PROCEEDINGS OF SCIENCE

ROUND TABLE DISCUSSION
Correlations and fluctuations theory : Soft and hard processes in nuclear collisions

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Mike Tannenbaum:

The p_T spectrum at ALICE is exponential whereas people are saying that 98% of the ALICE p_T spectrum represents hard processes. This makes no sense. All invariant p_T spectra for charge-averaged non-identified hadrons in p+p and A+A collisions show a spectrum close to e^{-6p_T} for $p_T < 1$ GeV/c and show an increase above this spectrum at higher p_T, typically a power-law for p_T > 2-3 GeV/c which represents hard-scattering and which is strongly dependent on the c.m. energy. The break in the spectrum separating the soft (exponential) processes from the hard (power-law) processes comes roughly 2 orders of magnitude down in the inclusive single particle p_T spectrum and 5 or 6 orders down in multi-particle spectra (E_T distributions). A claim that 98% or any other fraction of the p_T spectrum represents hard or soft processes should be proved, not simply asserted, since a simple look at the spectrum seems to indicate otherwise. A log-log plot of the p_T spectrum easily indicates the range of validity of the power law. See for instance Fig. 26 in PHENIX White paper [1]. Hard-scattering exhibits x_T scaling independent of details of structure and fragmentation functions or theoretical calculations. From this figure, both x_T scaling and the power law stop working at $x_T \sim 0.003$ at 1.8 TeV c.m. energy (CDF) or $p_T \sim 3$ GeV/c, at least 2 orders of magnitude down the p_T spectrum.

It is true that jets fragment mostly to soft particles. However, e.g. 10 GeV/c or higher p_T jets represent a tiny fraction of the total cross section so that their low-p_T fragments are buried under the predominant low-p_t particles from soft processes. Of course, that doesn't mean that they can't be found, but I personally would guess that the statement 98% of the ALICE p_T spectrum represents SOFT processes is more correct than 98% hard. However, hard processes are very easy to find by selecting pions with p_T > 2 GeV/c so the issue isn't really about hard processes, it is about soft processes. The big issue for LHC will be whether any alleged flow found using e.g. particles with p_T < 1 GeV/c is due to hydrodynamics of soft (thermalized) particles or whether it is just due to the differential suppression of hard-scattered partons in an almond shaped overlap zone. I would like to hear the arguments of the 98% hard proponents on this subject.

Reinhard Stock:

500 MeV pions can't come from hard processes. The question is, how does one distinguishes hard processes from soft? Why are there arguments that there are hard scattering products down to 350 MeV? How to distinguish between hard and soft processes from the point of view of QCD?

Tom Trainor:

We could begin by taking a lesson from elementary collisions. We see in Dave Kettler's presentation that the mode of fragmentation functions in LEP $e^+ + e^-$ collisions is 1-2 GeV/c. Fragments from 'hard processes' at 91 GeV/c extend down below 100 MeV/c. In p+p collisions the lower limit is somewhat higher, about 350 MeV/c. In heavy ion collisions the situation is modified, but one cannot a priori rule out substantial contributions to the 'soft' p_T regime from parton fragmentation. Of course, fragmentation functions are described by pQCD typically only for the upper 10% of the particles. The rest is nonperturbative (roughly described by MLLA). But fragments from parton scattering at many 100s of GeV still lie mainly around 1 - 2 GeV/c.

I would follow up on Reinhard's questions by asking whether the terms soft and hard aren't misleading? Do we need to come up with better concepts to categorize spectrum components and particle production mechanisms?

Peter Steinberg:

But pQCD describes particles with p_T 2 - 200 GeV.

Ulrich Heinz:

At RHIC more than half of the particles have $p_T < 1$ GeV (no pQCD), less than half of them have $p_T > 1$ GeV. At the LHC the majority of hadrons will have $p_T > 1$ GeV, so pQCD may become useful for describing the bulk of hadron production. But pQCD will never be able to describe 500 MeV pions in the final state.

R. Stock:

If the QGP is long lived it is not prescribable to use pQCD. At RHIC the particles > 2 GeV reshuffle their momenta but the multiplicity does not change.

Gunther Roland:

(re: elliptic flow fluctuations) It is now clear that eccentricity fluctuations are significant in flow measurements.

U. Heinz:

What fluctuates is the initial condition. For a given initial eccentricity, hydrodynamic flow in the final state does not fluctuate.

T. Trainor:

Hydrodynamics (your model) may not fluctuate, but the physical system may. And why do you say a hydrodynamic system cannot fluctuate? What about turbulence, which could be very relevant at the LHC?

Stanislaw Mrowczynski:

If a hydrodynamic variable fluctuates, this means thermodynamic variables fluctuate.

U. Heinz:

Yes, but in hydrodynamics flow fluctuations result only from event-by-event fluctuations in the initial conditions.

T. Trainor:

Even if the eccentricity is fixed, v_2 can still fluctuate. That remark is a counter to Uli's comment. It says that even if the initial conditions were held fixed, a system that is nominally hydrodynamical in its evolution can vary locally within an event and from event to event. One expects that from nonlinear systems. If you do not believe that, then where in hydro is it written?

U. Heinz:

Hydrodynamics evolves the initial conditions deterministically. Identical initial conditions yield identical final conditions (flow patterns) – every time.

Burak Alver: Gluon scattering can contribute to v_2 fluctuations.

T. Trainor:

Exactly. The system may seem hydrodynamical to some global observables, but may have complex local structure accessible with other more-differential measures. We see this structure in fact. If you have not searched for such structure with known sensitivity and appropriate measures you cannot rule it out a priori.

U. Heinz:

This is outside the hydrodynamic framework. Of course, in real life there will be non-thermal fluctuations superimposed on the hydrodynamic flow, and these may fluctuate from event to event, even with identical geometric initial conditions. If the non-thermal fluctuations are large enough, they may even modify the hydrodynamic flow, generating flow fluctuations. Hydro describes only the thermalized part of the local momentum spectrum.

R. Stock:

(on universal scaling of multiplicity) - Why is it so? Could one get a correlation length from multiplicity. Why does the energy dependence saturate in peripheral collisions?

J. Mitchell:

Preliminary PHENIX data on charged hadron multiplicity fluctuations as a function of centrality were presented at this conference for 200 and 62 GeV Au+Au and Cu+Cu collisions. These data are corrected for contributions due to impact parameter fluctuations within a centrality bin.

All four systems exhibit a universal power law behavior when plotted as σ^2/μ^2, which can be related to the compressibility of the system in the Grand Canonical Ensemble versus $N_{participants}$. The same power law curve can also describe the NA49 data in Pb+Pb collisions at SPS energies. As a system approaches a critical point, it is expected that the compressibility diverges as $k_T = A((T - T_C)/T_C)^{/gamma}$, where the critical exponent γ is identical for all systems belonging to the same universality class. Hence, one possible explanation for the universal scaling of the multiplicity fluctuations is the onset of critical behavior from central to peripheral collisions, assuming that there is variation of the system temperature as a function of centrality.

As detailed in K. Homma's presentation at this conference and using a method pioneered by the AGS Experiment E802, it is also possible to extract correlation lengths from multiplicity fluctuations. Near the critical point, the correlation length of a system is also expected to diverge. PHENIX preliminary data of correlation lengths in pseudorapidity and azimuth also lie on a universal power law curve as a function of $N_{participants}$.

References

[1] K. Adcox *et. al* for PHENIX Collaboration, *Nucl. Phys.* **A757** (2005) 184-283.