ENTROPY PRODUCTION IN HIGHLY TRANSPARENT COLLIDING SYSTEMS

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- The LHC, Geneva, is almost 2 orders of magnitude increase in beam energy.
- However, how much is it in enmtropy? (In continuum physics S is more important than E!)
- So how much S/N is expected at 7000+7000 GeV E/N?

- Note that:
- S/N was 50±5 at 158 GeV E/A fixed target (≈9+9 GeV E/N). (Rafelski, Letessier and Tounsi, several times from yields)
- E_{beam} is not the internal energy.
- Ordered motion does not produce S!

Also, carefully, because

- S is a par excellence thermodynamical quantity;
- But the internal state of the matter is very anisotropic.
- The cross-sections are very forward-peaked at such energies, so after a few collisions the particles move still almost unperturbed (so S/N cannot be big).

- So we need thermodynamics with an extra anisotropy degree of freedom so that S=0 at undisturbed ambidirectional flow of any velocities
- +
- A relativistically exact anisotropic continuum dynamics.
- Let us do it!

THE FORMALISM

[1] B. Lukács & K. Martinás: Dynamically Redundant Particle Components in Mixtures. Acta Phys. Slov. **36**, 81 (1986)

[2] H-W. Barz, B. Kämpfer, B. Lukács, K. Martinás & G. Wolf: Deconfinement Transition in Anisotropic Matter. Phys. Lett. **194B**, 15 (1987)

[3] H-W. Barz, B. Kämpfer, B. Lukács & G. Wolf: Anisotropic Nuclear Matter with Momentum-Dependent Interactions. Europhys. Lett. **8**, 239 (1989)

[4] B. Kämpfer, B. Lukács, K. Martinás & H-W. Barz: Fluid Dynamics in Anisotropic Media. KFKI-1990-47

[5] H-W. Barz, B. Kämpfer, B. Lukács & G. Wolf: Obobshennaya gidrodinamika vzaimopronikayushchih potokov yadernoi materii. Yad. Phys. **51**, 366 (1990)

[6] B. Kämpfer, B. Lukács, G. Wolf & H-W. Barz: Description of the Stopping Process within Anisotropic Thermodynamics. Phys. Lett. **240B**, 237 (1990)

Almost archaeology. However…

- You cannot be sure in too much; but
- $T^{ir}{}_{;r} = 0$
- $n^{r}{}_{;r} = 0$
- $s^{r}{}_{;r} \geq 0$
- And that will be enough!

$$T^{ik} = \alpha u^i u^k + \beta(u^i t^k + t^i u^k) + \gamma t^i t^k + (d^i u^k + u^i d^k) + (b^i t^k + t^i b^k) + c^{ik}$$

$$d_r u^r = d_r t^r = b_r u^r = b_r t^r = c_{ir} u^r = c_{ir} t^r = 0$$

Vector d^i is heat current; local equilibrium approach neglects it. If so, we may neglect b^i as well. We may assume that c^{ik} (a 2*2 tensor) is "as isotropic as possible".

$$T^{ik} = e u^i u^k + \beta(u^i t^k + t^i u^k) + k\{g^{ik} + u^i u^k - t^i t^k / t^2\}$$

where we wrote $\alpha \rightarrow e$ due to the usual definition

$$T^{ik} u_i u_k \equiv e$$

β is 0 in a mirror-symmetric state, see [5]. Then

$s^i = su^i + zt^i$

Let us see z later.

Vector anisotropy is t^i . It is in beam direction. Its length is t.

The *extent* of anisotropy is t, so let the anisotropy extensive be

$Q = Vnt = Vq = Vnt$

and the proper thermodynamical potential density s

$s = s(e,n,q)$

By change of variable

$\check{s} \equiv \check{s}(e,n,t) = s(e,n,q=nt)$

$$\check{s}_{,t} Dt + (\check{s} - n\check{s}_{,n} - e\check{s}_{,e} - k\check{s}_{,e}) u^{r}{}_{;r} + t^{r}(z_{,r} - \check{s}_{,e}\beta_{,r}) + t^{r}{}_{;r}(z - \check{s}_{,e}\beta) - \check{s}_{,e}\beta t^{r} u^{s} u^{r;s} - \check{s}_{,e}(\gamma - k/t^{2}) t^{r} t^{s} u_{r;s} \geq 0$$

$$D \equiv u^{s}\partial_{s}$$

identically; and it holds identically only if the coefficients satisfy

$$k = p(e,n,t) + \omega T \check{s}_{,t} + \delta u^{r}{}_{;r}$$

$$p = T(\check{s} - n\check{s}_{,n} - e\check{s}_{,e})$$

$$z = \beta / T$$

$$\omega \geq 0$$

$$\delta \geq 0$$

$$1/T \equiv \check{s}_{,e}$$

So

$$Dt = \lambda + \nu(T_{,r} + T u_{r;s} u^s) t^r + \theta t^r t^s u_{r;s} + \omega u^r{}_{;r}$$

$$\check{s}_{,t} \lambda \geq 0$$

$$\nu = \beta / T^2 \check{s}_{,t}$$

$$\theta = (k/t^2 - \gamma)/\check{s}_{,t}$$

As well we can take the approximation $\omega=\delta=0$.

Then λ is the *only* new quantity governing "thermalisation".

Then we have got the full system of evolution eqs. as:

$$Dn + nu^r{}_{;r} = 0$$

$$De + (e+p+q)u^r{}_{;r} = 0$$

$$Du + \{D(p+q) + (p+q)_{,x}\}/(e+p+q) = 0$$

$$Dq + (q+q/v)u^r{}_{;r} - \lambda = 0$$

where $q = nt$.

Equation of state: for a nuclear matter with ideal gas + compression + pion gas with fully relativistic ambidirectional flow:

$p = nT + (\pi^2/30)T^4 + (K/9)n_0x^2(\text{varctgv} - 1 + x(2/y - y))$

$e = mny + (3/2)nT + (\pi^2/10)T^4 + (K/18)n(x-1)^2 + (K/9)n(y-1)(x/y^2((y+1)(x/y - 1) + (1 - x^2/y)/2)$

$q = mxn_0\ln(v+y) + (K/9)n_0((x/2)\ln(v+y) - x^2\text{arctgv} + vx^2((3x/2y) -1/y^2 - xv^2/y^3))$

$y \equiv (1+v^2)^{1/2}$

$x \equiv n/n_0$

where $-v/T$ is the intensive conjugate to $Q \equiv Vq$.

- We are just integrating and calculating yields (that is another matter going back to 1991 in thermodynamics) with A. Steer.