Thermal Model Description of Collisions of Small Nuclei

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arXiv:1603.09553
Use of Thermal Concepts in Heavy-Ion Collisions  Comparison of Chemical Freeze-Out Criteria  The Energy Region of NICA, FAIR, NA61, BES,... Disappearance of Maxima in Small Systems Conclusion

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Outline

Use of Thermal Concepts in Heavy-Ion Collisions

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Disappearance of Maxima in Small Systems

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Particle Multiplicity in Heavy Ion Collisions

\[ \frac{dN_{\text{ch}}}{d\eta} \]

- ALICE (PRL 106 (2011) 032301)
- ATLAS (PLB 710 (2012) 363-382)
- CMS (JHEP 1108 (2011) 141)

\[ \eta \]

-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5 5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8 5.9 6

0-5% 5-10% 10-20% 20-30%

ALICE symmetrized Double Gaussian fit

NICA, FAIR, NA61, BES...
Particle Multiplicity in Heavy Ion Collisions

About 24 000 particles are produced in a heavy ion collision at the LHC.

Hence: Use Concepts from Statistical Mechanics to analyze the final state
e.g. use Energy Density, Particle Density, Pressure, Temperature, Chemical Composition, ...

These concepts turn out to be useful at other energies, RHIC, SPS, SIS, NICA ...
Chemical Freeze-Out Temperature

Unexpected Result: Maximum in the Net Baryonic Density

\[ \sqrt{S_{\text{NN}}} \]

\[ \varepsilon^* = \varepsilon - m_N \rho \]

J. Randrup & J. Cleymans
K. Grebieszkow (NA61/SHINE) talk at CPOD2016:
Maximum in the $K^+ / \pi^+$ ratio disappears in small systems
To analyze the particle ratios use:

- the Wroblewski factor
- $s/T^3 = 7$ describes chemical freeze-out
Strangeness in Heavy Ion Collisions

vs

Strangeness in pp - collisions

Use the Wroblewski factor

\[ \lambda_s = \frac{2 \langle s\bar{s} \rangle}{\langle u\bar{u} \rangle + \langle d\bar{d} \rangle} \]

This is determined by the number of newly created quark – anti-quark pairs and before strong decays, i.e. before \( \rho \)'s and \( \Delta \)'s decay.

Limiting values:
\( \lambda_s = 1 \) all quark pairs are equally abundant, SU(3) symmetry.
\( \lambda_s = 0 \) no strange quark pairs.
Wroblewski Factor

![Graph showing the Wroblewski Factor $\lambda_s$ vs. $\sqrt{s_{NN}}$ (GeV)](image-url)
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**Comparison of Chemical Freeze-Out Criteria**

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- **Disappearance of Maxima in Small Systems**
- **Conclusion**

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**Graph:**

- **$s/T^3$** vs. **$\sqrt{s_{NN}}$ (GeV)**

- **Total**
- **Mesons**
- **Baryons**

---

In the statistical model a rapid change is expected as the hadronic gas undergoes a transition from a baryon-dominated to a meson-dominated gas. The transition occurs at a

- temperature $T = 151$ MeV,
- baryon chemical potential $\mu_B = 327$ MeV,
- energy $\sqrt{s_{NN}} = 11$ GeV.

In this region the interplay between temperature and baryon chemical potential leads to peaks in the $\Lambda/\langle \pi \rangle$, $K^+/\pi^+$, $\Xi^-/\pi^+$ and $\Omega^-/\pi^+$ ratios which occur at different beam energies.

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Small systems.

- Use the canonical ensemble with strangeness conservation (see Ph.D. thesis of Krzysztof Redlich).
- Introduce two volumes: global volume and a strangeness correlation volume.
- Reduce the strangeness correlation volume to describe small systems.

J.C., B. Hippolyte, H. Oeschler, K. Redlich, N. Sharma
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Maximum in $K^+ / \pi^+$ ratio disappears

THERMUS, SCE
$\mu_q = 0, \gamma_s = 1, R=10 \text{ fm}$

$\sqrt{s_{NN}} [\text{GeV}]$

$K^+ / \pi^+$

- $R_c = 9.5 \text{ fm}$
- $R_c = 6.0 \text{ fm}$
- $R_c = 4.0 \text{ fm}$
- $R_c = 3.0 \text{ fm}$
- $R_c = 2.5 \text{ fm}$
- $R_c = 2.0 \text{ fm}$
- $R_c = 1.5 \text{ fm}$
- $R_c = 1.2 \text{ fm}$
Maximum in $\Lambda/\pi^+$ ratio survives

**Graph:**

- **Title:** THERMUS, SCE
- **Equation:** $\mu_\gamma = 0$, $\gamma_s = 1$, $R=10$ fm
- **Legend:**
  - $R_c = 9.5$ fm
  - $R_c = 6.0$ fm
  - $R_c = 4.0$ fm
  - $R_c = 3.0$ fm
  - $R_c = 2.5$ fm
  - $R_c = 2.0$ fm
  - $R_c = 1.5$ fm
  - $R_c = 1.2$ fm

**Axes:**
- $\sqrt{s_{NN}}$ [GeV]
- $\Lambda/\pi^+$
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\[ \text{THERMUS, SCE} \]

\[ \mu_q = 0, \gamma_s = 1, R = 10 \text{ fm} \]
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Conclusions

- Maximum in $K^+ / \pi^+$ ratio disappears for small systems,
- Maximum in $\Lambda / \pi$ ratio SURVIVES for small systems,

If this is confirmed experimentally then a hadronic scenario explains the behaviour seen in the hadronic ratios and there is no need for other mechanisms.
Conclusions

• Maximum in $K^+/\pi^+$ ratio disappears for small systems,
• Maximum in $\Lambda/\pi$ ratio **SURVIVES** for small systems,

If this is confirmed experimentally then a hadronic scenario explains the behaviour seen in the hadronic ratios and there is no need for other mechanisms.
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Net baryon density $\rho_B$ (fm$^{-3}$)

Temperature $T$ (GeV)

Hadronic freeze-out

$S = 0$ & $Q/B = 0.4$

no excluded volume

excluded volume
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