S-Matrix HRG description of light flavour hadrons and (anti-)(hyper-) nuclei production at the LHC

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Abstract

The yields of light flavour hadrons and light (anti-)nuclei including (anti-)hypernuclei have been measured by the ALICE collaboration at LHC/CERN at various multiplicity bins in proton-proton, proton-lead and lead-lead collisions. It is observed that the strangeness and (anti-)nuclei production increase non-linearly with charged-particle multiplicity (dN_{ch}/dy) and is independent of the collision system. We compare the above data with the thermal model analysis that accounts for the exact conservation of quantum numbers such as strangeness and baryon number. The interactions among hadrons are included using the S-matrix corrections based on known phase shift analyses. We show that the above thermal model can capture the observed properties of light flavour hadron yields as well as light (anti-)nuclei including anti-hypertriton as a function of charged-particle multiplicity.

Introduction

- Particle yield from heavy-ion collisions have been successfully explained by the Hadronic Resonance Gas (HRG) model [1] with a common freeze out temperature (T_f) and chemical potentials $\vec{u}_f$ associated with the conserved charges.
- The increase in strangeness production with charged particle multiplicity as reported by the ALICE collaboration at LHC [2] is investigated.
- We used the strangeness canonical ensemble including the interactions among hadrons using the scattering matrix (S-matrix) corrections based on known phase shift analyses [3].

HRG model

The strangeness canonical partition function can be expressed as a series of Bessel functions

$$Z^{C}_{S=0} = \sum_{n,p=-\infty}^{\infty} I_n(S_2)\, I_p(S_3)\, I_{-2n-3p}(S_1)$$

The particle yields are obtained using the temperature (T), acceptance volume (V_A) and correlation volume (V_C) of global strangeness conservation. The mean multiplicity of particle *k* carrying strangeness *s* in the acceptance *A* is given as

$$\langle N_k^s \rangle_A \approx V_A n_k^s(T) \frac{I_s(S_1)}{I_0(S_1)}$$

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Model comparison with light flavour hadrons yields

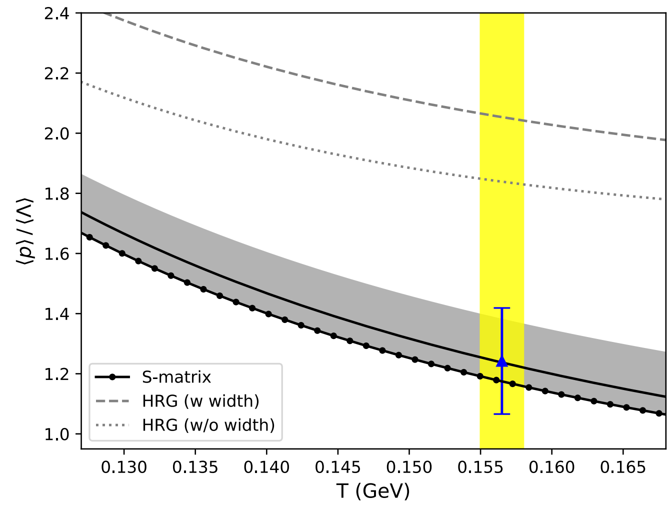
S-Matrix formalism

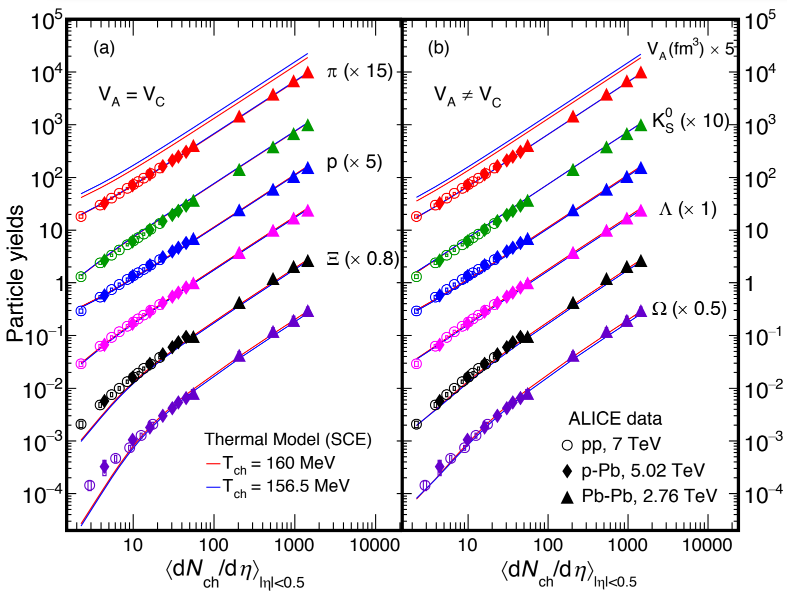
The scattering matrix includes interactions among hadrons which modifies DOS of a thermal system and hence abundance of hadrons. If $B_a(M)$ describes the energy dependent component of channel-*a* to full spectral function. The channel yield can be obtained as

$$n_a(T) = \int_{m_{th}}^{\infty} \frac{dM}{2\pi} B_a(M) n^{(0)}(T, M)$$

Here, M is center-of-mass energy of the system and $n^{(0)}$ is ideal gas formula for the particle density.

Figure shows the comparison of ratio of protons to $(\Lambda + \Sigma^0)$ baryons from HRG model, HRG+S-matrix and ALICE data as function of temperature [4].





Model results and ALICE data

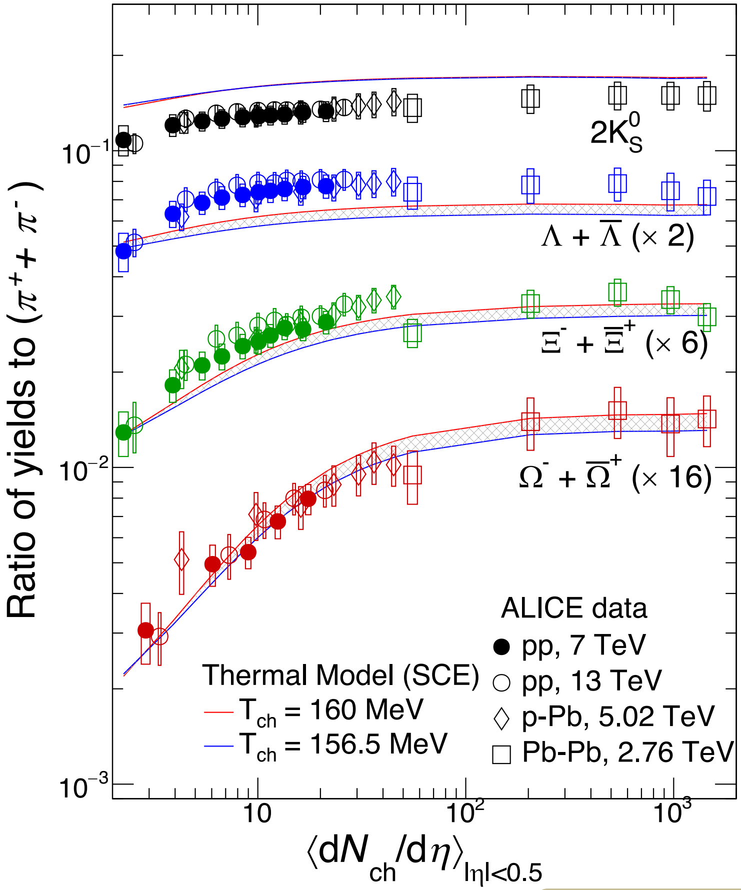
Light flavour hadron yields as measure by ALICE for pp collisions at $\sqrt{s} = 7\ TeV$ is fitted for each multiplicity classes. Free parameters: V_A & V_C

Fixed parameters: $T_{ch} = 156.5\ MeV$ & $160\ MeV$, $\gamma_s = 1$, *and all* $\vec{u}_f = 0$.

Figure shows the comparison of light flavour hadron yields from model and data as a function of charged particle multiplicity [4].

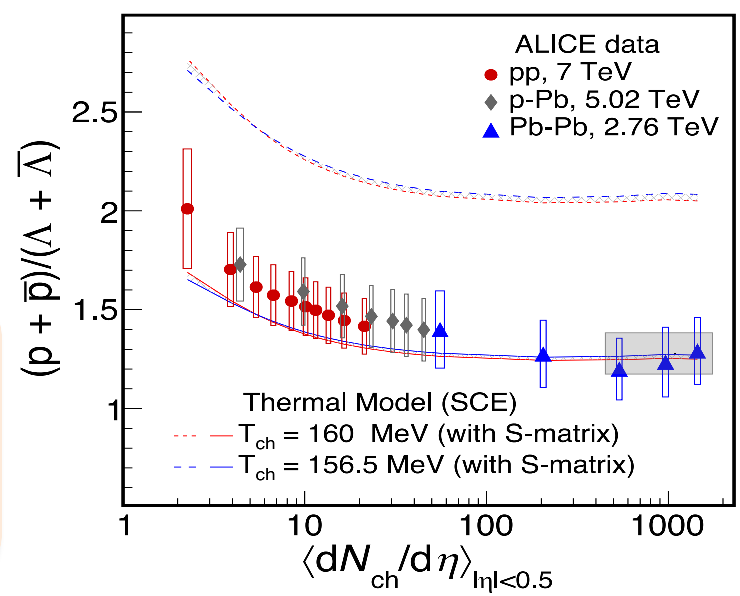
The canonical correlation volume larger than the fireball volume at the mid-rapidity describes the low multiplicity data well.

Model comparison with light flavour hadrons ratios



Strange particle to pion ratios

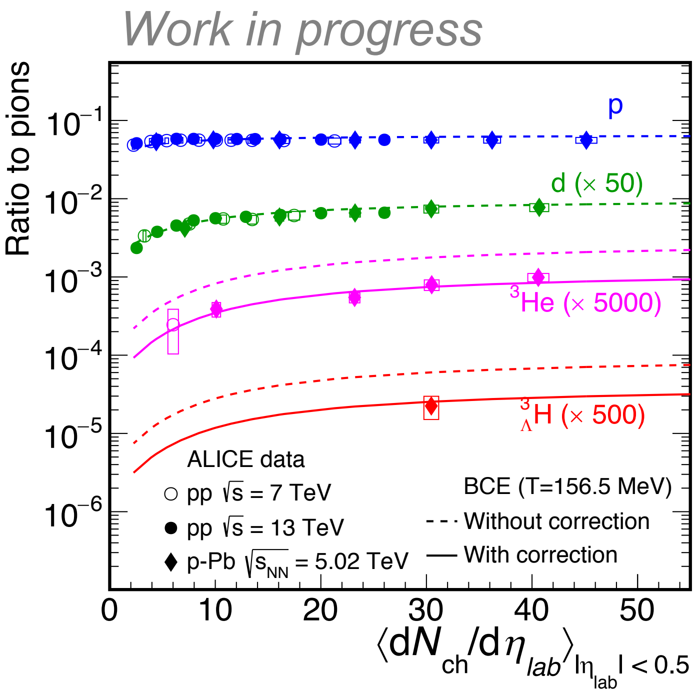
- Figure shows the ratio of strange particle to pion yields as a function of charged particle multiplicity [4].
- The SCE model successfully explains the strangeness enhancement with increase in charged particle multiplicity and saturation for heavy-ion collisions.
- The model explains the observed increase in the strangeness suppression factor with increase in strangeness quantum number.



Proton to lambda ratios

- Figure shows the comparison of the protons to $(\Lambda + \Sigma^0)$ baryons ratio from the HRG model with and without S-matrix formalism as a function of charged particle multiplicity [4].
- The S-matrix correction is essential to explain the data.

Light nuclei study and summary



Light nuclei to pion ratios in small systems

Proton and deuteron yields as measured by ALICE are fitted using the baryon canonical ensemble (BCE) model with and without S-matrix.

Fixed parameters: $T_{ch} = 156.5\ MeV,\ \gamma_s = 1,\ all\ \vec{u}_f = 0,$ $and\ V_A\ fixed\ as\ in\ Ref.[3].$

Free parameter: V_C

The BCE model explains the protons and deuterons yields in low multiplicity and also observed increase in the baryon suppression factor with increasing nuclei mass.

Figure shows the ratio of light nuclei yields to pion as a function of charged particle multiplicity for small systems.

$^{3}He\ and\ ^{3}_{\Lambda}H$ yields are predicted. The S-matrix correction is essential to explain the data.

Summary and outlook

- The HRG model using SCE including the S-matrix corrections successfully describe the measured light flavour hadrons yields at LHC at a common freeze out temperature T_f = 156.5 MeV.
- In low multiplicity - Protons and deuterons yields can be explained by the BCE model, however the corrections are needed to explain $^{3}He\ and\ ^{3}_{\Lambda}H$ yields.

References

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[5] J. Adam et al. (ALICE Collaboration), arXiv: 2107.10627 [nucl-ex].