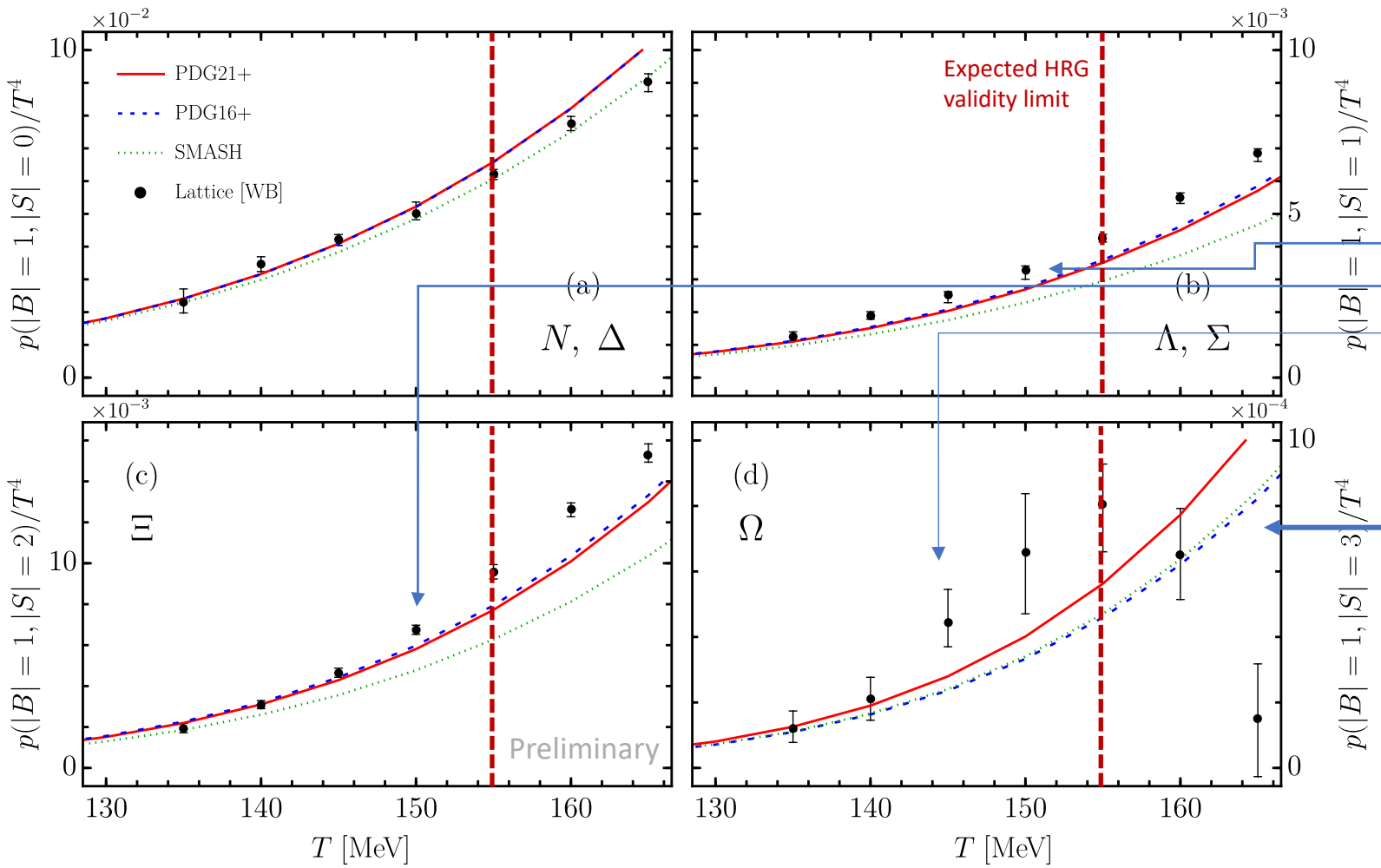
The new PDG2021+ list is in agreement with the previous results from PDG2016+.

Disagreement with lattice data hints at missing strange resonances (Λ, Σ, Ξ, Ω)

see KLF Collaboration proposal at JLAB, 2207.10779

$$\frac{p}{T^4} = \phi_0 + \phi_{01}\cosh(\mu_S/T) + \phi_{10}\cosh(\mu_B/T) + \phi_{11}\cosh(\mu_B/T - \mu_S/T) + \phi_{12}\cosh(\mu_B/T - 2\mu_S/T) + \phi_{13}\cosh(\mu_B/T - 3\mu_S/T)$$

HRG partial pressures vs LQCD



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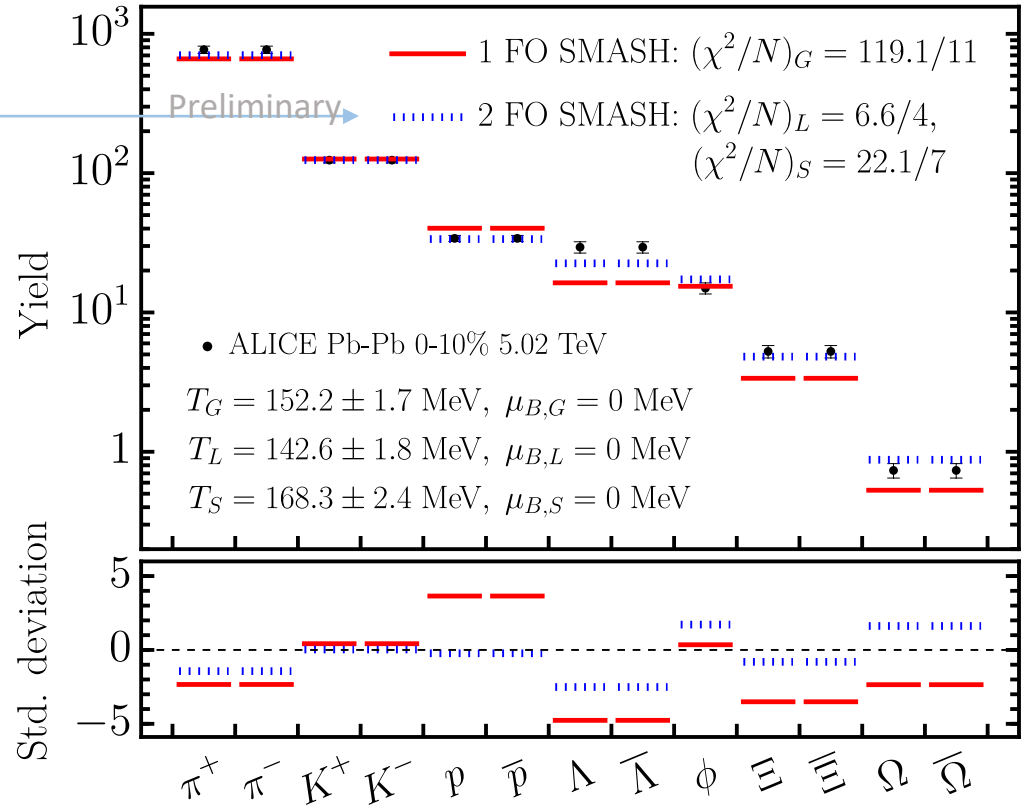
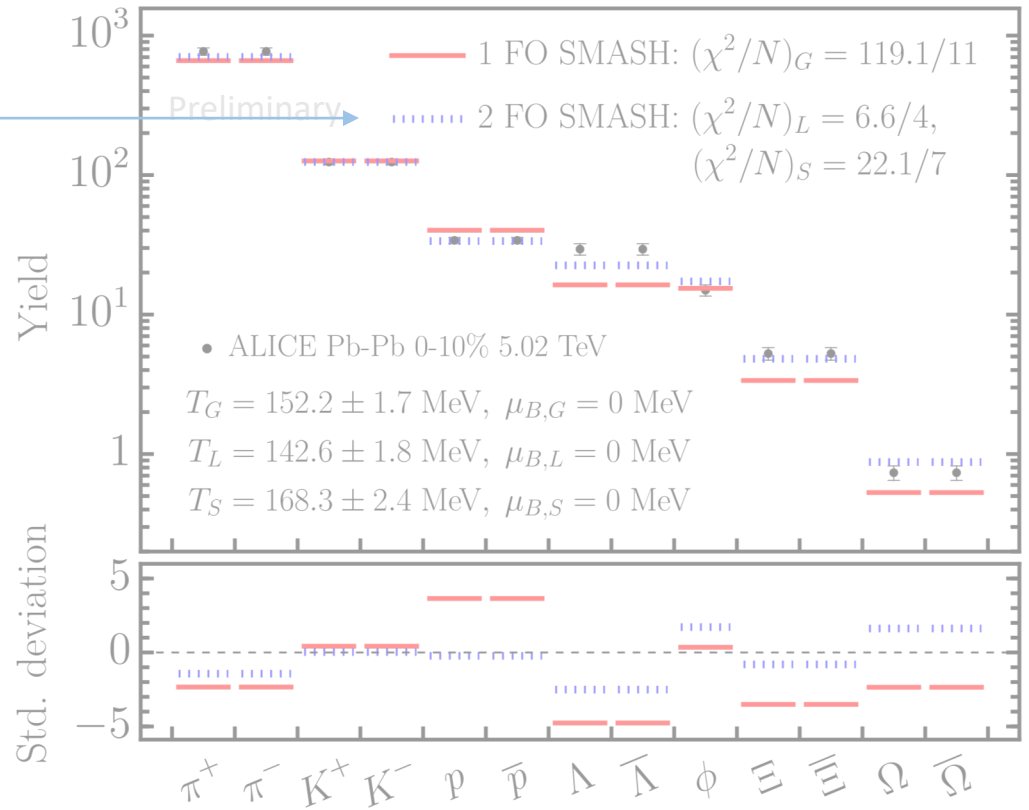
New high-confidence Ω baryon contributes pronouncedly to the triple-strange partial pressure

Thermal model yields



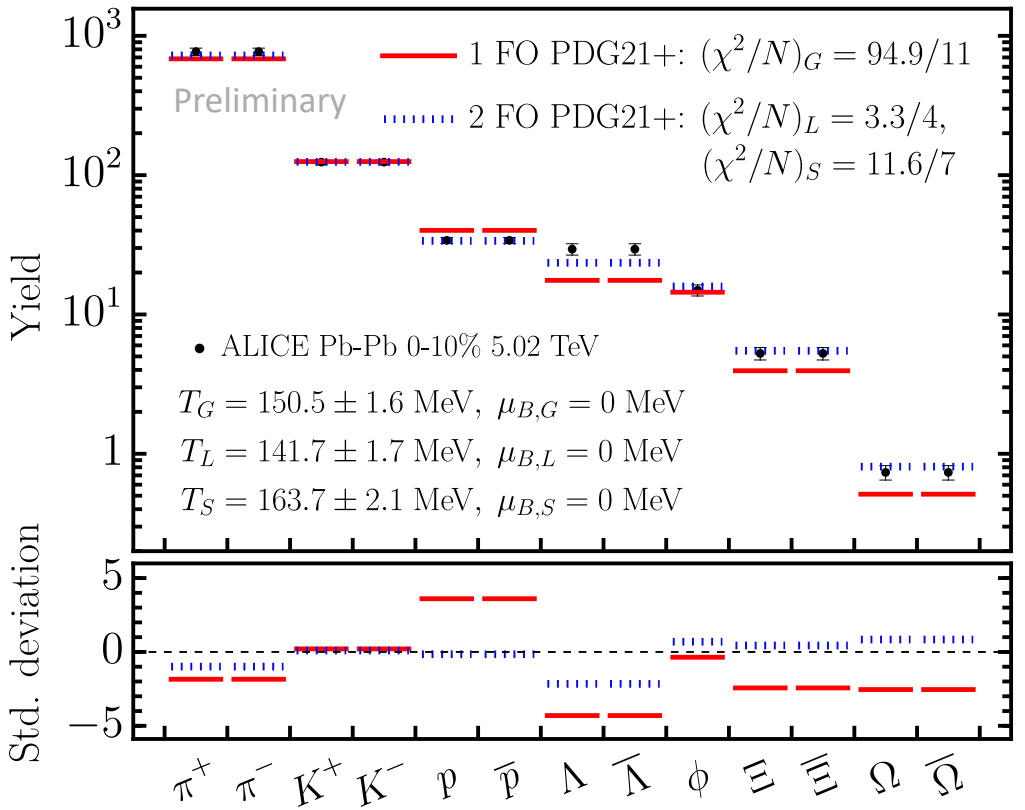
A two-freeze out scenario has a better agreement with experimental data

Thermal model yields



A two-freeze out scenario has a better agreement with experimental data

New hadronic list



The new resonances and decays significantly improve the fits to experimental data at LHC energies

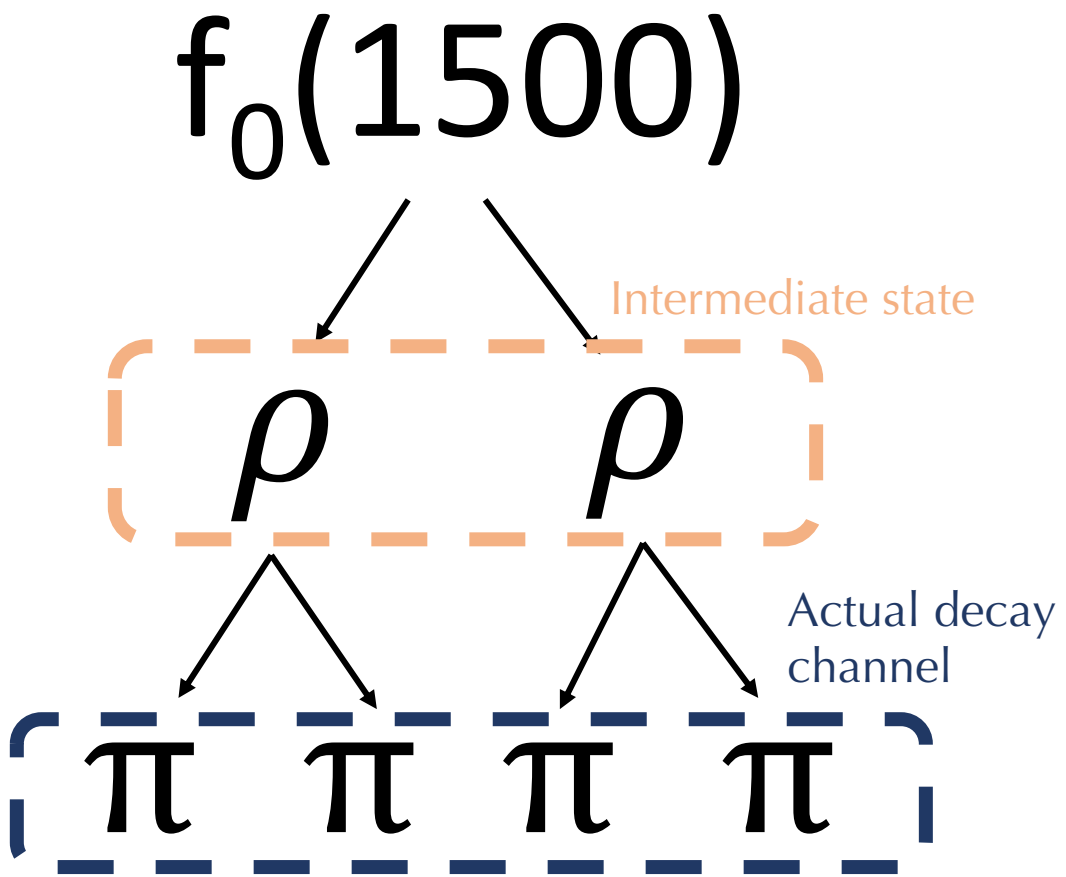
Modeling the list with intermediate states

$1 \rightarrow 2$ decays needed for SMASH

Model 3 and 4-body decays with intermediate states

SMASH input:
1. Particle list
2. Decay modes

J. Weil *et al.*, PRC 94 (2016) 054905
D. Oliinychenko *et al.*, SMASH-transport (2021), https://doi.org/10.5281/zenodo.5796168

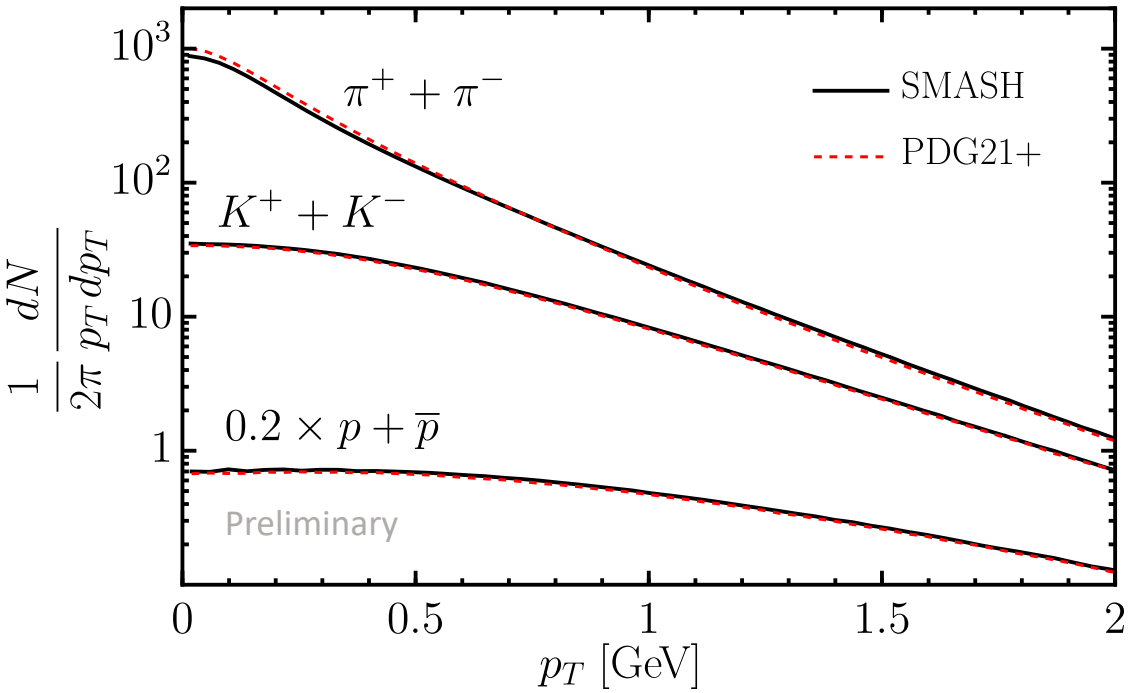


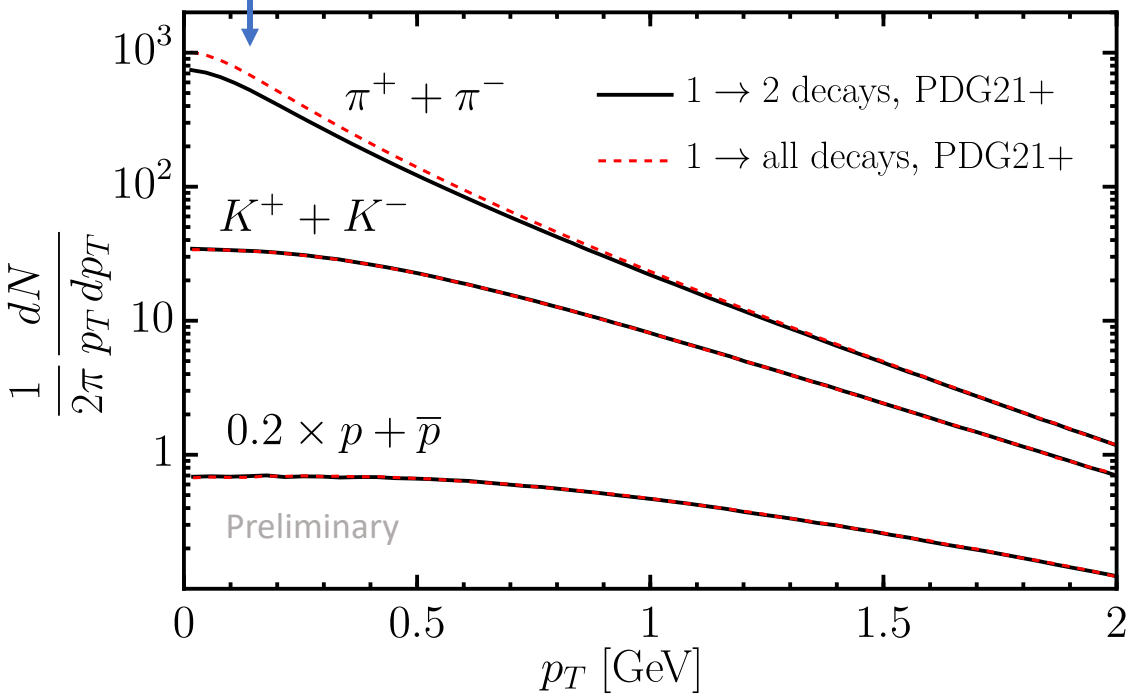
Identified particles spectra

The addition of more resonances and modification of decay channels has a small effect on the particle spectra

The adaptation of the list to only have 1 → 2 decays causes the slope to change

Impact on extracted bulk viscosity with SMASH as afterburner



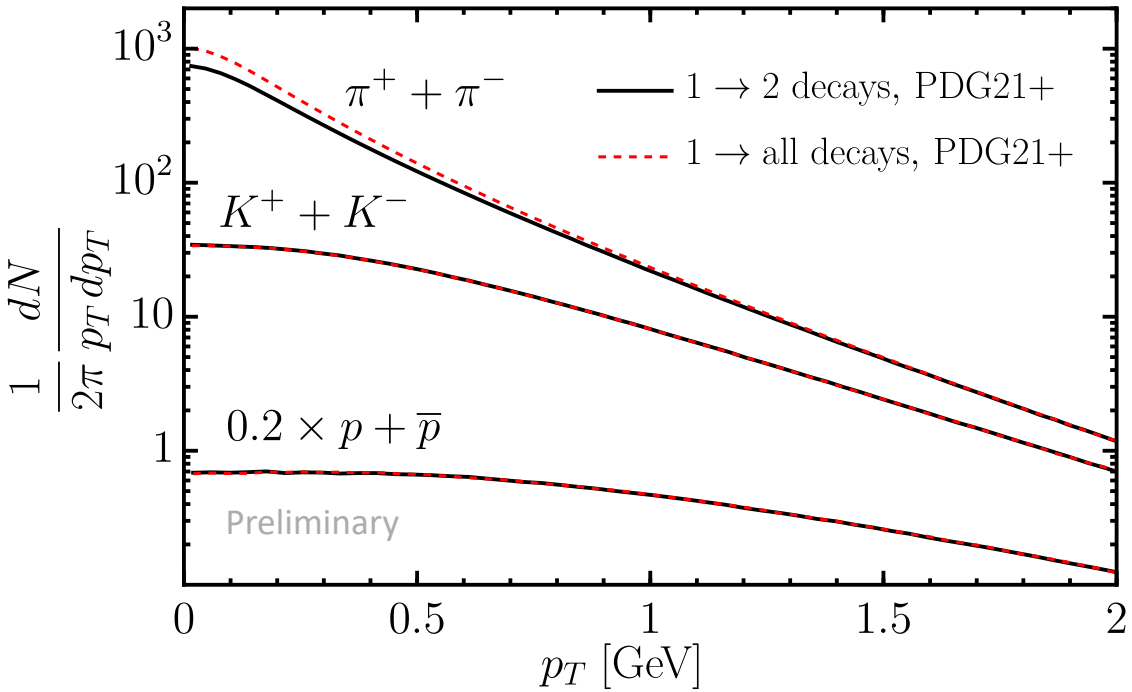


Identified particles spectra

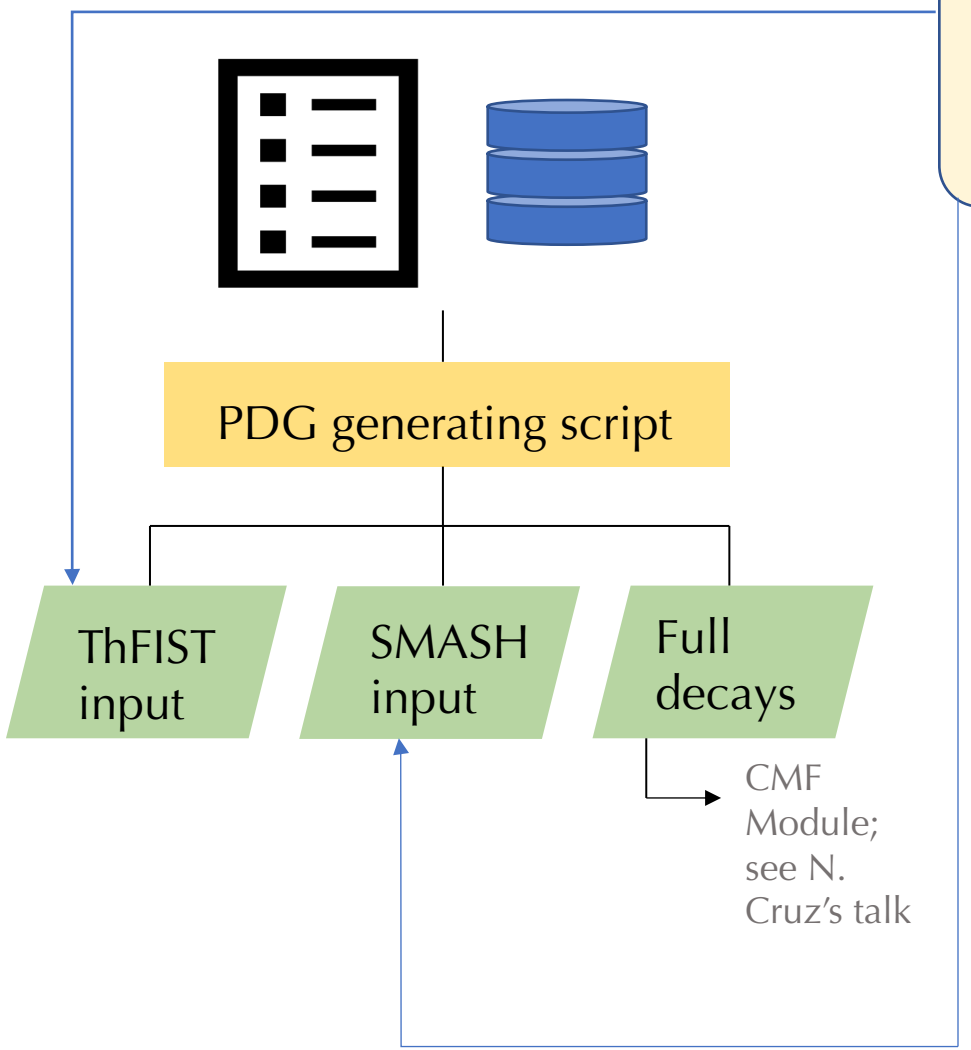
	$\pi^+ + \pi^-$	$K^+ + K^-$	$p + \overline{p}$
SMASH list	0.7495	1.109	1.6015
PDG2021+ ($1 \rightarrow 2$ decays)	0.602	0.908	1.4155
PDG2021+ ($1 \rightarrow$ all decays)	0.566	0.908	1.4165
Experiment	0.5682 ± 0.0320	0.9177 ± 0.0140	1.4482 ± 0.0244

Although changing the list does not affect the spectra too much, it impacts $\langle p_T \rangle$

The mean-transverse momentum is affected by using $1 \rightarrow 2$ or $1 \rightarrow$ all decays

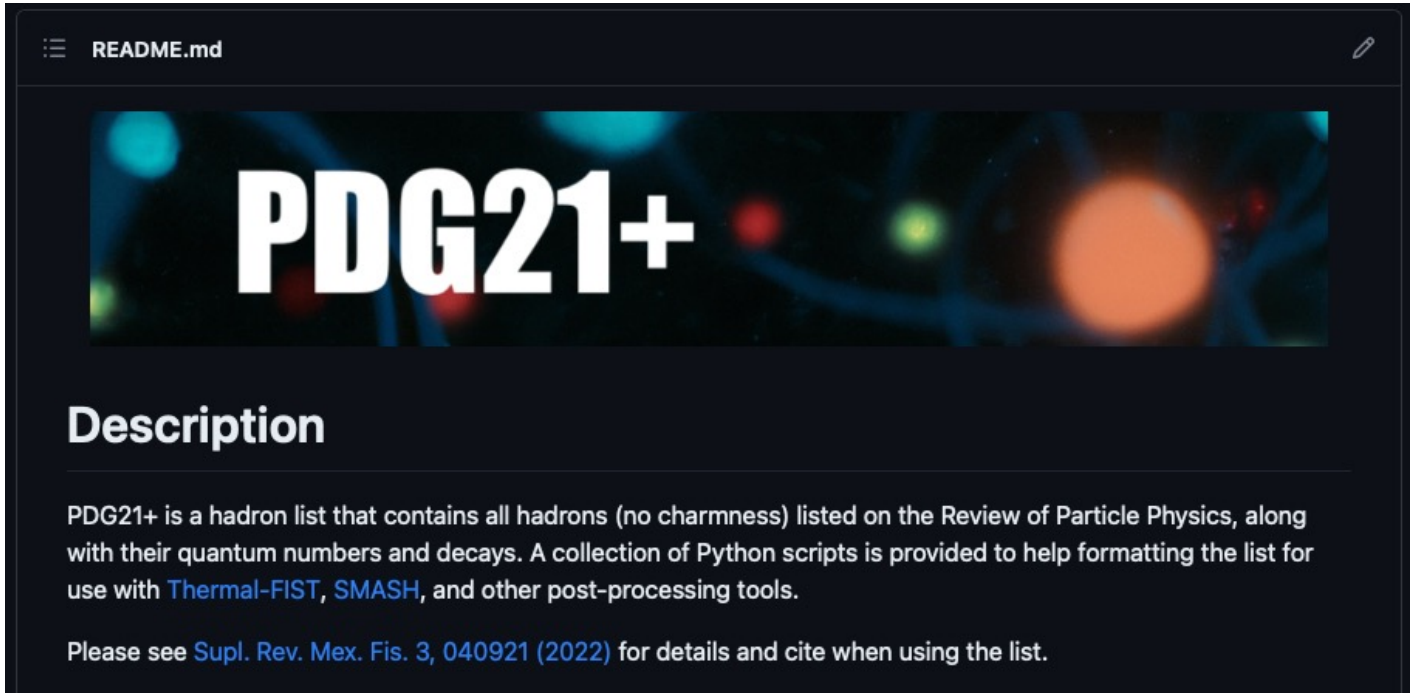


Open-source code



The list can be easily updated and coupled to external tools

List and generating scripts will be publicly released



Conclusions/Outlook

- Lattice hints at additional strange hadronic states
- Hadronic resonances push HRG toward a better agreement with lattice at temperatures near the transition
- A new list, PDG21+, was built with the latest experimental data available
- The list was implemented into SMASH with help of intermediate states
- Future work is directed towards building an EoS and study freeze-out (J. Karthein, C. Ratti and students)
- KEY TAKEAWAY: If SMASH is used as an afterburner, one wants a consistent EoS-afterburner relation to be consistent with lattice → updated SMASH particle list