EXPECTATIONS FOR SPECIFIC ENTROPY AT LHC

B. Lukács & A. Ster
CRIP RMKI

ON THE ANISOTROPIC STATE

- There is a flux vector, ni , timelike. It can always be decomposed as
- $n^i \equiv nu^i; u^r u_r = 1$ (1)
- where u^i is the velocity field of the continuum and n is the comoving particle number density. In local equilibrium the velocity field u^i is not only the average of the individual particle velocities, but also a significant part of the particles have velocities near to u^i. However now the two original nuclei do not stop each other but they interpenetrate. The momenta at m^*u^i are almost depopulated. This is a nontrivial situation for Thermodynamics.
- S must be a unique function of the set of independent extensives, homogeneous linear function,
- $S = Y_R X^R = S_{,R} X^R$ (2)
- In Ref. [1] was manufactured the simplest extension for anisotropic local states, with one extra extensive Q. In the simplest case Q has a dimension momentum*volume, so Q/V is momentum (or, alternately, momentum*particle number), and if Q=0 then the local state is isotropic. So for order of magnitude we expect Q/V to be similar to the measure of momentum anisotropy.

DYNAMICS 1

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- $T^{ri}{}_{;r} = 0$ GR (3)
- $n^{r}{}_{;r} = 0$ conservation (4)
- $s^{r}{}_{;r} \geq 0$ 2nd Law of Thermo (5)
- (5) is an unequality as an *identity*: not just as an accident.
- We have some *anisotropy*, here characterized by a spacelike t^i. Then
- $T^{ik} = \alpha u^i u^k + \beta(u^i t^k + t^i u^k) + \gamma t^i t^k +$

  $+(d^i u^k + u^i d^k) + (b^i t^k + t^i b^k) + c^{ik}$ (6)
- $d_r u^r = d_r t^r = b_r u^r = b_r t^r = c_{ir} u^r = c_{ir} t^r = 0$ (7)

DYNAMICS 2

- Vector d^i is ~ heat current, often neglected. Then we may neglect bi as well. If c^{ik} (a 2*2 tensor) is "as isotropic as possible", then
- $T^{ik} = eu^iu^k + \beta(u^it^k+t^iu^k) + k\{g^{ik}+u^iu^k-t^it^k/t^2\}$ (8)
- + we expect mirror symmetry everywhere locally and then [2]
- $\beta = 0$ (9)
- A toy model, but let us use. Without the neglections see [3].
- For the entropy current, if b=d=0, then
  - $s^i = su^i + zt^i$ (10)
- Then eq. (3) is an evolution equation for the extensive density e, plus the equation for the acceleration (so for u^i). Eq. (4) is the continuity eq. for n. We still have uneq. (5).

DYNAMICS 3

- Anisotropy t is *not* an extensive; it looks like rather as a *specific* extensive. However a good candidate seems to be e.g.
- $Q = Vnt$ (11)
- and then the extra extensive density is
- $q \equiv nt$ (12)
- and the proper thermodynamical potential density s is
- $s = s(e,n,q)$ (13)
- in the simplest case. A long derivation was made by B. L. on the 2007 Zimányi Conference; here I jump to the conclusion

DYNAMICS 4

- $Dn + nu^r_{;r} = 0$
- $De + (e+p+q)u^r_{;r} = 0$
- $Du + \{D(p+q) + (p+q)_{,x}\}/(e+p+q) = 0$ (14)
- $Dq + (q+q/v)_{ur;r} - \lambda = 0$
- $s_{,q}\ \lambda \leq 0$
- where x is the beam direction, and –v/T is the canonical conjugate of q.
- Equations of state are in [4], now the Skyrme potential and the pion component are neglected:

$p = nT$
- $e = mny + (3/2)nT$ (15)
- $q = mxn_0 \ln(v+y)$
- $y \equiv (1+v^2)^{1/2}$
- $x \equiv n/n_0$
- n_0 = 0.16 fm-3
- m = 938 MeV

CALCULATION

The dynamical eqs. were integrated ages ago for E/A ~ 1 GeV [5]. 3 orders of magnitude higher we now apply a 3-stage approximation:

- 1) From touching to total overlap: eqs. (14) in the overlap domain with a boundary cond. of incoming nucleons with the original velocity;
- 2) From total overlap until the separation, eqs. (14) with vacuum boundary;
- 3) Then breakup.
- Most particles scatter almost forward (see later). So the durations of the first two stages can be calculated as $\Delta t \approx D/c$ where t is CM time.

ON THE DECAY OF THE LONGITUDINAL p

- As for λ, eq. (14) shows that it is the decay rate of the density of extra momentum in beam direction, nt. In ultrarelativistic situations, as now, the momentum distribution in beam direction has two peaks with widths ~T and separation ~t~E_{beam}. So in first approximation the distribution is sharp.
- Now consider a collision. Most collisions happen between particles moving oppositely with almost ±p_{beam}. So it is enough to evaluate such a collision.
- Differential cross sections are not easy for inelastic collisions at LHC energies. We use the total cross section with the momentum transfer dependence of the elastic one.

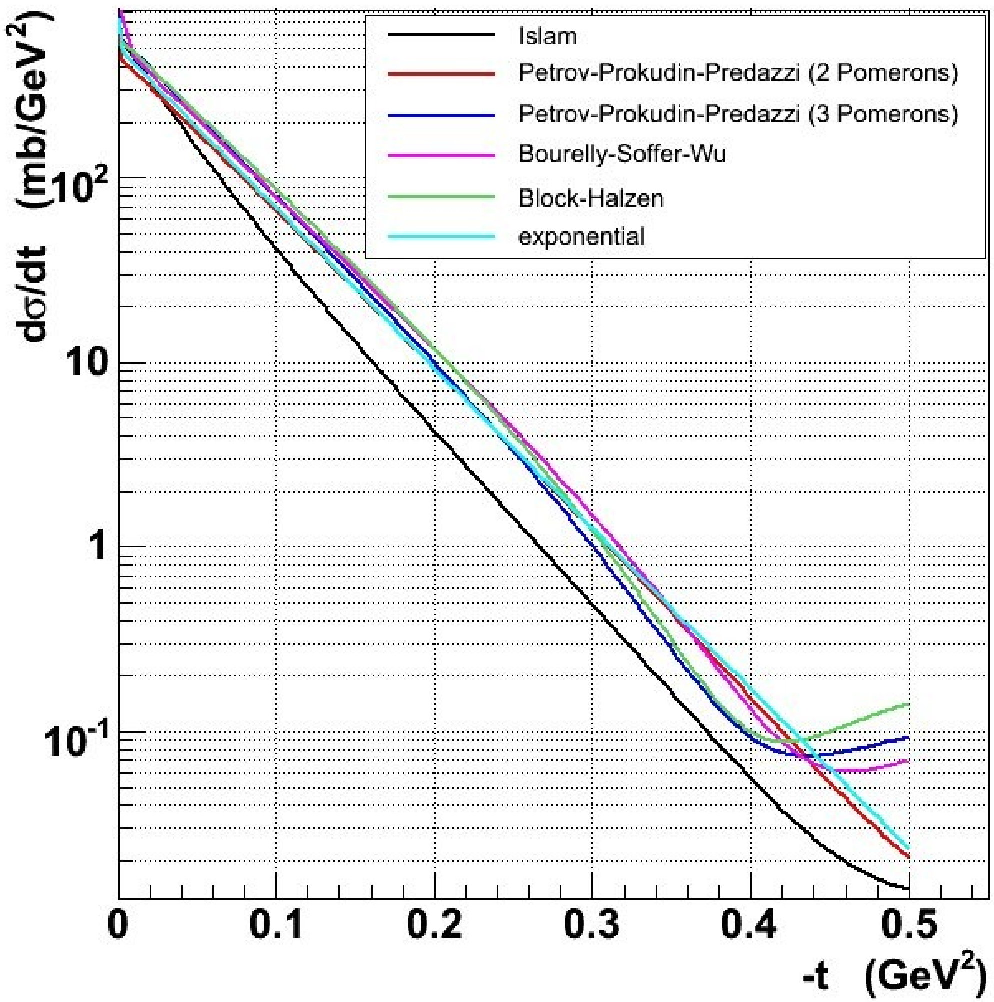
THE λ TERM 1

- Consider an elastic two-body collision where the incoming two particles have the original momenta of the beams. By appropriate choice of the coordinate system and by momentum conservation we always can write:
- $u_{1/2}^{\ i} = \{(1+v^2)^{1/2}, \pm v, 0, 0\}$ (λ.1)
- $u_{3/4}^{\ i} = \{(1+v^2)^{1/2}, \pm(v^2-w^2)^{1/2}, \pm w, 0)$ (λ.2)
- Now, the collision is characterised by a triad (s,t,u) which here for clarity will be written in **bold**. They are defined as
- $\mathbf{s} = (p_1+p_2)^2$ (λ.3)
- $\mathbf{t} = (p_1-p_3)^2$ (λ.4)
- $\mathbf{u} = (p_1-p_4)^2$ (λ.5)
- but here we will not use **u**. Using eqs. (λ.1-2) we get

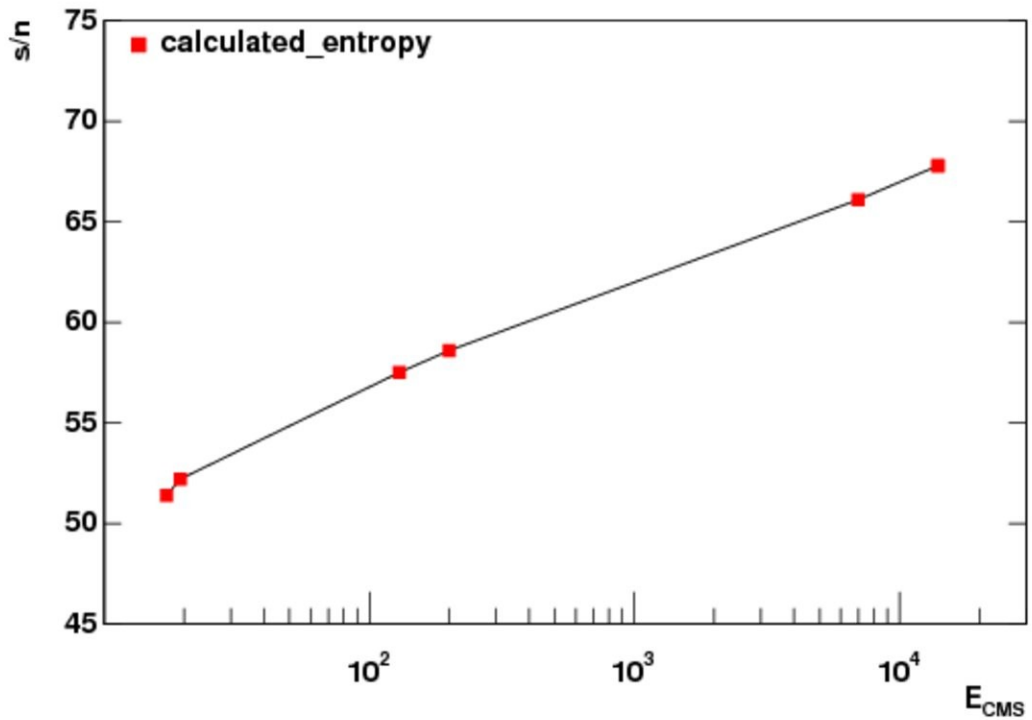
THE λ TERM 2

- $\mathbf{s} = 4m^2(1+v^2)$ (λ.6)
- $\mathbf{t} = -2m^2v(v-(v^2-w^2)^{1/2})$ (λ.7)
- Expressing it with the decrease of v, (v2-w2)1/2≡v-Δ, it is simply
- $\Delta = \mathbf{t}/2m^2c^2v$ (λ.8)
- The average loss of the longitudinal momentum per collision is then
- $\langle\Delta\rangle = (1/2m^2c^2v)(\int\mathbf{t}\sigma(\mathbf{t})d\mathbf{t}/\int\sigma(\mathbf{t})d\mathbf{t})$ (λ.9)
- where v can be substituted by **s** via eq. (λ.6).
- Since λ is the source term of q, the density of the momentum-like extra extensive, λ must be the product of 3 terms: the collisions/time calculated from the total cross section, the average momentum loss in one collision (this is <Δ>), and the actual density. The last is cca. $2n_0$.

CROSS SECTION



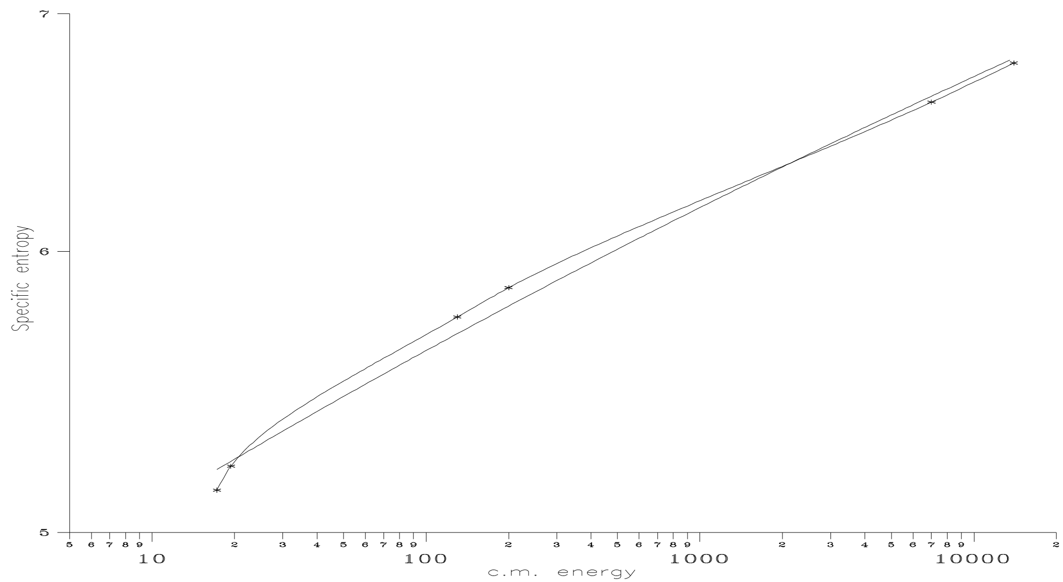
RESULT 1



RESULT 2

- $E_{CM,SUM}$ GeV S/N
- 17.26 51.4
- 19.41 52.2
- 130 57.5
- 200 58.6
- 7000 66.1
- 14000 67.8

WHAT IS THIS CURVE?



WHAT IS…2

- $S/N \approx 2.377 * \ln E_{CM} + 45.313$
  - S/N is in tens, E is in GeV. The spline and the best logarithmic curve.
- Without energy scale (ultarel. regime) the only results could be constant or logarithm.

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