General aspects of the Freeze-Out model and Cooper-Frye formula

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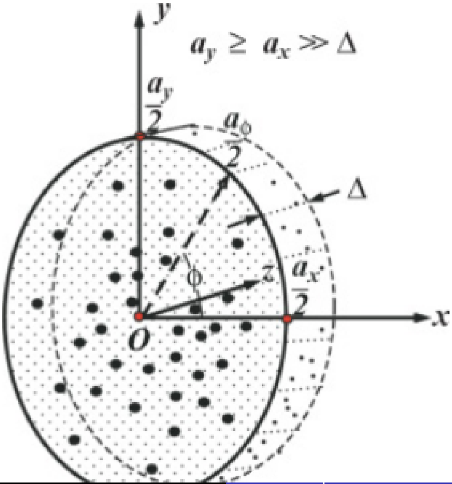
The Landau hidrodynamic model gives the foundation for the time evolution analysis of the fluid generaded rigth after a heavy ion collition. The ideas of a freeze-out expansion stage are taken to work out the particle distribution in the Cooper-Frye formula.

Landau hidrodynamic model

Landau modeled the sistem after a heavy ion collition as a relativistic fluid and made some assumptions of its behavior [1].

1. The hidrodynamic expantion is adiabatic.
2. The net number of generated particles is proportional to entropy.
3. The entropy of the system do not change.
4. The expansion is given in two stages.

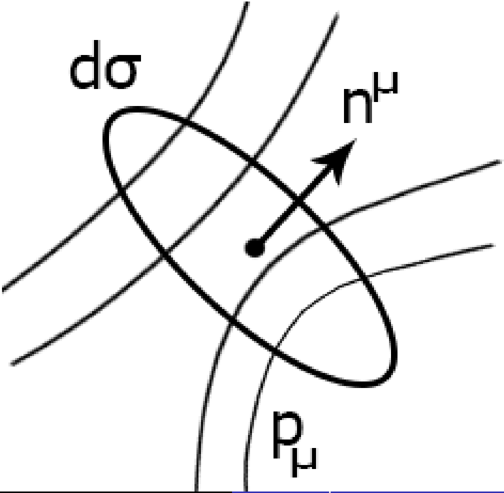
The first stage consists of independent expansions in the transverse and longitudinal direction, as shown in the figure 4.



In the second stage, the transverse displacement $x(t)$ becomes comparable to a in $t = T_{FO}$, therefore we can neglate the hidrodynamics forces and the rapidity y «freezes out». Equivanlently, the angle θ between the trajectory of the fluid and the collition axis freezes.

Cooper-Frye formula

Now, let's considere the world lines crossing a differencial surface



The number of worldlines that make a positive transition in the differential surface is [2]

$$dN = f(x,p)\epsilon(n)p^{\mu}n_{\mu}dpd\sigma \tag{1}$$

Cooper and Freye expresed it like [3]

$$dN = f(x,p)p^{\mu}d\sigma_{\mu}Dp \tag{2}$$

$$Dp = 2\delta^{+}(p^2 - m^2)d^4p \tag{3}$$

Therefore, the total number of world lines crossing a surface σ is

$$N = \int_p Dp \int_\sigma f(x,p) p^\mu d\sigma_\mu \tag{4}$$

So, the particle distribution in momentum space can be expresed like this

$$E\frac{dN}{d^3p} = \int_\sigma f(x,p)p^\mu d\sigma_\mu \tag{5}$$

The ideas of the Landau hidrodynamic model are applied to Cooper-Frye formula considering the σ surface as the freeze-out surface.

[1] C.-Y. Wong, "Landau hydrodynamics reexamined," *Physical Review C*, vol. 78, no. 5, p. 054902, 2008.

[2] W. Israel, "Relativistic kinetic theory of a simple gas," *Journal of Mathematical Physics*, vol. 4, no. 9, pp. 1163–1181, 1963.

[3] F. Cooper and G. Frye, "Single-particle distribution in the hydrodynamic and statistical thermodynamic models of multiparticle production," *Physical Review D*, vol. 10, no. 1, p. 186, 1974.