Thermal Model Description of Collisions of Small Nuclei

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Work done in collaboration with:

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Krzysztof Redlich (Poland)

arXiv:1603.09553

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Outline

Use of Thermal Concepts in Heavy-Ion Collisions

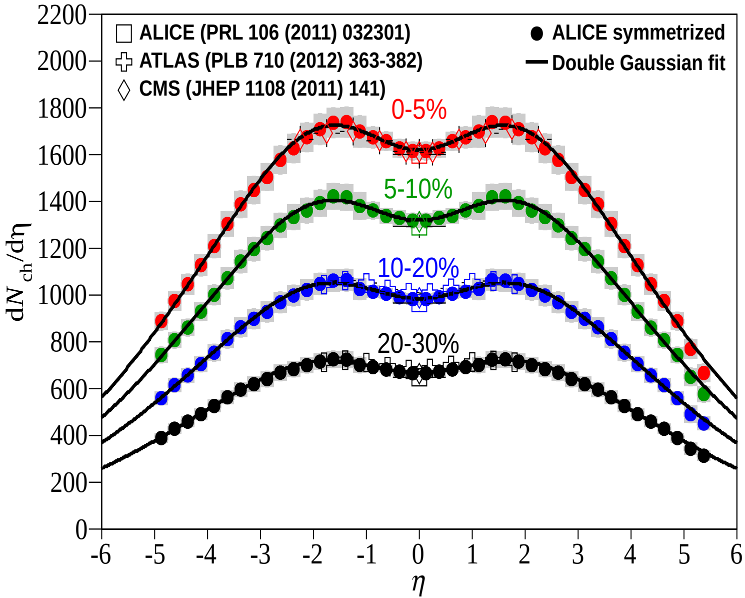
Comparison of Chemical Freeze-Out Criteria

The Energy Region of NICA, FAIR, NA61, BES,...

Disappearance of Maxima in Small Systems

Conclusion

Particle Multiplicity in Heavy Ion Collisions



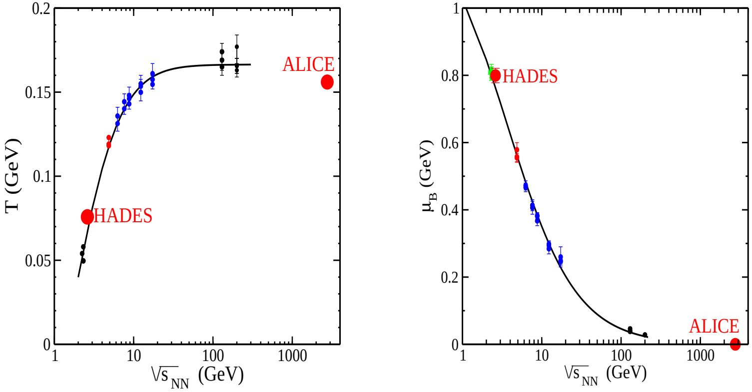
Particle Multiplicity in Heavy Ion Collisions

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, ...

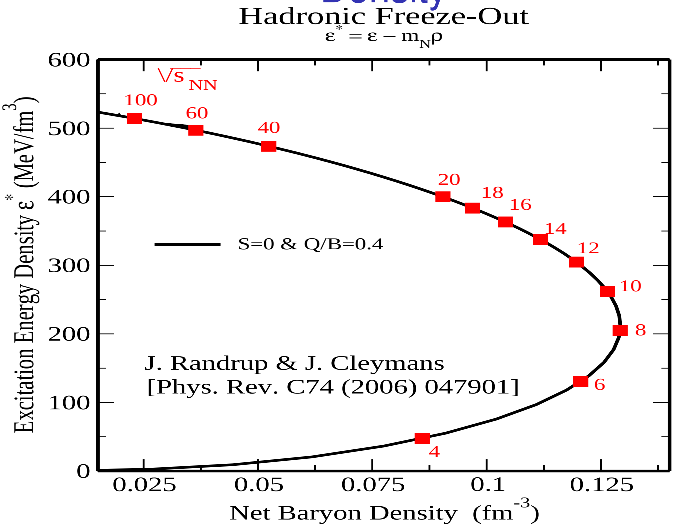
These concepts turn out to be useful at other energies, RHIC, SPS, SIS, NICA ...

Chemical Freeze-Out Temperature

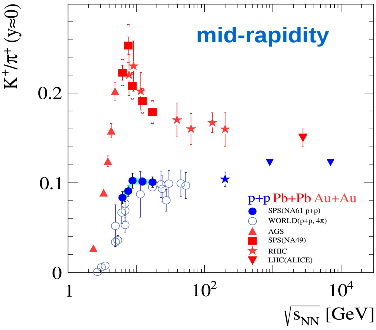


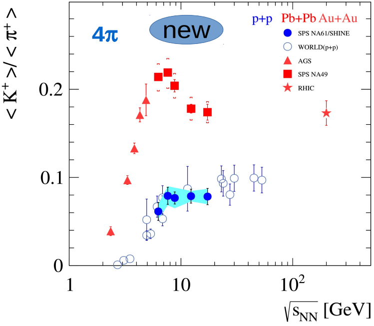
J.C., H. Oeschler, K. Redlich, S. Wheaton, Phys. Rev. C73 (2008) 054001

Unexpected Result: Maximum in the Net Baryonic Density



K. Grebieszkow (NA61/SHINE) talk at CPOD2016: Maximum in the K^+/π^+ 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

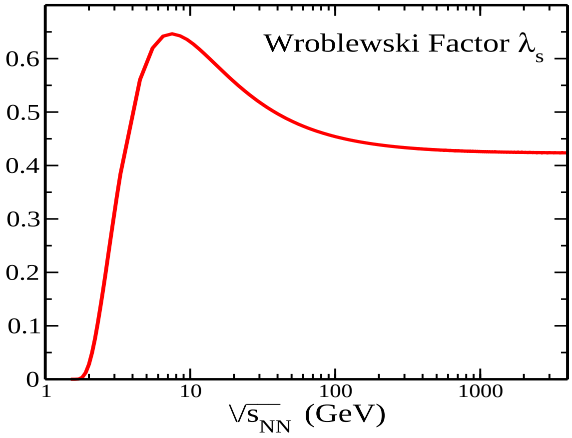
Use the Wroblewski factor

$$\lambda_s = \frac{2\,\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle}$$

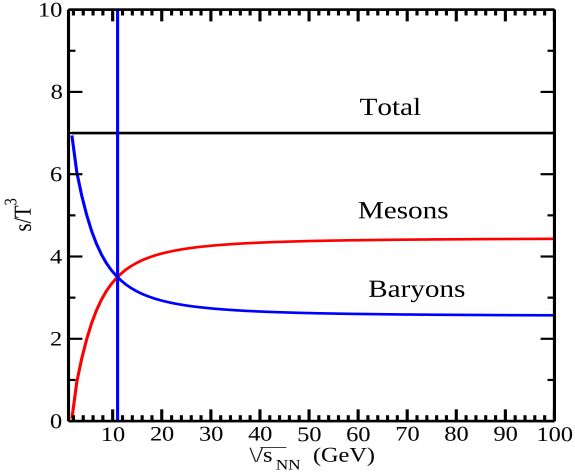
This is determined by the number of **newly** created quark – anti-quark pairs and **before** strong decays, i.e. before ρ's and Δ's decay.

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

Wroblewski Factor



s/T^3



J. C., H. Oeschler, K. Redlich and S. Wheaton, Physics Letters B615 (2005) 50-54.

J.C., H. Oeschler, K. Redlich, S. Wheaton, Phys. Lett. B615 (2005) 50-54

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^+/π^+, Ξ^-/π^+ and Ω^-/π^+ ratios **which occur at different beam energies.**

P. Braun-Munzinger, J.C., H. Oeschler, K. Redlich, Nucl. Phys. A697 (2002) 902.

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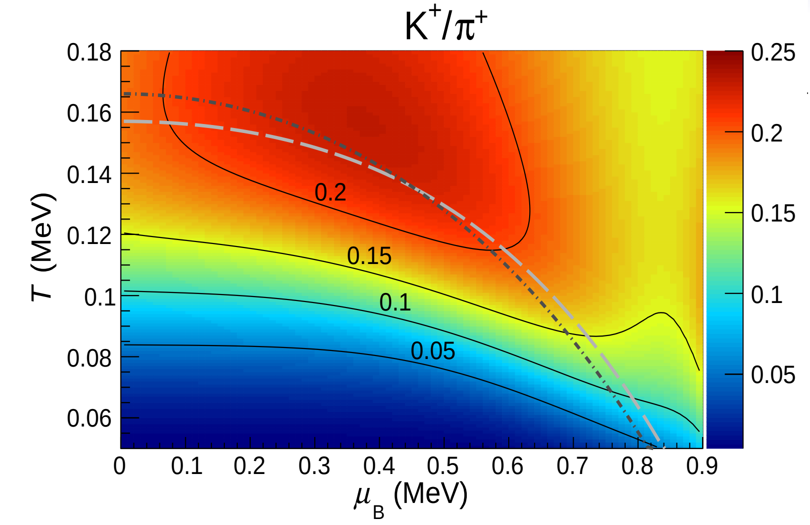
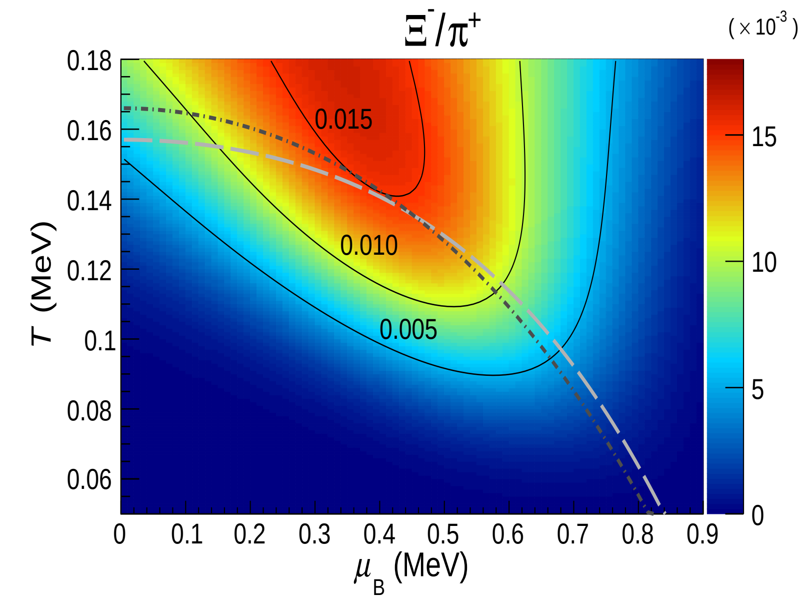


J.C., B. Hippolyte, H. Oeschler, K. Redlich, N. Sharma arXiv:1603.09553

V. Vovchenko, V.V. Begun, M.I. Gorenstein, arXiv:1512.08025[nucl-th]



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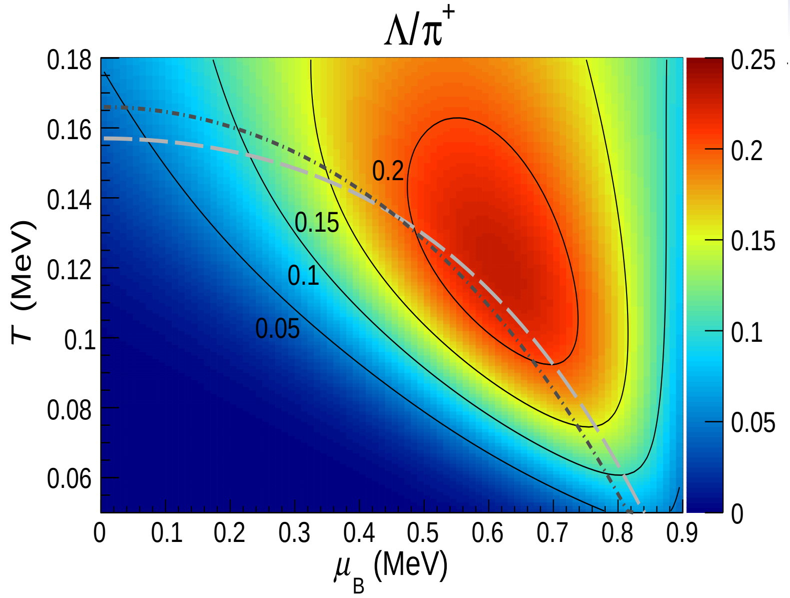

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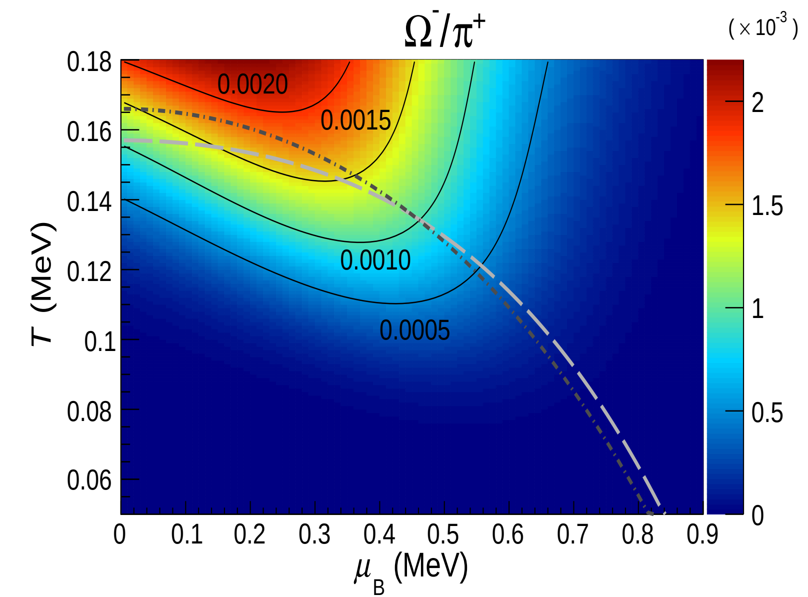

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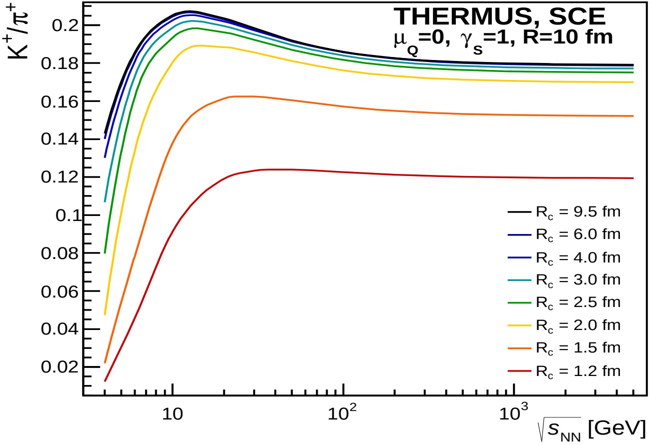
Small systems.

- 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
arXiv:1603.09553

S. Hamieh, K. Redlich and A. Tounsi, Phys. Lett. B486 (2000) 61

Maximum in K^+/π^+ ratio disappears



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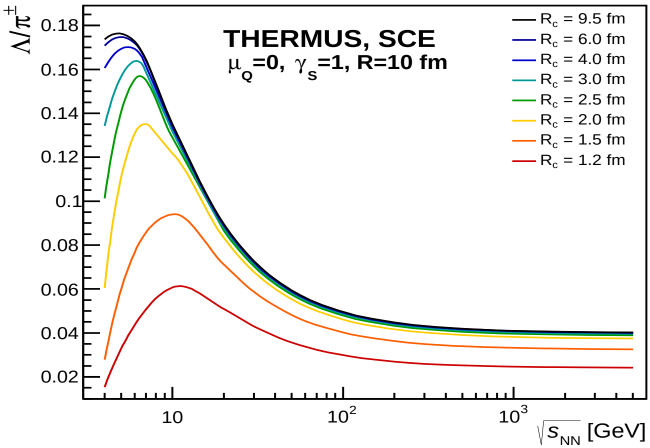
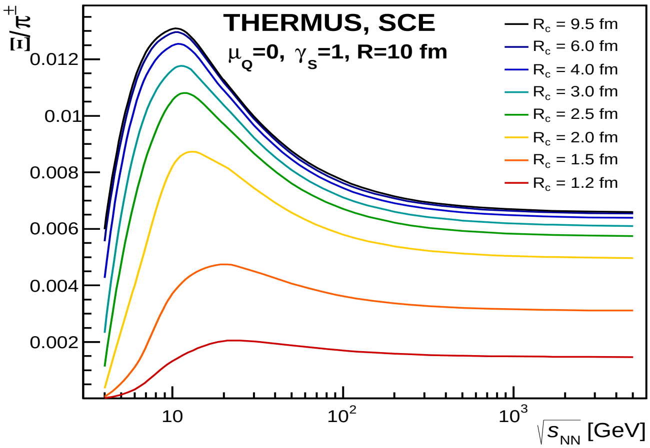
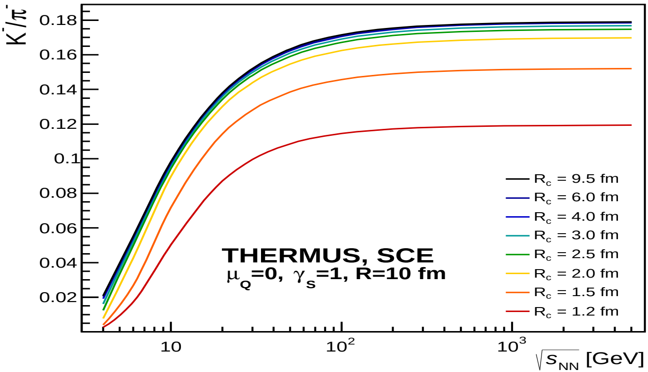
Maximum in Λ/π^+ ratio survives




THERMUS, SCE
μQ=0, γs=1, R=10 fm
Rc = 9.5 fm
Rc = 6.0 fm
Rc = 4.0 fm
Rc = 3.0 fm
Rc = 2.5 fm
Rc = 2.0 fm
Rc = 1.5 fm
Rc = 1.2 fm
Ξ/π±
0.012
0.01
0.008
0.006
0.004
0.002
10
10²
10³
√sNN [GeV]



K⁻/π⁻
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
10
10^2
10^3
$\sqrt{s_{NN}}$ [GeV]
THERMUS, SCE
μ_Q=0, γ_s=1, R=10 fm
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

Conclusions

- Maximum in K^+/π^+ ratio disappears for small systems,
- Maximum in Λ/π 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

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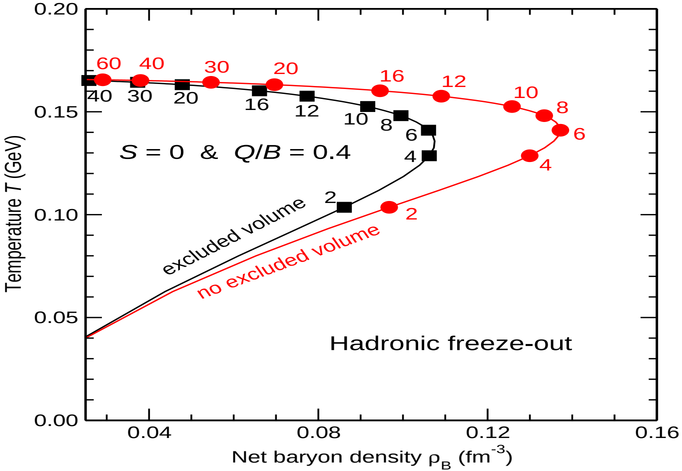
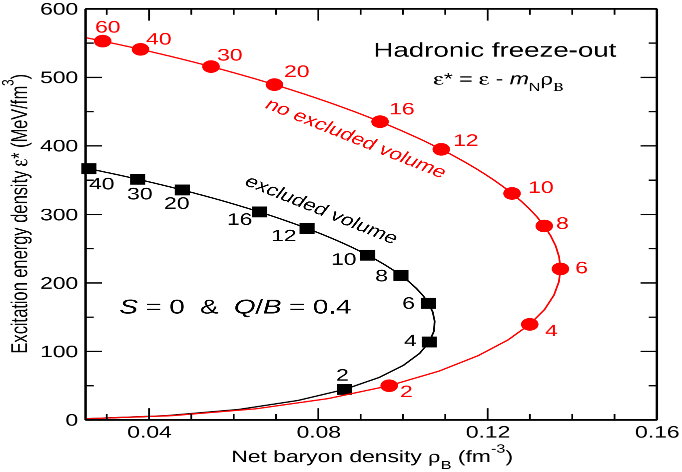

0.20
0.15
0.10
0.05
0.00
0.04
0.08
0.12
0.16
Temperature T (GeV)
Net baryon density ρB (fm-3)
S = 0 & Q/B = 0.4
excluded volume
no excluded volume
Hadronic freeze-out
60
40
30
20
16
12
10
8
6
4
2
40
30
20
16
12
10
8
6
4
2



Hadronic freeze-out
ε* = ε - m_N ρ_B
no excluded volume
excluded volume
S = 0 & Q/B = 0.4
Excitation energy density ε* (MeV/fm^3)
Net baryon density ρ_B (fm^-3)
600
500
400
300
200
100
0
0.04
0.08
0.12
0.16
60
40
30
20
16
12
10
8
6
4
2