A step-by-step analysis of the Equilibration of Hadron matter from the Microscopic Model (UrQMD model 3.3)

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Outline

- MOTIVATION
- TRANSPORT THEORY OF NUCLEAR COLLISIONS
  - *RELATIVISTIC TRANSPORT EQUATION*
- THE UrQMD MODEL
- EQUILIBRATION OF HADRON GAS
  - *CHEMICAL EQUILIBRIUM*
  - *THERMAL EQUILIBRIUM and TEMPERATURE*
- CONCLUSION

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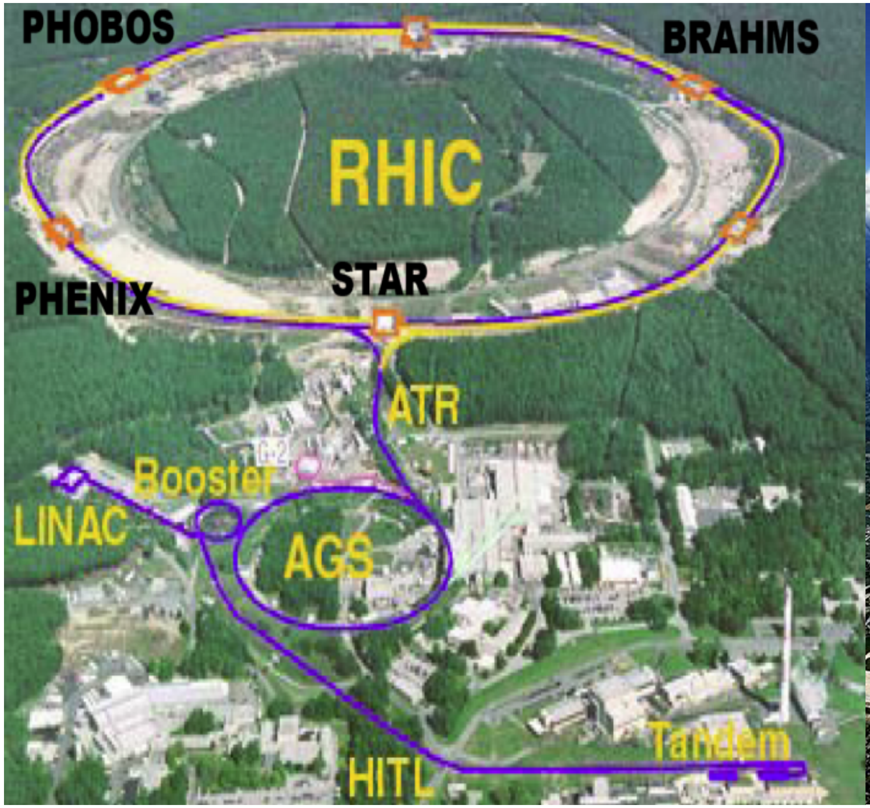
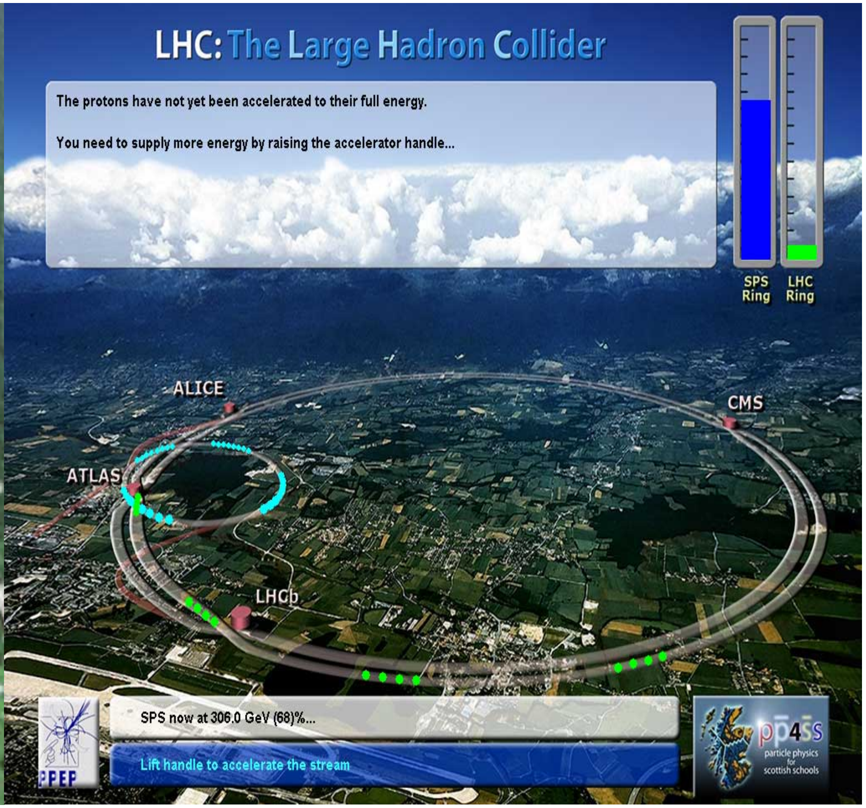
Motivation

- Through the thermal and chemical equilibration one can obtain equilibrium temperature, energy densities which can be used to observe the equation of state (EoS) of matter.
- To investigate the equilibration phenomena of the system we look at the particle densities and energy distributions of each particle.
- EoS is important for the observation of the phase transition of the QGP into hadron gas.
- The extracted temperature will be used to study the transport coefficients such as shear viscosity using the Green-Kubo formula.
- In studying the equilibration of the hadron gas we would like to maintain detailed balance in the simulations.

The evolution of Heavy Ion Collision





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Transport theory of Nuclear Collision

Is this what you are thinking? then if it is think again!!!

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Relativistic transport equation

Collision term

$$[p_\mu \partial^\mu{}_x + (p_\nu F^{\mu\nu} + m(\partial^\mu{}_x m))\partial^p{}_\mu] f(x,p) = C_{coll}(x,p)$$

•The relativistic transport equation is written in terms of an RBUU tensor

•The Right hand side is the interaction or the collision term given by

Transition probability

$$C_{coll}(x,p) = \frac{1}{2}\int \frac{d^4p_2}{E_{p_2}(2\pi)^4}\int \frac{d^4p_3}{E_{p_3}(2\pi)^4}\int \frac{d^4p_4}{E_{p_4}(2\pi)^4} \times W(p,p_2 \,|\, p_3,p_4) \times [f(x,P_3)f(x,P_4)(1 - f(x,P))(1 - f(x,P_2)) - f(x,P)f(x,P_2)(1 - f(x,P_3))(1 - f(x,P_4))]$$

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UrQMD model

UrQMD: Ultra-relativistic Quantum molecular Dynamics

- It is a Monte Carlo simulation package
- Built for Proton+Proton, Proton+nucleus, and nucleus+nucleus interaction
- It is a non-equilibrium transport model
- It includes 55 baryon species

  and 32 meson species

Is a model that uses probability distribution functions which are derived from the physics processes and uses random number to do calculations

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UrQMD model included species

32 meson species

ID	0^{-+}	ID	1^{--}	ID	0^{++}	ID	1^{++}
101	π	104	ρ	111	a_0	114	a_1
106	K	108	K^*	110	K_0^*	113	K_1^*
102	η	103	ω	105	f_0	115	f_1
107	η'	109	ϕ	112	f_0^*	116	f_1'
ID	1^{+-}	**ID**	2^{++}	**ID**	$(1^{--})^*$	**ID**	$(1^{--})^{**}$
122	b_1	118	a_2	126	ρ_{1450}	130	ρ_{1700}
121	K_1	117	K_2^*	125	K^*_{1410}	129	K^*_{1680}
123	h_1	119	f_2	127	ω_{1420}	131	ω_{1662}
124	h_1'	120	f_2'	128	ϕ_{1680}	132	ϕ_{1900}

55 baryon species

nucleon	delta	lambda	sigma	xi	omega
N_{938}	Δ_{1232}	Λ_{1116}	Σ_{1192}	Ξ_{1315}	Ω_{1672}
N_{1440}	Δ_{1600}	Λ_{1405}	Σ_{1385}	Ξ_{1530}	
N_{1520}	Δ_{1620}	Λ_{1520}	Σ_{1660}	Ξ_{1690}	
N_{1535}	Δ_{1700}	Λ_{1600}	Σ_{1670}	Ξ_{1820}	
N_{1650}	Δ_{1900}	Λ_{1670}	Σ_{1750}	Ξ_{1950}	
N_{1675}	Δ_{1905}	Λ_{1690}	Σ_{1775}	Ξ_{2030}	
N_{1680}	Δ_{1910}	Λ_{1800}	Σ_{1915}		
N_{1700}	Δ_{1920}	Λ_{1810}	Σ_{1940}		
N_{1710}	Δ_{1930}	Λ_{1820}	Σ_{2030}		
N_{1720}	Δ_{1950}	Λ_{1830}			
N_{1900}		Λ_{1890}			
N_{1990}		Λ_{2100}			
N_{2080}		Λ_{2110}			
N_{2190}					
N_{2200}					
N_{2250}					

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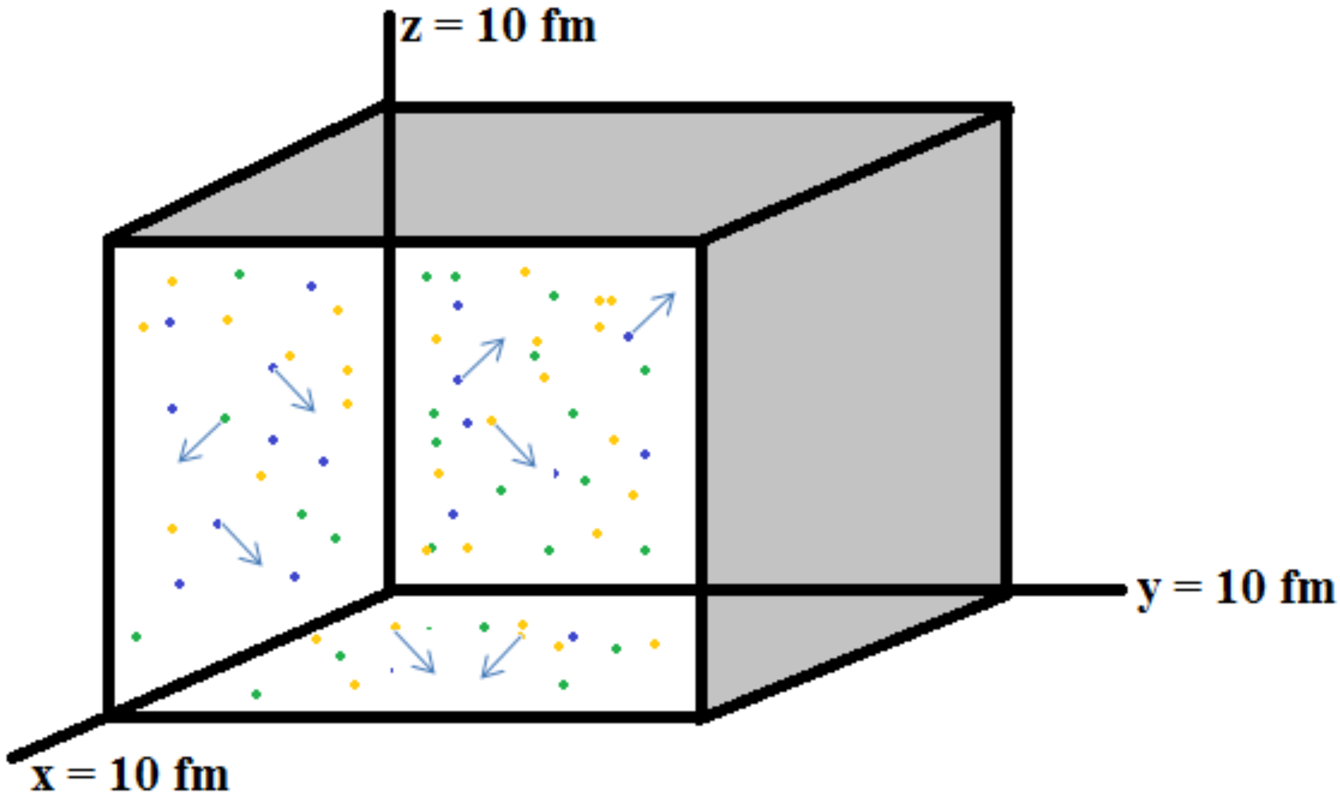
A sketch of the Box model system, which is simulated by the UrQMD model

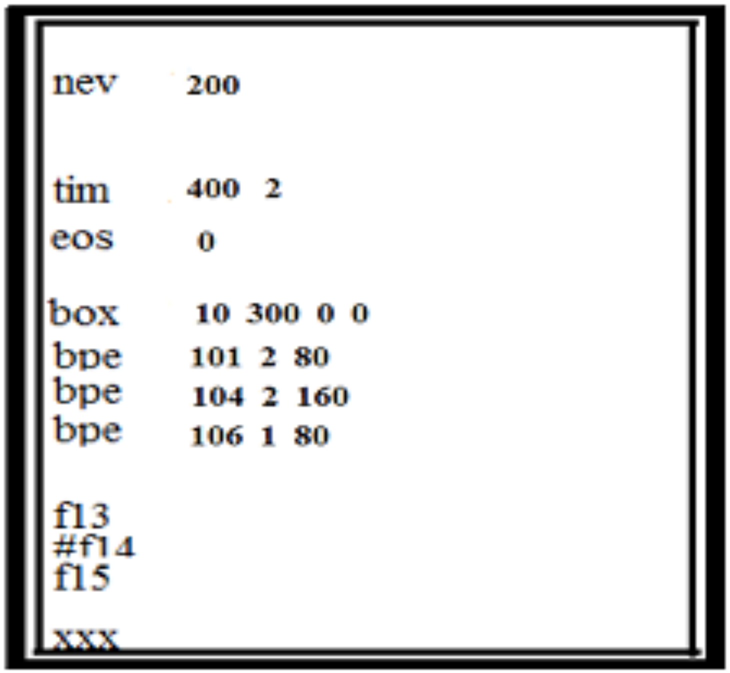
We consider a box with periodic boundary conditions

Green = Pions Blue = Rhos Orange = Kaons



The Simulation

The Input file



```
nev    200

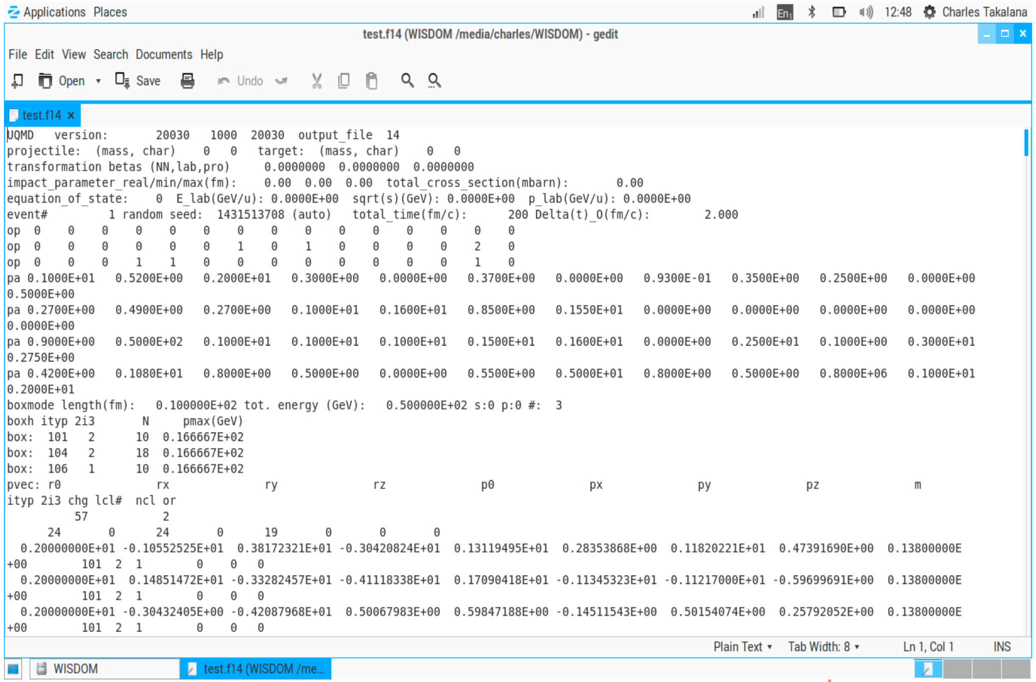
tim    400  2
eos    0

box    10  300  0  0
bpe    101  2  80
bpe    104  2  160
bpe    106  1  80

f13
#f14
f15

xxx
```

The output file




```
UQMD   version:       20030   1000  20030  output_file  14
projectile:  (mass, char)    0   0   target:  (mass, char)    0   0
transformation betas (NN,lab,pro)     0.0000000  0.0000000  0.0000000
impact_parameter_real/min/max(fm):    0.00  0.00  0.00  total_cross_section(mbarn):      0.00
equation_of_state:    0  E_lab(GeV/u): 0.0000E+00  sqrt(s)(GeV): 0.0000E+00  p_lab(GeV/u): 0.0000E+00
event#        1 random seed:  1431513708 (auto)   total_time(fm/c):      200 Delta(t)_O(fm/c):       2.000
op  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
op  0    0    0    0    0    0    1    0    1    0    0    0    0    2    0
op  0    0    0    1    1    0    0    0    0    0    0    0    0    1    0
pa 0.1000E+01   0.5200E+00   0.2000E+01   0.3000E+00   0.0000E+00   0.3700E+00   0.0000E+00   0.9300E-01   0.3500E+00   0.2500E+00   0.0000E+00
0.5000E+00
pa 0.2700E+00   0.4900E+00   0.2700E+00   0.1000E+01   0.1600E+01   0.8500E+00   0.1550E+01   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00
pa 0.9000E+00   0.5000E+02   0.1000E+01   0.1000E+01   0.1000E+01   0.1500E+01   0.1600E+01   0.0000E+00   0.2500E+01   0.1000E+00   0.3000E+01
0.2750E+00
pa 0.4200E+00   0.1080E+01   0.8000E+00   0.5000E+00   0.0000E+00   0.5500E+00   0.5000E+01   0.8000E+00   0.5000E+00   0.8000E+06   0.1000E+01
0.2000E+01
boxmode length(fm):   0.100000E+02 tot. energy (GeV):   0.500000E+02 s:0 p:0 #:  3
boxh ityp 2i3       N     pmax(GeV)
box:  101   2      10  0.166667E+02
box:  104   2      18  0.166667E+02
box:  106   1      10  0.166667E+02
pvec: r0              rx              ry              rz              p0              px              py              pz              m
ityp 2i3 chg lcl#  ncl or
          57             2
      24       0      24       0      19       0       0       0
  0.20000000E+01 -0.10552525E+01  0.38172321E+01 -0.30420824E+01  0.13119495E+01  0.28353868E+00  0.11820221E+01  0.47391690E+00  0.13800000E
+00        101  2  1        0    0   0
  0.20000000E+01  0.14851472E+01 -0.33282457E+01 -0.41118338E+01  0.17090418E+01 -0.11345323E+01 -0.11217000E+01 -0.59699691E+00  0.13800000E
+00        101  2  1        0    0   0
  0.20000000E+01 -0.30432405E+00 -0.42087968E+01  0.50067983E+00  0.59847188E+00 -0.14511543E+00  0.50154074E+00  0.25792052E+00  0.13800000E
+00        101  2  1        0    0   0
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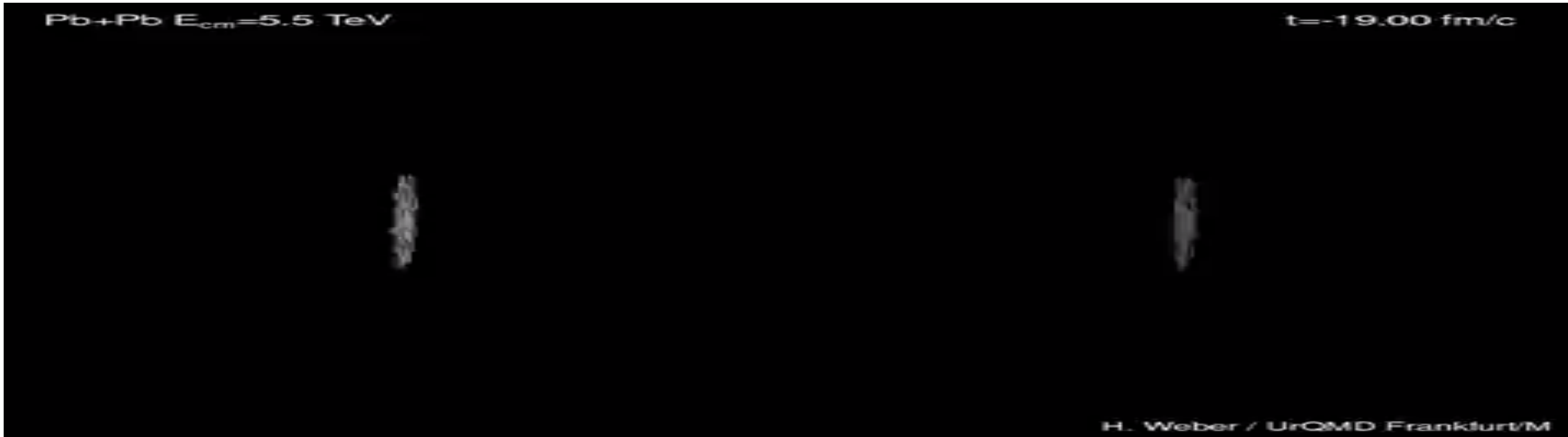
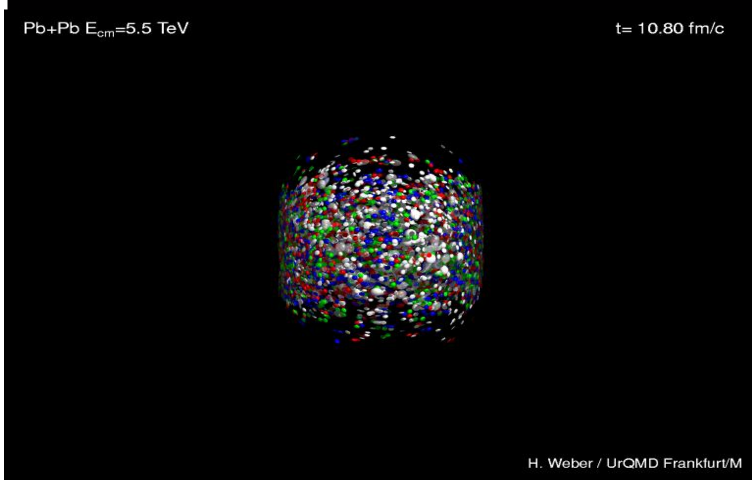
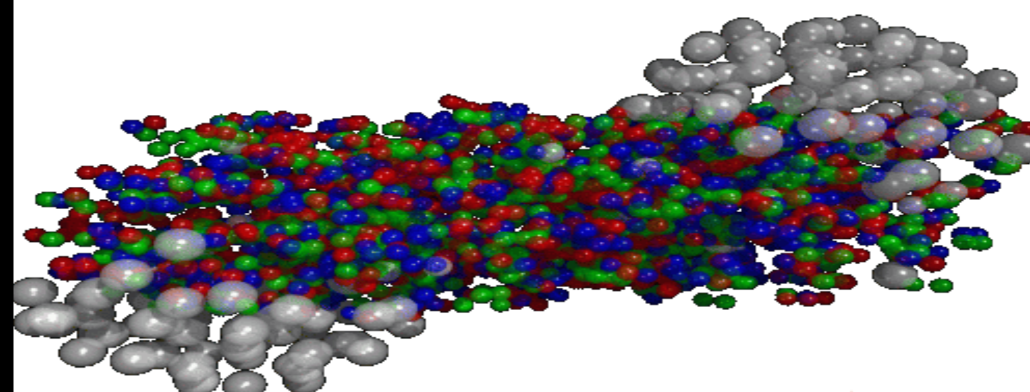
UrQMD model animation







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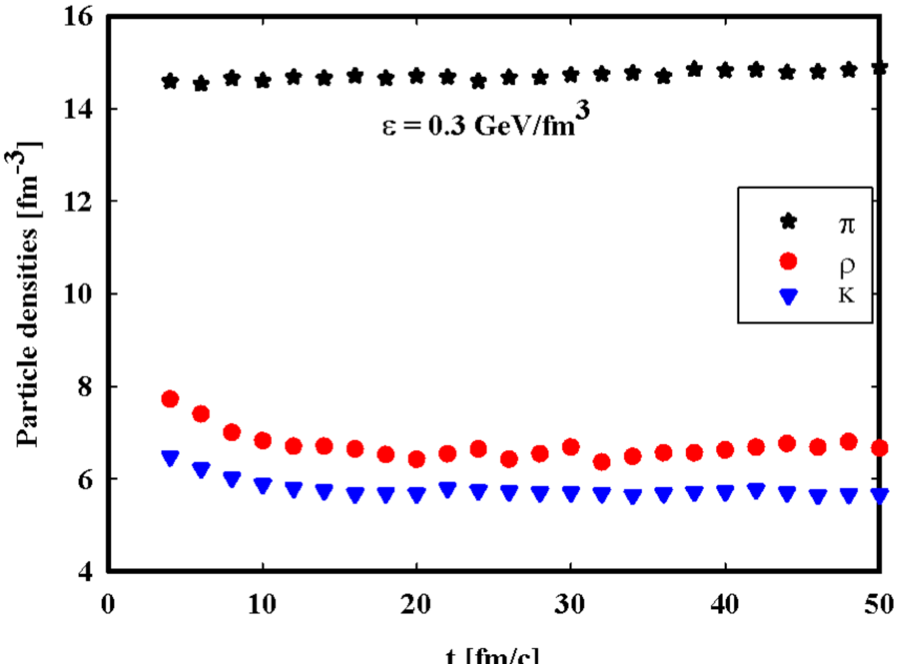
Results – Chemical, Thermal equilibrium

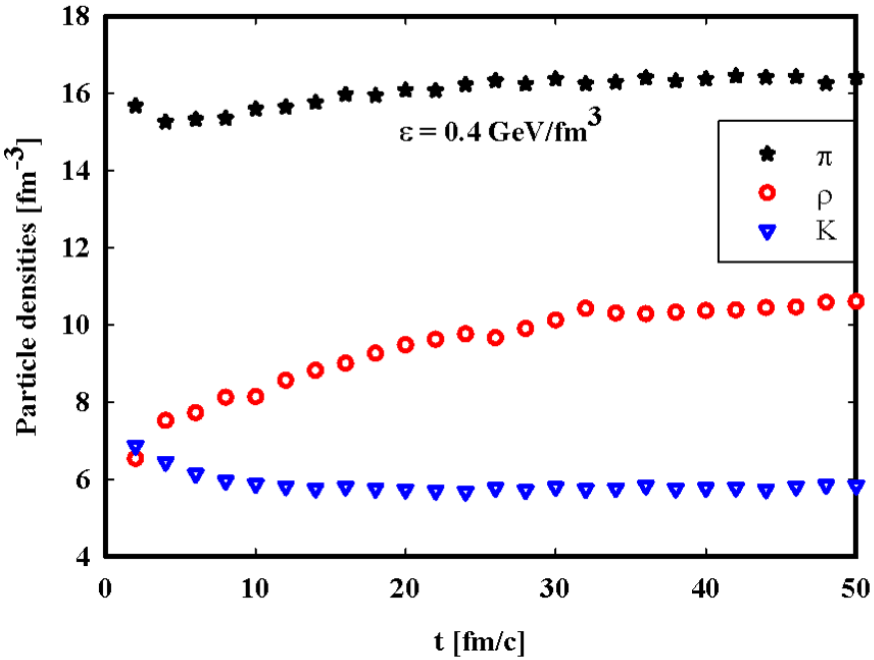
- What is the approach of chemical and thermal equilibrium?
- We study time evolution of
  - Particle number density
  - Energy spectra for different meson species
- Saturations of particle multiplicity determined chemical equilibrium.
- Convergence of particle slopes to common value of temperature, determine thermal equilibrium.

Results - Chemical equilibrium

Particle number density at lower time t < 50 fm/c

It is not yet clear if chemical equilibrium is reached





At t = 20 fm/c for 0.3 GeV/fm^3 and t = 32 fm/c for 0.4 GeV/fm^3 number density of different meson species start to saturate.

Pions have a larger number density due to decaying of heavier mesons to form large amount of pions in the system.

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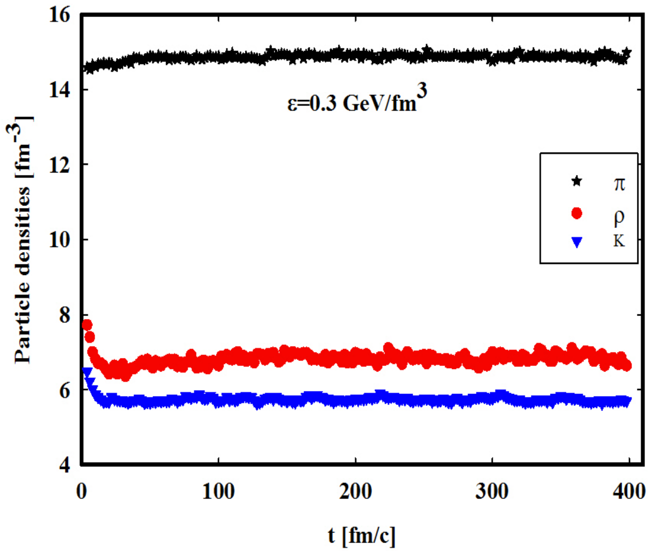
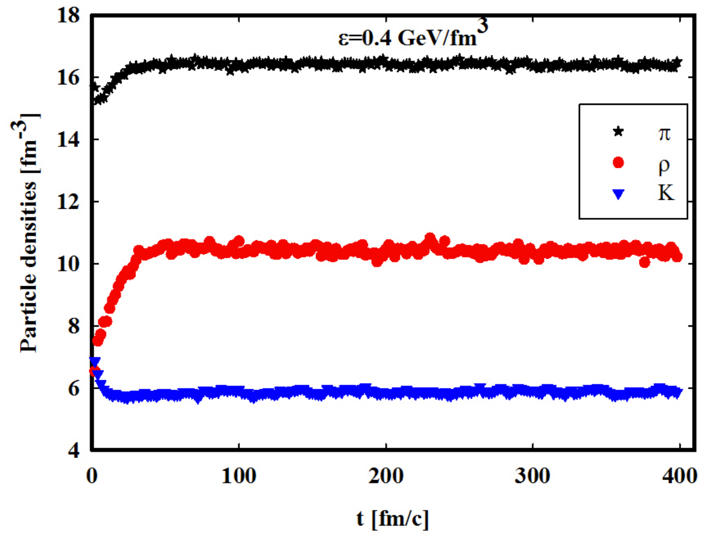
Results - Chemical equilibrium

- Particle number density: $n = \frac{1}{V}\sum_{k=1}^{N} N_k$





While studying chemical equilibrium
it is for best to look at longer time in order
to have clear indication if all the particles
have indeed saturated

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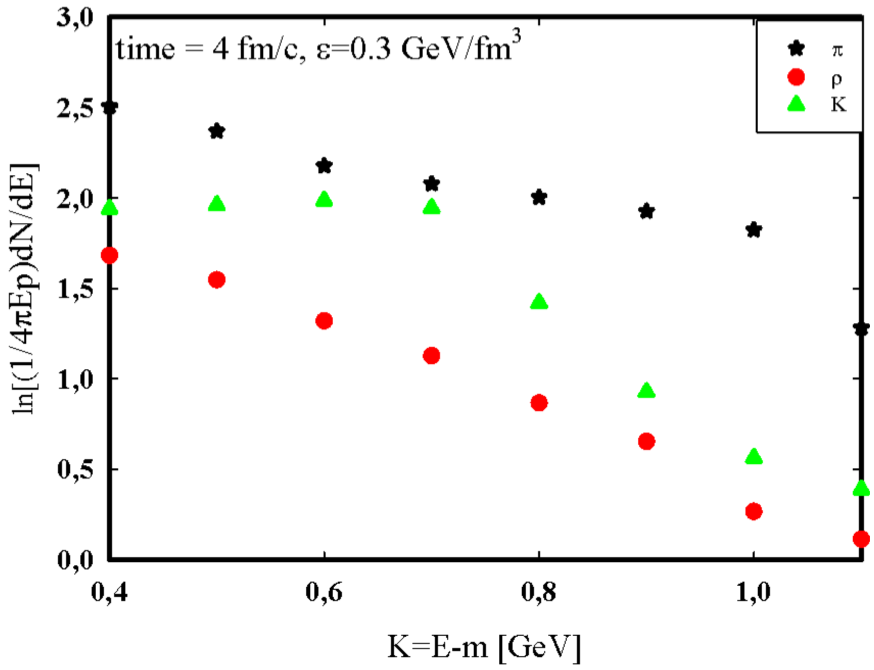
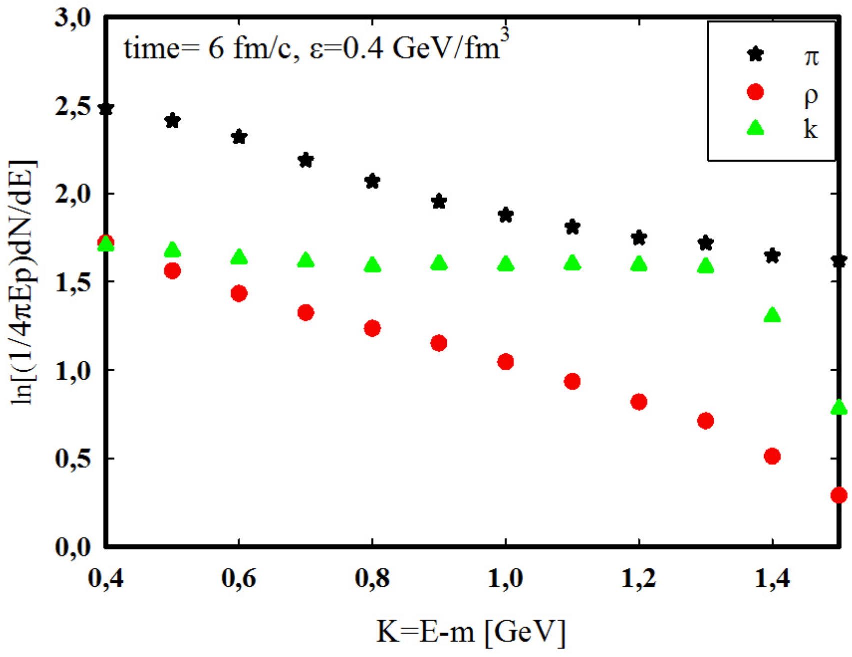
Results - Thermal equilibrium

- Particle spectra: $\frac{dN_k}{d^3p} = \frac{dN}{4\pi E p dE} \propto Ce^{-\beta E_k}$

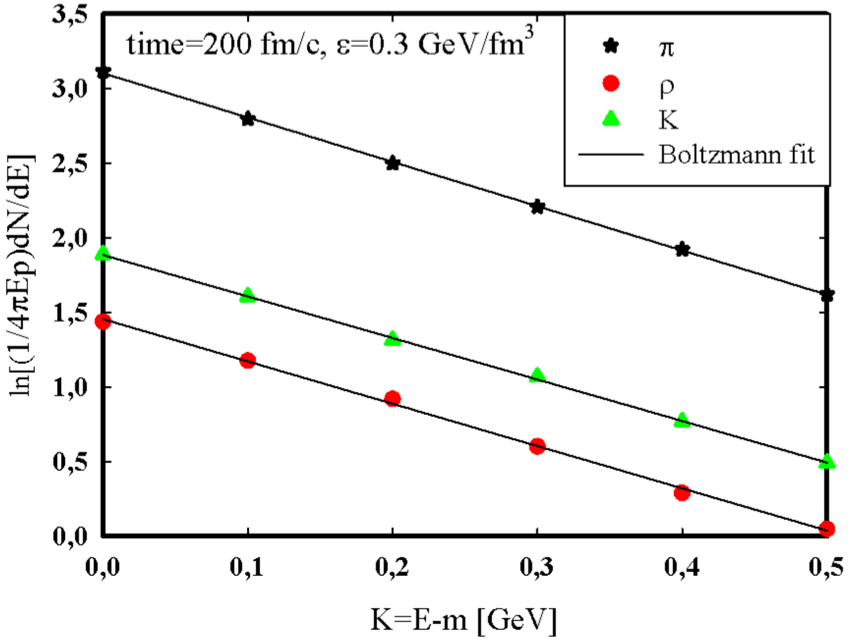


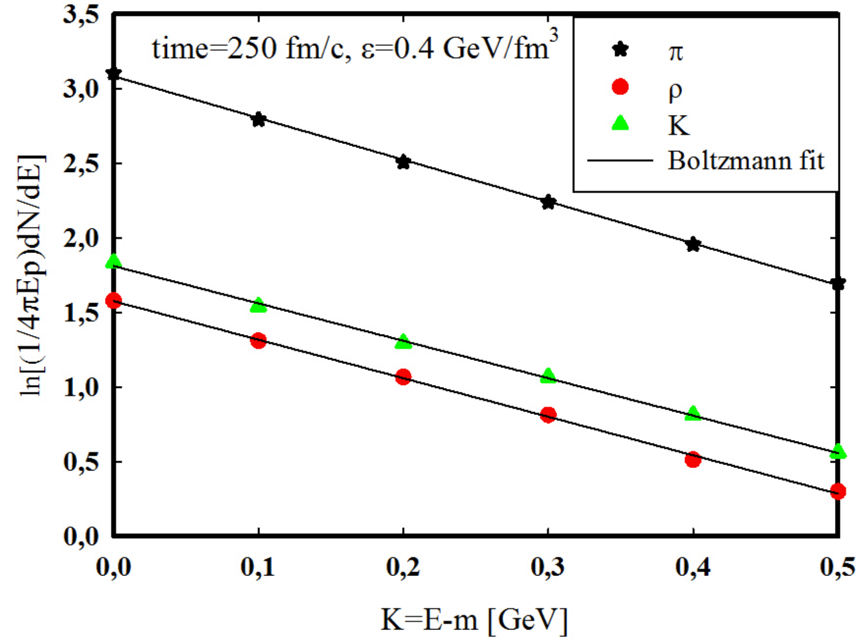


At t = 4 fm/c for 0.3 GeV/fm^3 and t = 6 fm/c for 0.4 GeV/fm^3 the slopes of energy spectra of different light meson species does not converges to common value of temperature. Those thermal equilibrium is not yet reached.

Results - Thermal equilibrium

- Particle spectra: $\frac{dN_k}{d^3p} = \frac{dN}{4\pi E p dE} \propto Ce^{-\beta E_k}$





At t = 200 fm/c for 0.3 GeV/fm^3 and t = 6 fm/c for 0.4 GeV/fm^3 the slopes of energy spectra of different light meson species converges to common value of temperature T = 150,1 MeV and T = 161,97 MeV respectively.

Results: Temperature (T) extracted from each energy density (ε)

- For each energy density used for the initialization of the input file to simulate the heavy ion collision in a cubic box the following temperatures where obtained.

$$\varepsilon = \frac{1}{V}\sum_{k=1}^{N} E_k$$

Energy density (ε) GeV/fm³	Temperature (T) MeV
0.175	95.23
0.2	118.3
0.225	131.7
0.25	139.3
0.275	145.9
0.3	150.1
0.325	153.2

Energy density (ε) GeV/fm³	Temperature (T) MeV
0.35	158.5
0.375	160.5
0.4	161.97
0.425	164.7
0.45	164.7
0.475	166.9

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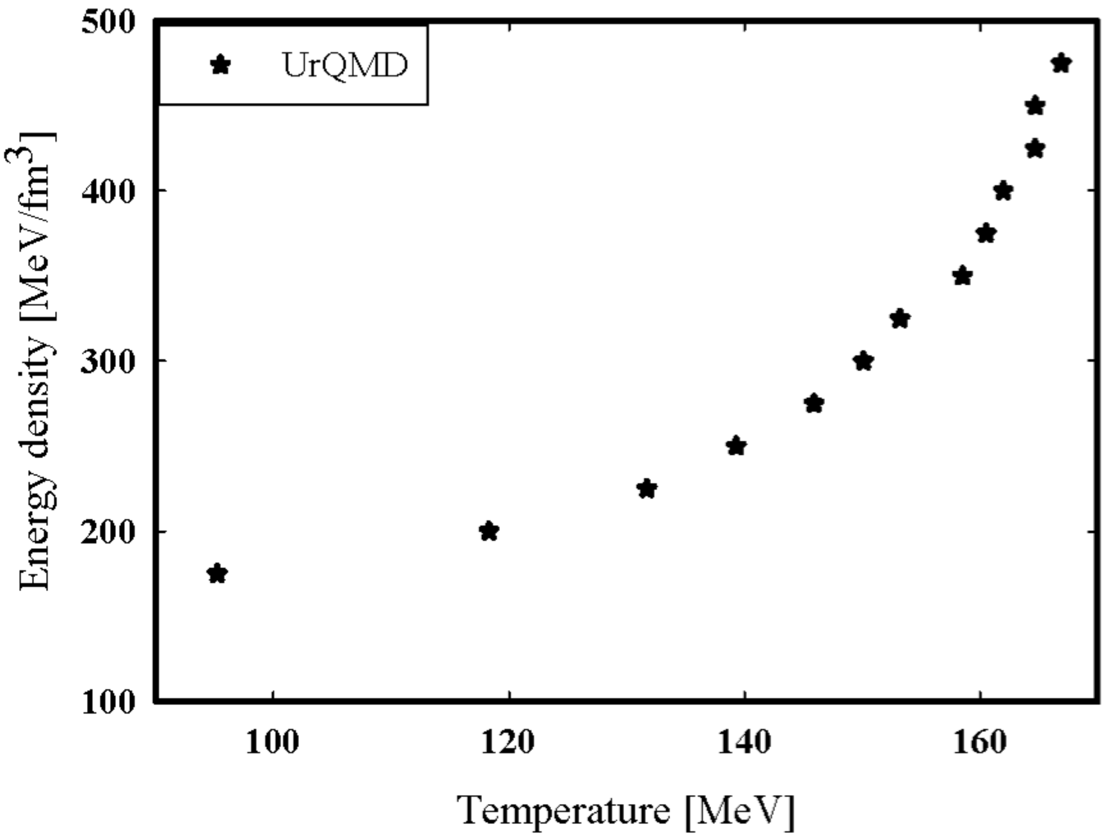
Results: Temperature (T) extracted from each energy density (ε)

The relationship between the energy density and temperature is known as EoS

EoS is important for the determination of the phase transition of QGP
At Higher temperature EoS behaves like a power law



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Conclusion

- At different time t fm/c particle number density of different meson species start to saturate.
- Pions has larger number density due to decaying of heavier mesons to form large amount of pions in the system.
- At different time t fm/c, the slopes of energy spectra of different light meson species converges to common value of temperature T MeV.
- The results shows that an increase in energy density influence an increase in temperature
- Thermal equilibrium is reached at different temperatures for different energy densities
- Both chemical and thermal equilibrium has been reached after simulating heavy ion collision from a cubic box with periodic boundary condition using the UrQMD model 3.3

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