Using the latest resonances from PDG in SMASH and their impact on cross sections

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Roadmap to coupling SMASH and eHIJING

HRG with the latest experimental data
PDG: pdg.lbl.gov

Compare thermodynamics with lattice results

Adapt hadronic list to SMASH

Calibrate SMASH
Modify cross-sections in SMASH.
Possible formation time-dependence.

Merge with lattice

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

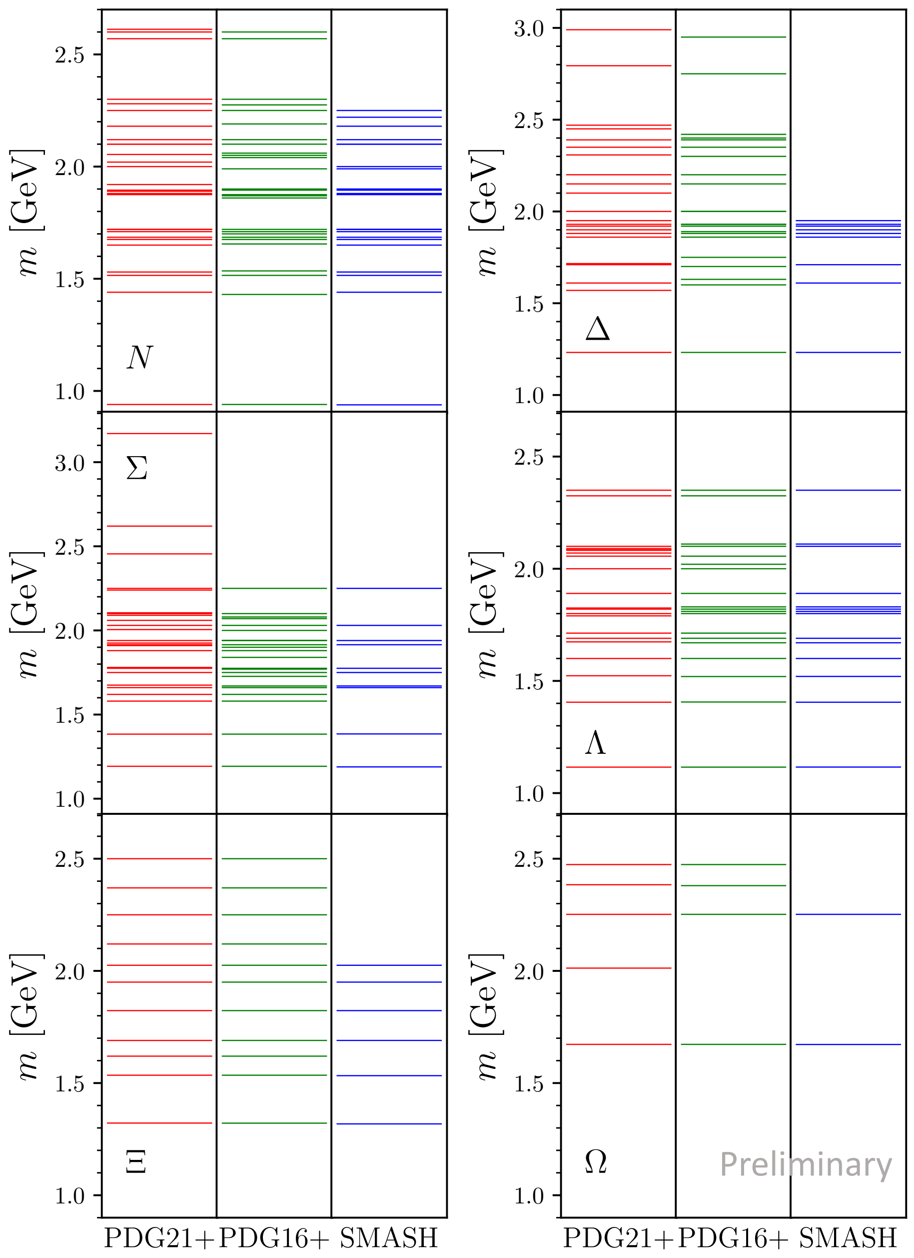
P. Parotto, D. Mroczek, J. Noronha-Hostler, C. Ratti et al., 1805.05249

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

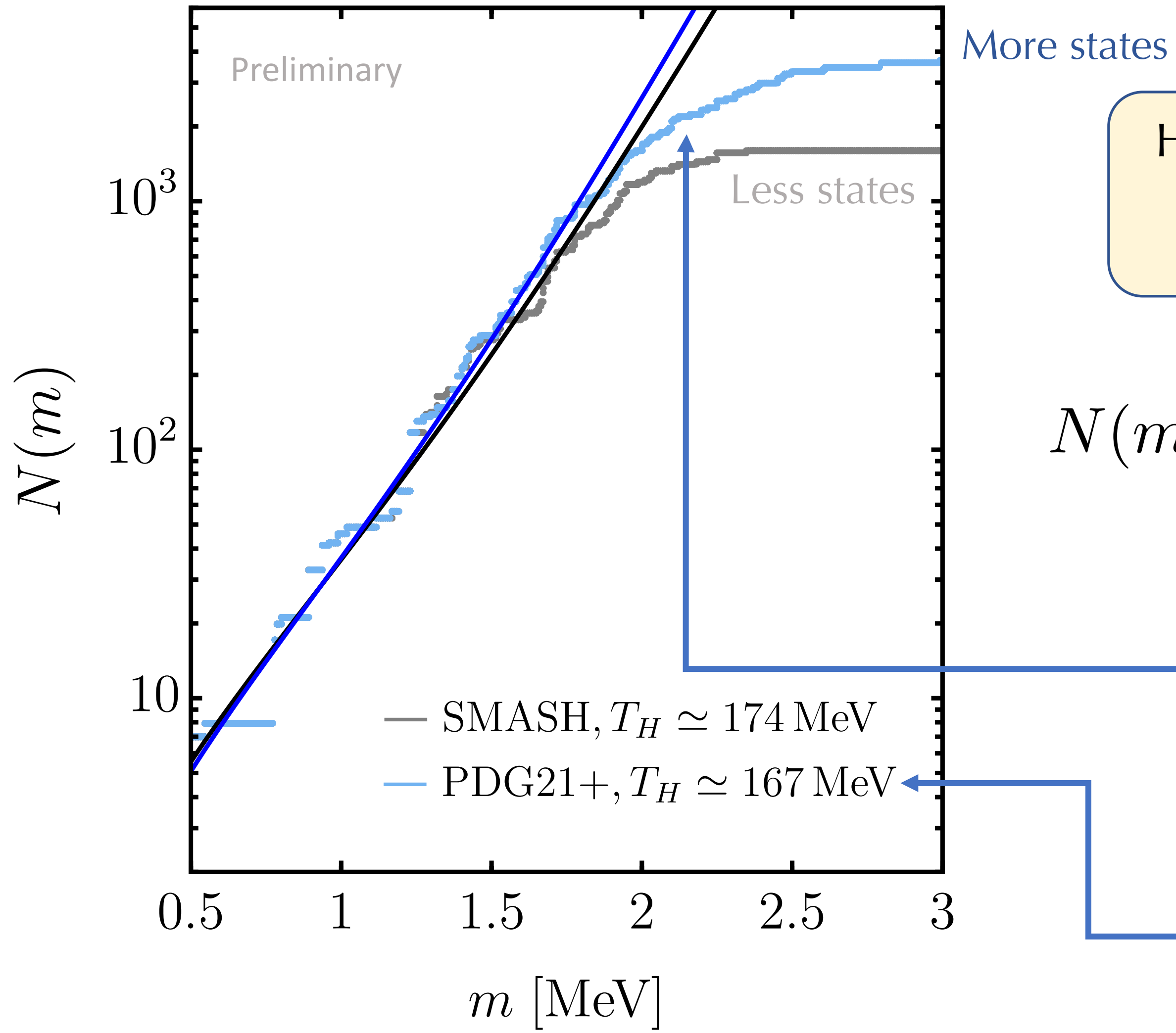
Couple eHIJING and SMASH with the same particle list

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

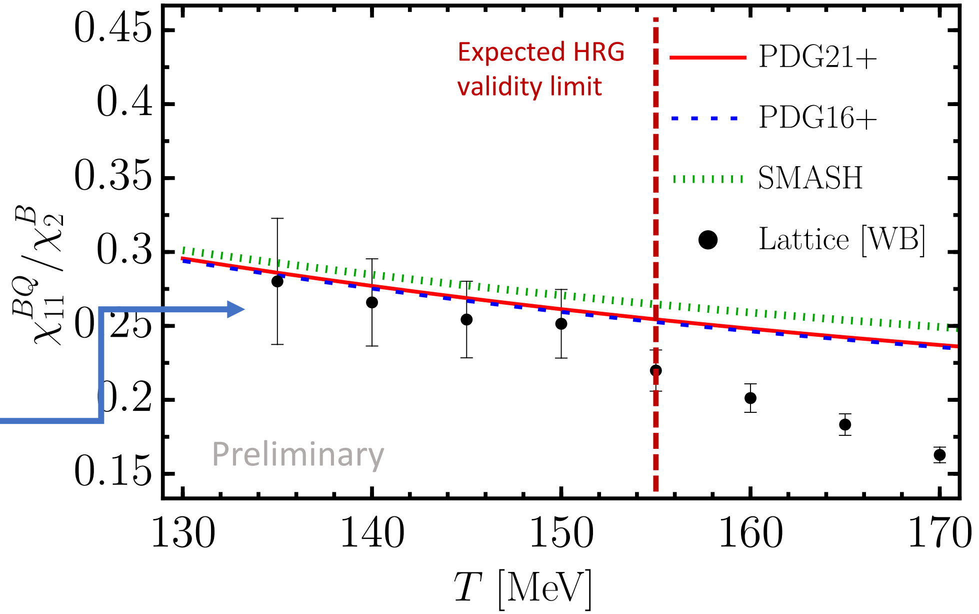
The extracted temperature becomes closer to the pseudo-critical temperature from LQCD

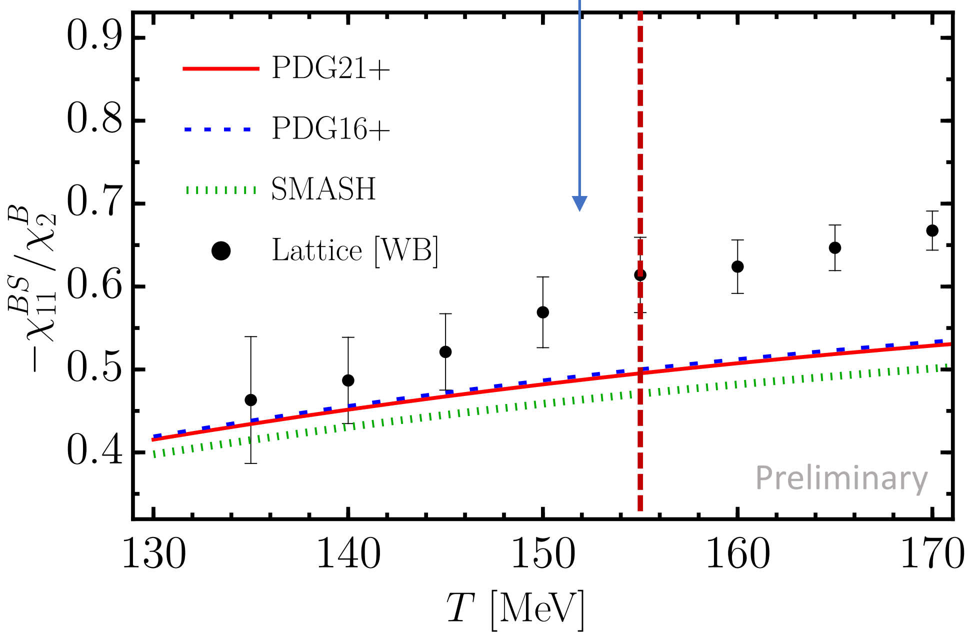
HRG susceptibilities vs LQCD

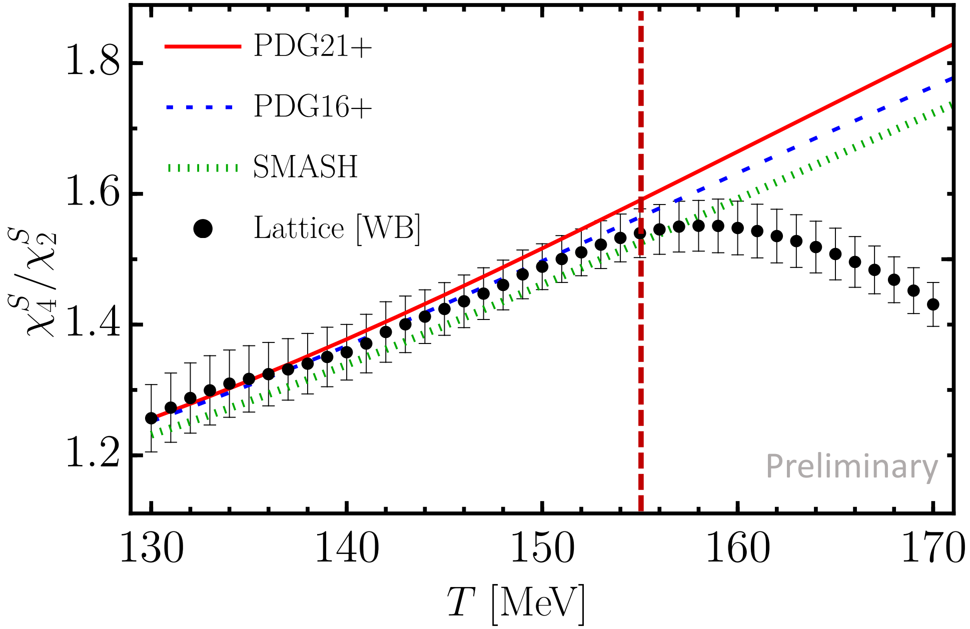
Disagreement with lattice data hints at missing strange resonances (Λ, Σ, Ξ, Ω)

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



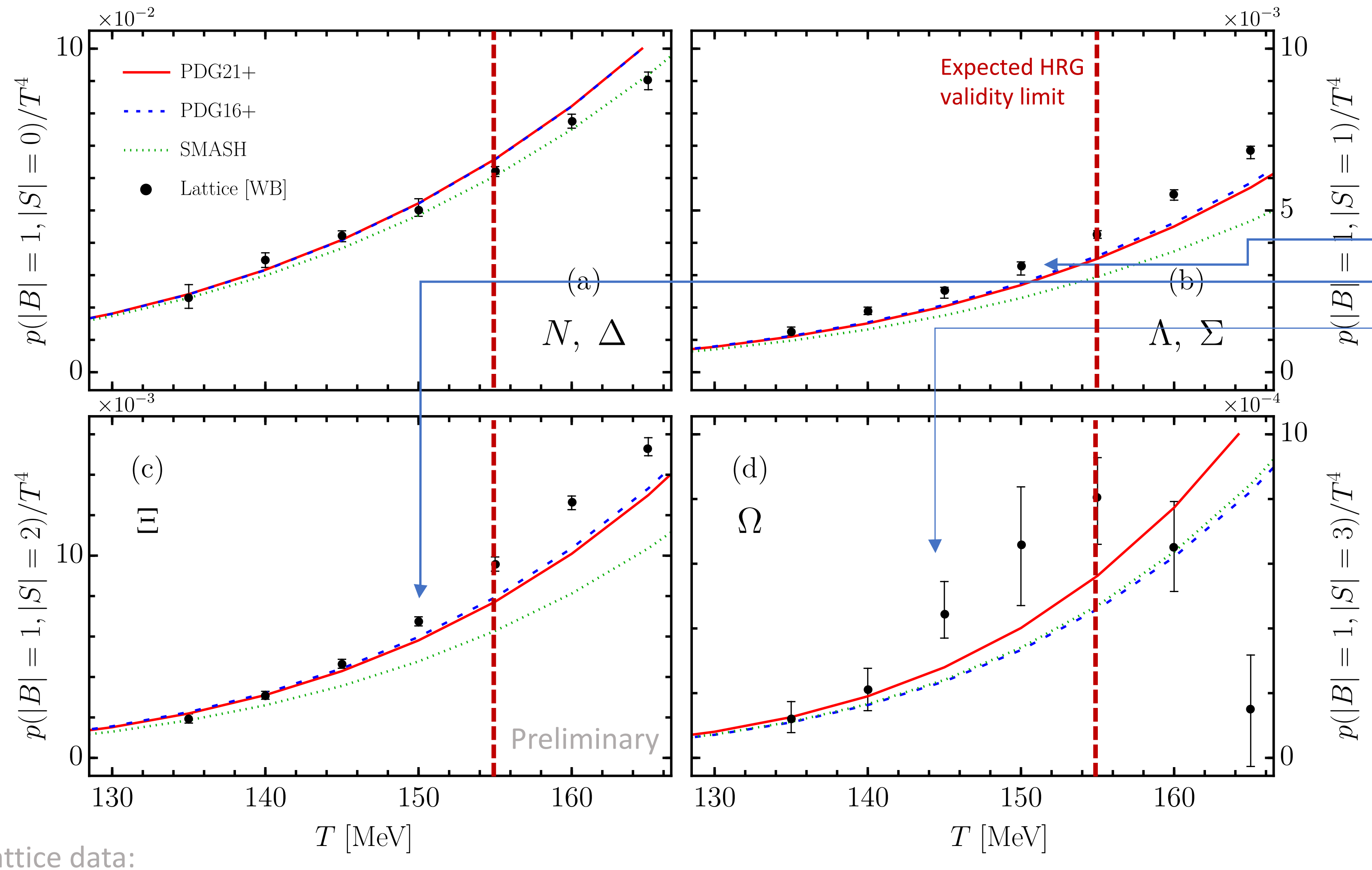




Excluded volume can capture the drop; see 2107.00588

Lattice data:
PRD **92**, 114505 (2015)
PRD **96**, 034517 (2017)
PRD **101**, 034506 (2020)

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

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

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PRD **96**, 034517 (2017)

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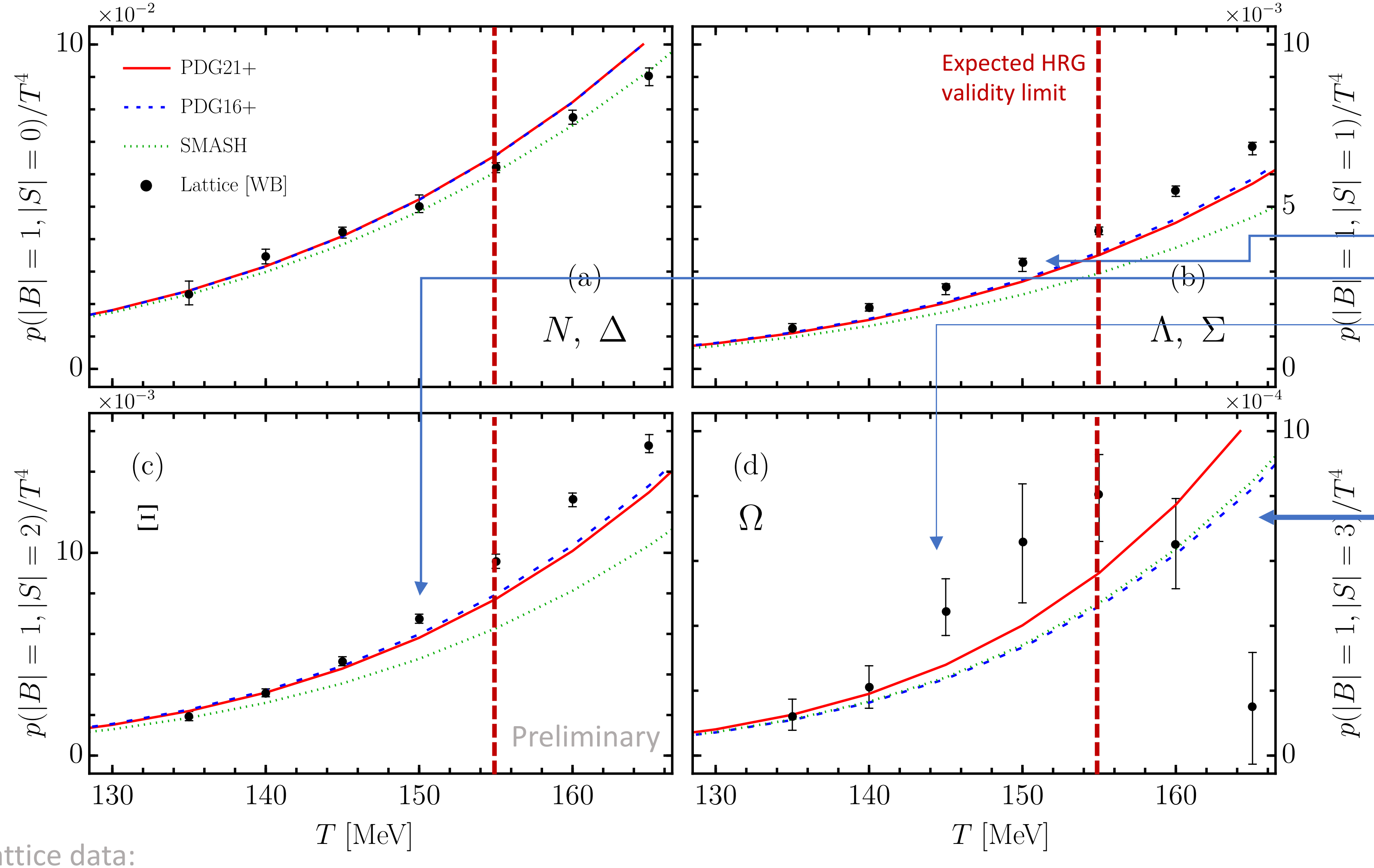

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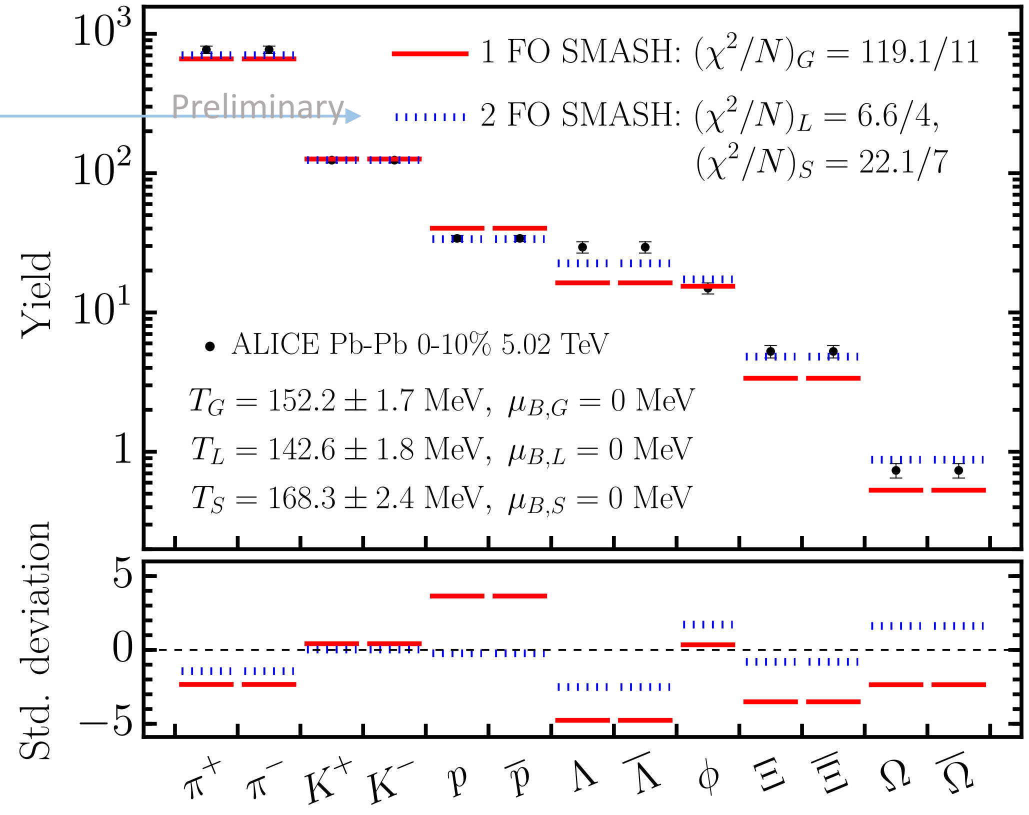
New high-confidence Ω baryon contributes pronouncedly to the triple-strange partial pressure

Lattice data:
PRD **96**, 034517 (2017)

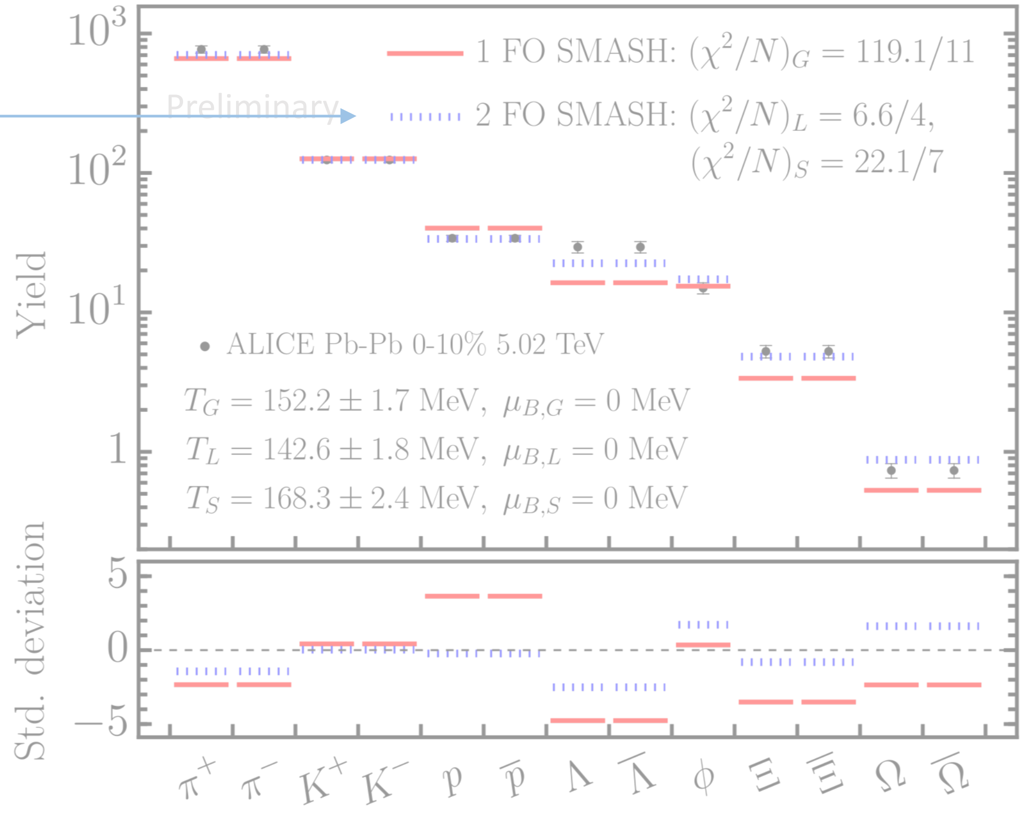
Thermal model yields

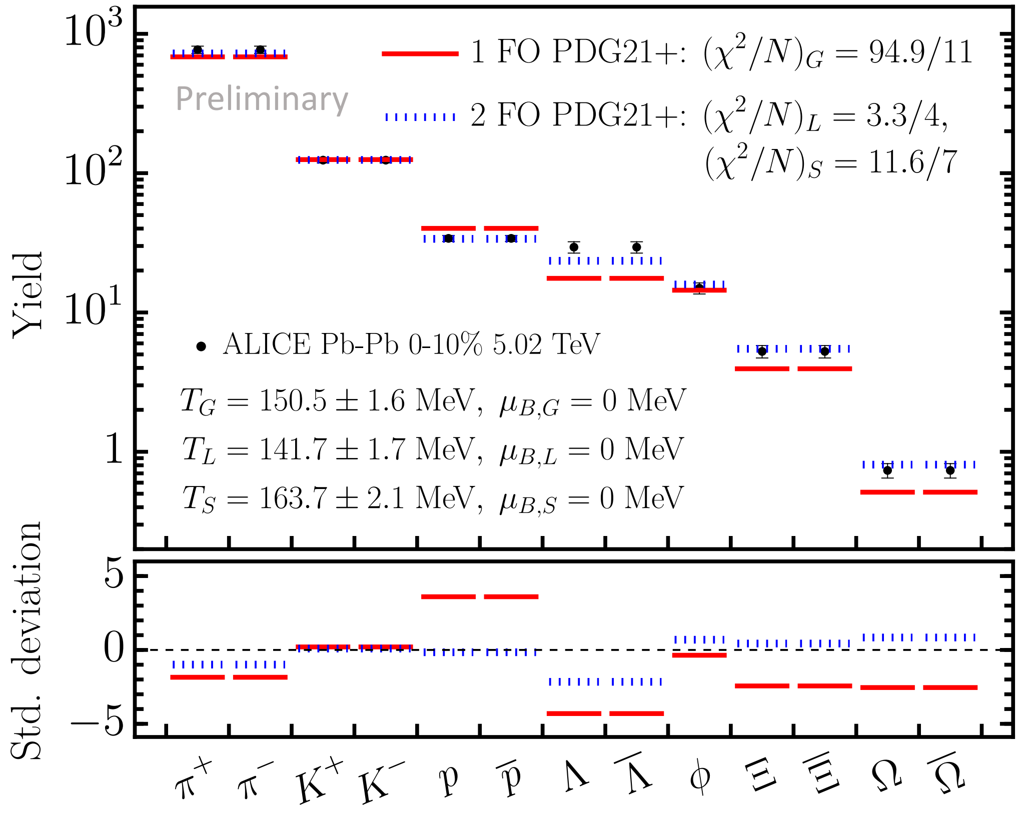


A two-freeze out scenario has a better agreement with experimental data

Thermal model yields

New hadronic list





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

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

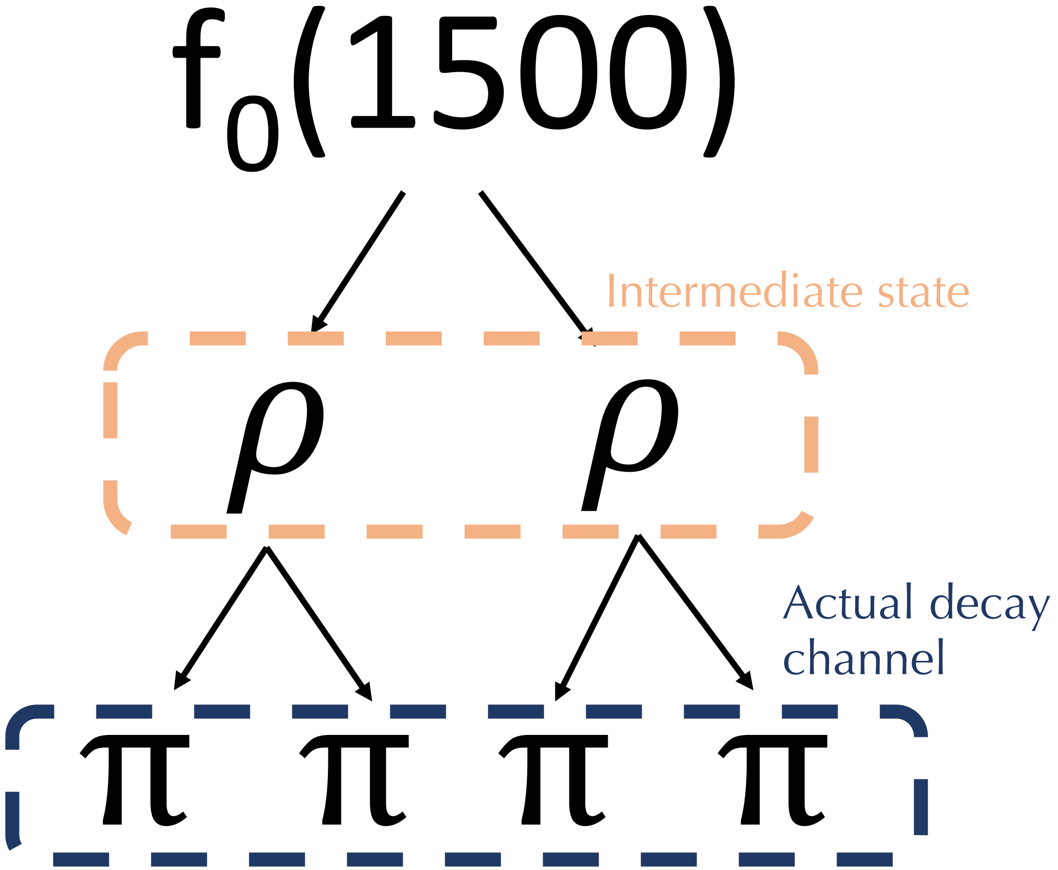
Modeling the list with intermediate states

1 → 2 decays needed for SMASH

$$d_{\text{trans}} < \sqrt{\frac{\sigma_{\text{tot}}}{\pi}}$$

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

Model 3 and 4-body decays with intermediate states

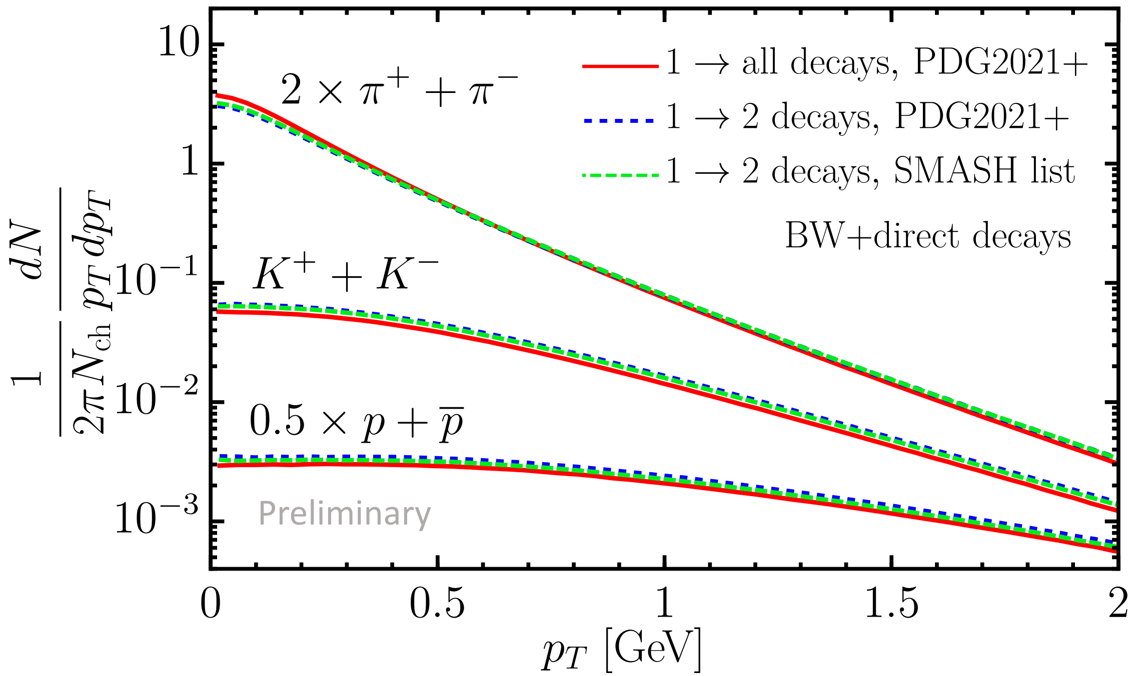


SMASH input:

1. Particle list
2. Decay modes

Identified particles spectra

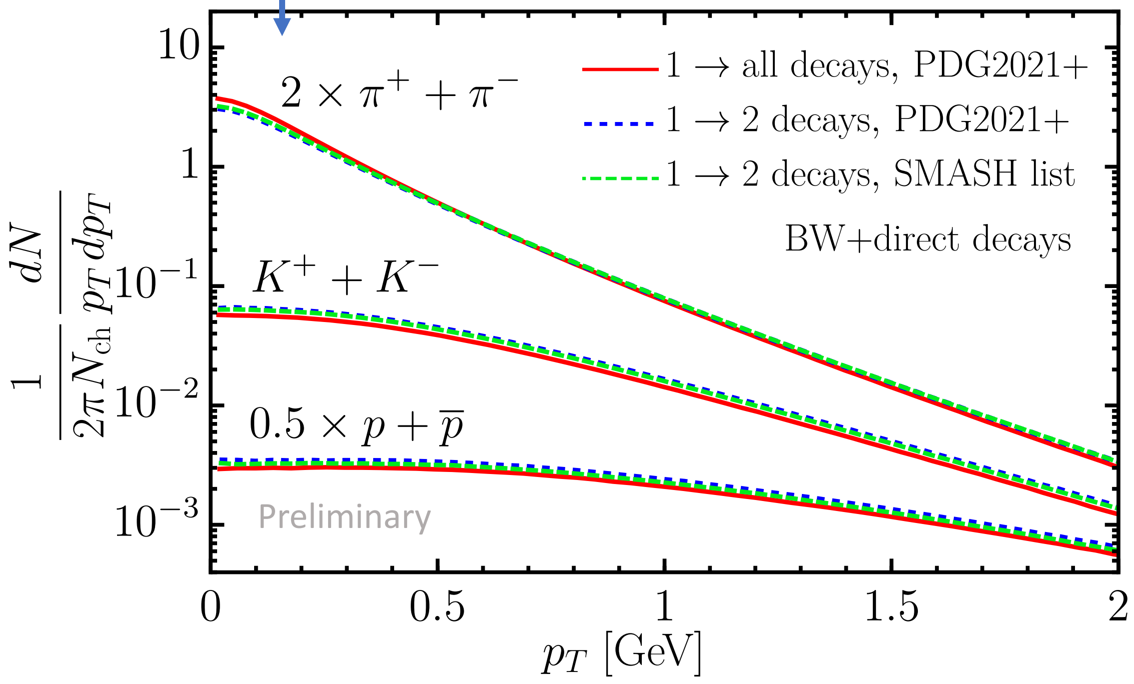
The addition of more resonances and modification of decay channels has an effect on the particle spectra



Identified particles 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

BW+direct decays	$\pi^+ + \pi^-$
SMASH list	0.548 ± 0.001
PDG2021+ ($1 \to 2$ decays)	0.551 ± 0.001
PDG2021+ ($1 \to$ all decays)	0.523 ± 0.001
BW+SMASH	$\pi^+ + \pi^-$
SMASH list	0.5463 ± 0.0001
PDG2021+ ($1 \to 2$ decays)	0.5467 ± 0.0001
Experiment	0.56965 ± 0.02505

Preliminary

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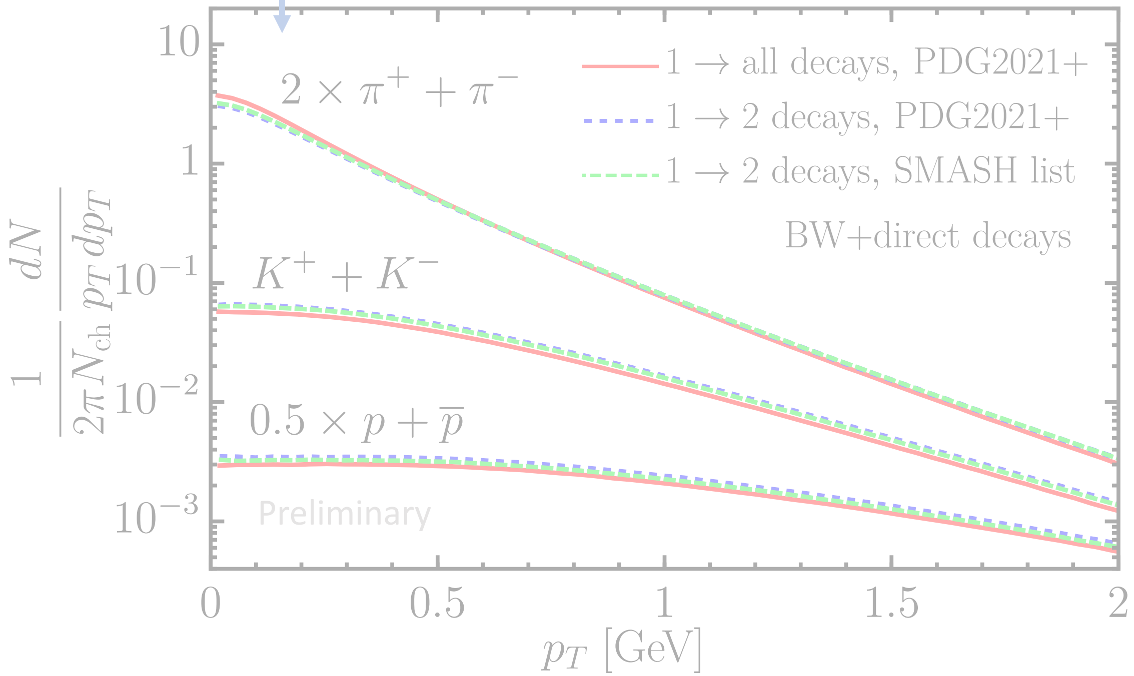
Data: PRC **101**, 044907 (2020)

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

Impact on extracted bulk viscosity with SMASH as afterburner



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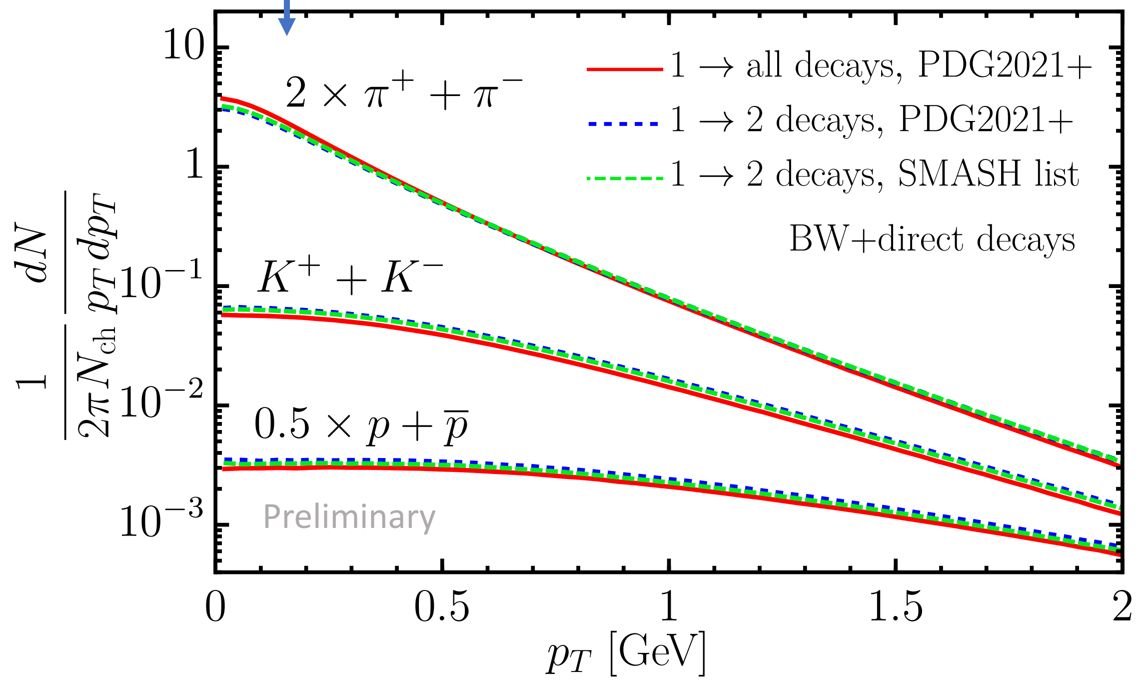
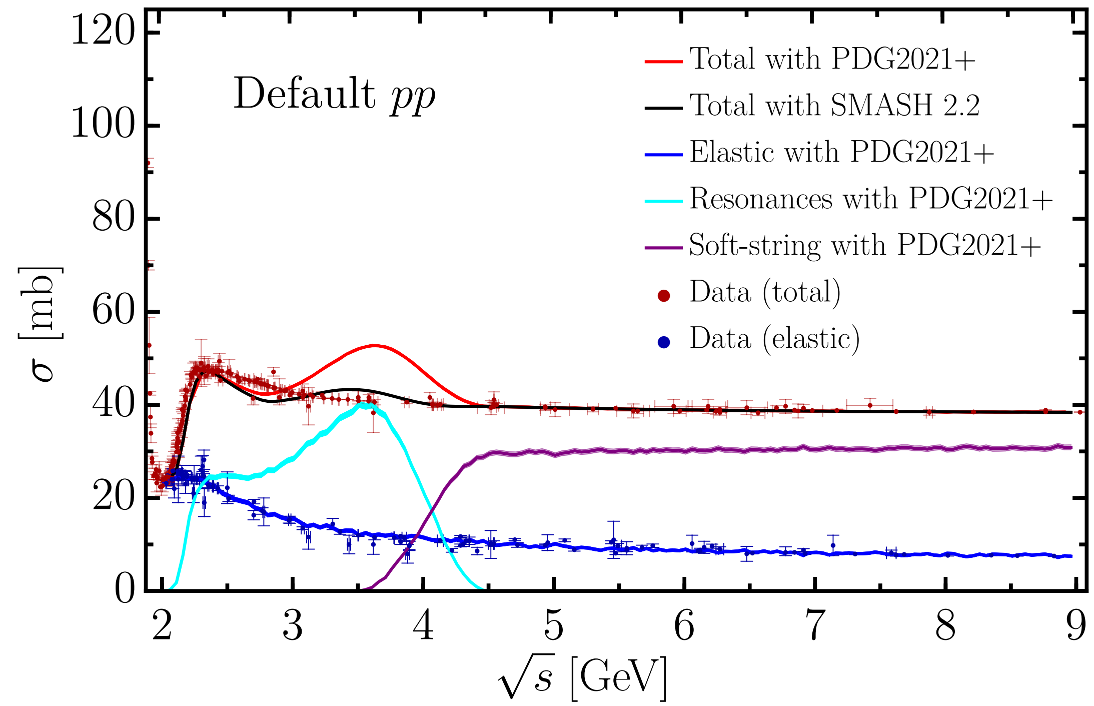
Although changing the list does not affect the $\langle p_T \rangle$ too much, it impacts spectra slightly

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

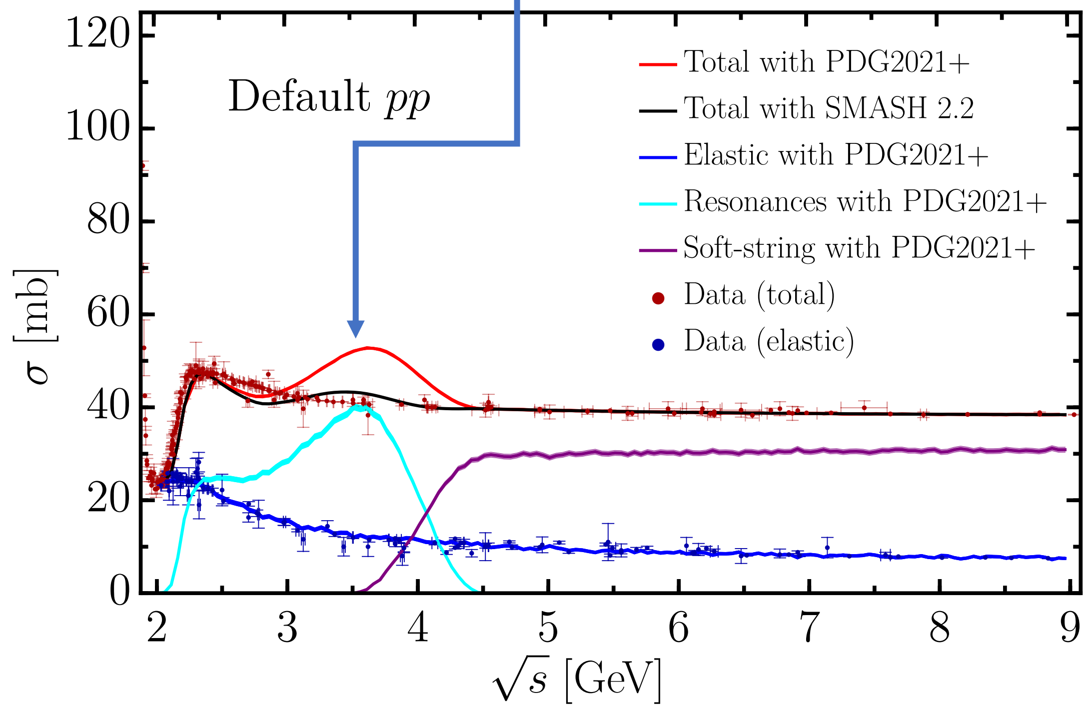


Cross section rescaling



Cross section rescaling

The inclusion of new resonances spoils tuned cross sections -> need to rescale



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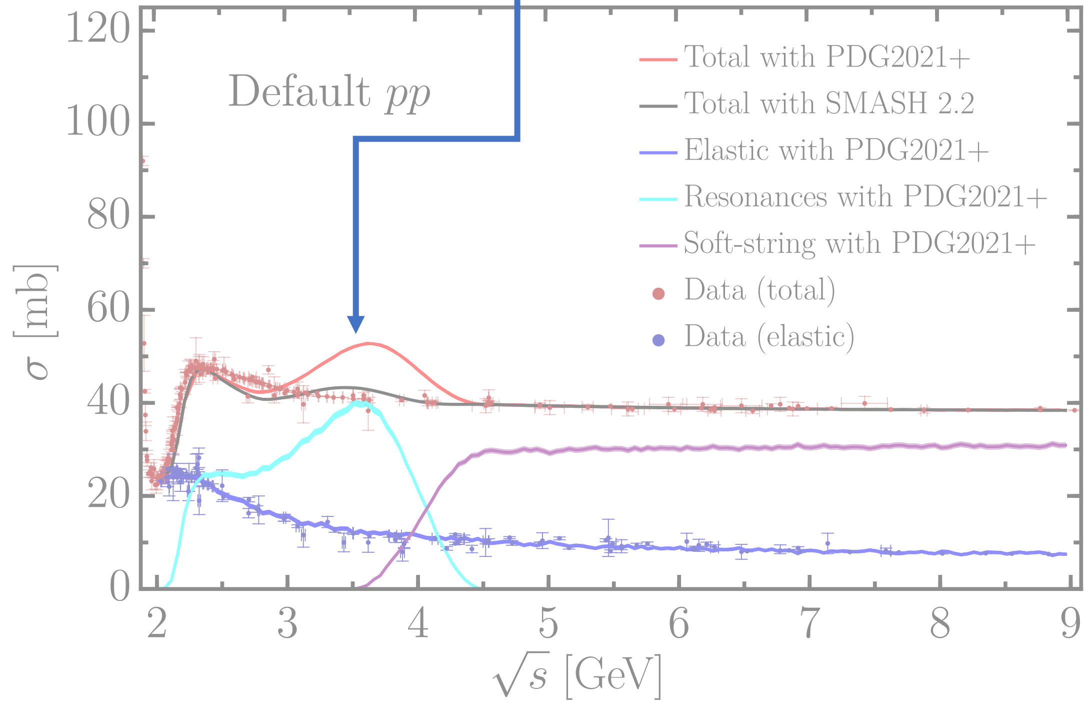

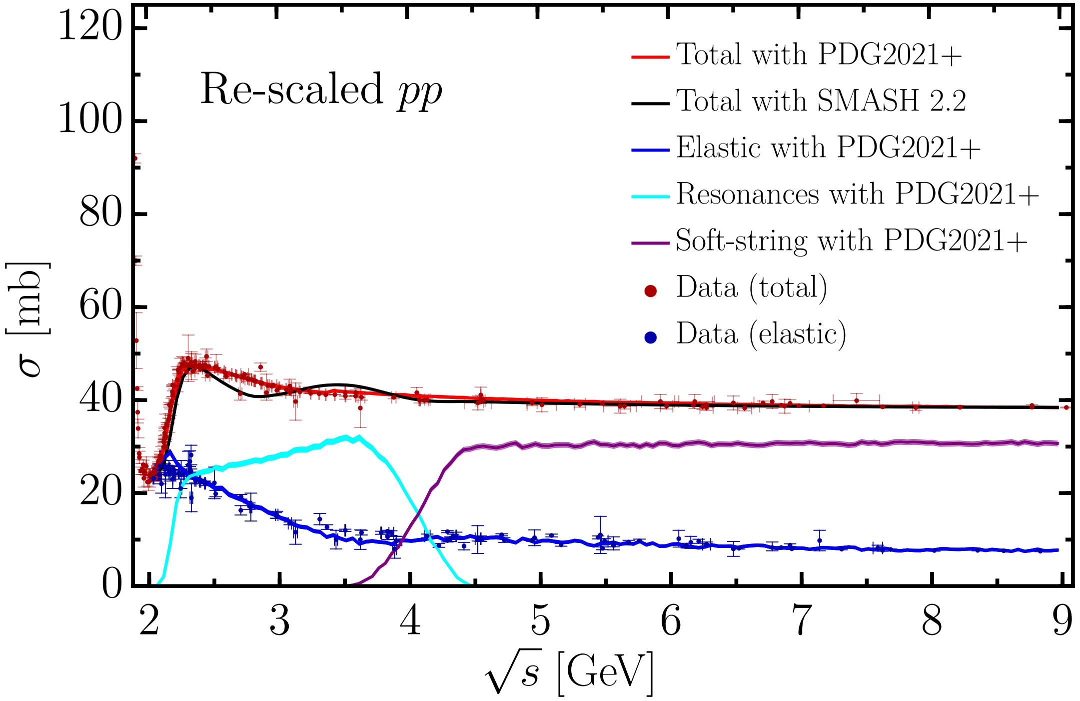

Cross sections and string fragmentation

SMASH implements string excitation and fragmentation for hard processes

A string forms hadrons by producing quark-antiquark pairs (but should not be done simultaneously)

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In SMASH a cross section scaling factor controls *when* hadrons are allowed to interact, i.e., normally at the point of closest approach

$$f_\sigma(t) = (1 - f_0)\left(\frac{t - t_{\text{prod}}}{t_{\text{form}} - t_{\text{prod}}}\right)^\alpha + f_0$$

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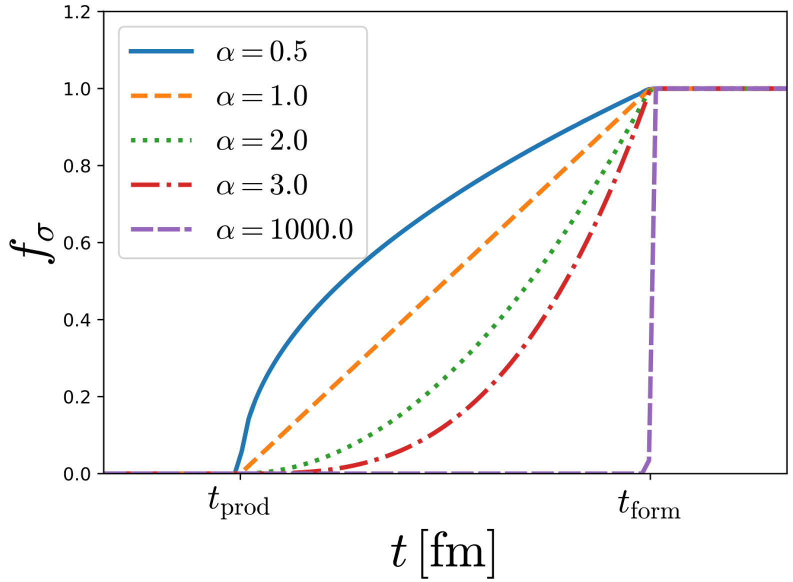
The scaling factor can be a function of time, to mimic a continuous formation process

SMASH on scaling factor:
J. Phys. G **47**, 065101 (2020)

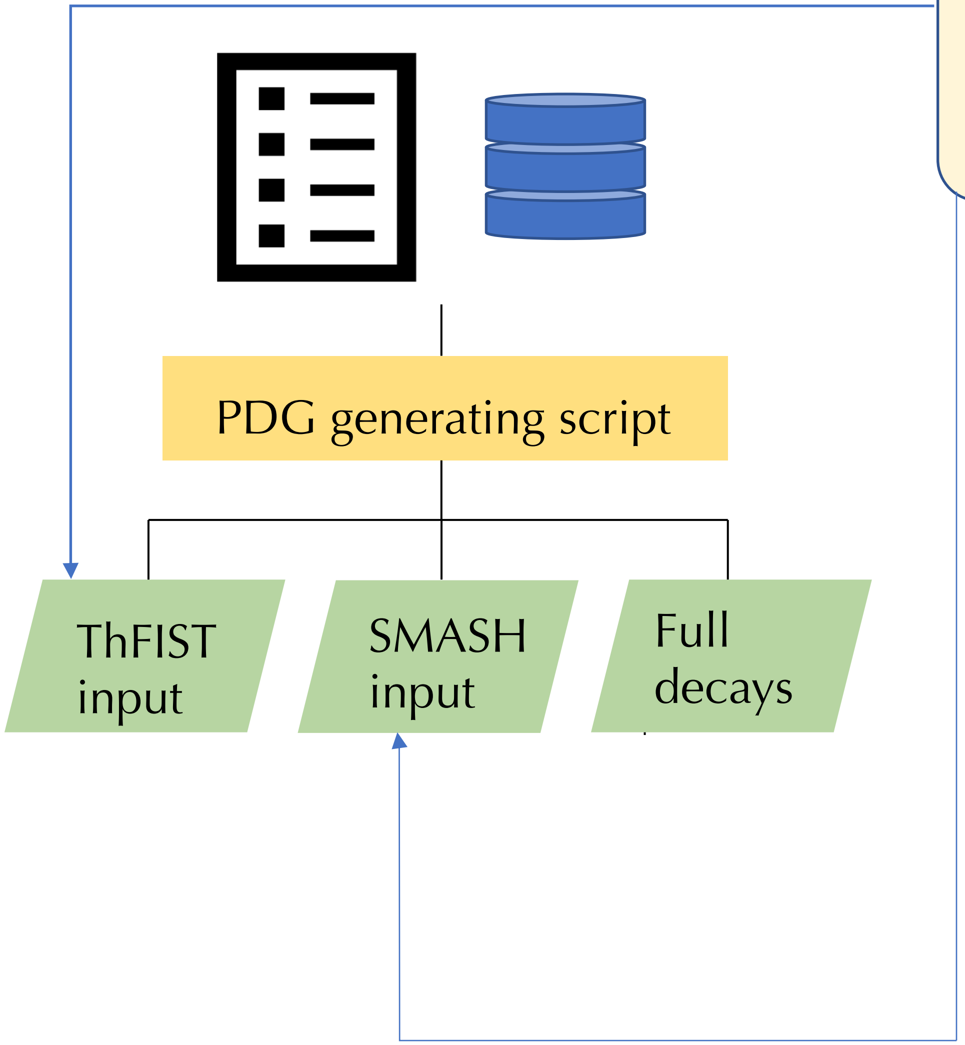
Previous study using GiBUU:
Nucl. Phys. A **801**, 68 (2008)

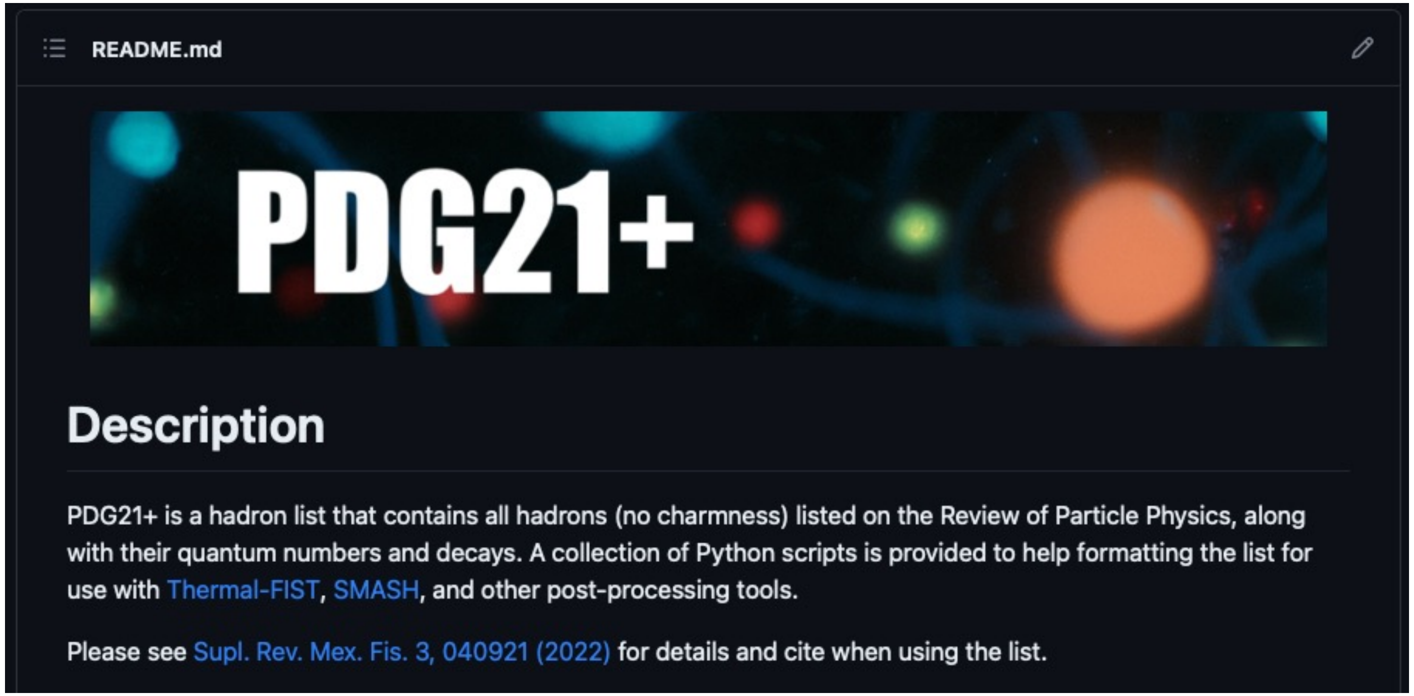


Open-source code

The list can be easily updated and coupled to external tools

List and generating scripts will be publicly released





Conclusions

- Lattice hints at additional strange hadronic states
- A new list, PDG21+, was built with the latest experimental data available
- The new resonances come with a need to retune cross sections
- Final state hadronic interactions can be studied as functions of formation times
- If SMASH is used as a hadron scattering phase evolver, one wants a consistent treatment of the particle list → updated SMASH particle list

Outlook

- We have to make sure to use the same resonances in SMASH and eHIJING
- We can test the formation time dependence of final state interactions by modifying the scaling factor
- Previous studies have found that indeed time dependent cross-sections seproduce data more accurately
- Extensions of these studies can be tested on HERMES and EMC data at low energies
- Further extrapolation to cover EIC can be done by coupling to PYTHIA