Relating RHIC and SPS Heavy Ion Data

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Abstract: We have demonstrated recently that RHIC heavy ion data concerning particle production at small and intermediate transverse momenta become very transparent, if one realizes that there are two sources of particles production: the corona – due to the interactions of the peripheral nucleons of either nucleus, and the core – representing the high density central zone. We extend our analysis to SPS heavy ion data. Again, we find that the nontrivial centrality dependence of particle production (being stronger than at RHIC) is simply due to an increasing corona contribution with decreasing centrality. The core contribution shows no centrality dependence (concerning particle ratios), and can be described in exactly the same way as at RHIC, with one exception: there is somewhat less collective radial flow at SPS compared to RHIC. Apart of this (and a trivial volume effect), the core portions produced in different colliding systems at different energies (RHIC, SPS) look the same.

One of the spectacular results from SPS heavy ion research is the very strong enhancement of strange (in particular multi-strange) baryons compared to proton-proton scattering. Although this goes qualitatively into the right direction, having in mind the production of a quark-gluon-plasma [1], a quantitative understanding is still lacking.

We do not really claim to explain these data, we simply want to stress that they show an almost trivial behavior, if one takes into account the “corona effect”: the peripheral nucleons of either nucleus essentially perform independent pp or pA-like interactions, with a very different particle production compared to the high density central part. For certain observables, this “background” contribution completely spoils the “signal”, and to properly interpret the data, we need to subtract this background.

In order to get quantitative results, we employ exactly the same method as described recently [2] for analyzing RHIC heavy ion data: we use EPOS [3], which has proven to work very well for pp and dAu collisions at RHIC and for pp scattering at SPS. EPOS is a parton model, so in case of a nuclear collision there are many binary interactions, creating partons, which then hadronize employing a phenomenological procedure called string fragmentation. Here, we modify the procedure: we have a look at the situation at an early proper time \(\tau_0\), long before the hadrons are formed: we distinguish between string segments in dense areas (more than \(\rho_0\) segments per unit proper volume), from those in low density areas. We refer to high density areas as core, and to low density areas as corona. In order to make a quantitative statement, we adopt the following strategy: the low density part will be treated using the usual EPOS particle production which has proven to be very successful in pp and dAu scattering (the peripheral interactions are essentially pp or pA scatterings). For the high density part, we simply try to parameterize particle production, in the most simple way possible. To do so, we consider the core contributions sepatately in different longitudinal segments. Connected core regions in a given segment are considered to be clusters, whose energy and flavor content are complete determined by the corresponding string segments. Clusters are then consid-
ferred to be collectively expanding. We assume that the clusters hadronize at some given energy density $\varepsilon_{\text{hadr}}$, having acquired at that moment a collective radial flow, with a linear radial rapidity profile from inside to outside, characterized by the maximal radial rapidity $y_{\text{rad}}$.

In addition, we impose an azimuthal asymmetry proportional to the initial space eccentricity. Hadronization then occurs according to covariant phase space. For more details and parameters see [2].

So we employ exactly the same procedure as we did for RHIC, with even the same parameters – up to two exceptions, concerning the parameters $\tau_0$ and $y_{\text{rad}}$. Whereas at RHIC the final results are insensitive to variations of $\tau_0$ (in the range 1-2fm), this is no longer the case at SPS, the reason being the finite reaction time $\tau_{\text{rea}}$ (time it takes for the two nuclei to pass through each other), which is somewhat more than a fermi. So we use $\tau_0 = \tau_{\text{rea}}$, representing the minimum possible value. Since we have smaller initial core densities at SPS compared to RHIC, we also expect a smaller radial flow, so we take the freedom to use $y_{\text{rad}}$ as a free parameter, fixed by comparing to SPS data (the only free parameter when going from RHIC to SPS!). We actually use $y_{\text{rad}} = 0.60$ at SPS, instead of 0.83 at RHIC.

In the following, we will discuss results for PbPb collisions at 158 GeV. In fig. 1 we compare the core contribution corresponding of a central (0-5%) PbPb collision (full lines) and proton-proton scattering (dashed). The PbPb spectra are divided by the number of collisions.

In fig. 2, we compare the full contribution (core and corona) of a central (0-5%) PbPb collision and proton-proton scattering. The PbPb pion line crosses the pp line at large $p_t$, which is due to the fact that the core contains particles from pA like collisions, where we have a “Cronin-enhancement” due to parton ladder splitting, discussed in detail in [3], which has been introduced in order to understand dAu scattering at RHIC. In fig. 3 we plot the relative contribution of the core (relative to the complete spectrum, core + corona) as a function of $m_t - m$, for different particle species. For central collisions, the core contribution dominates largely (around 90%), whereas for semi-central collisions (40-50%) the core contribution decreases, giving more and more space for the corona part. The precise $m_t$ dependence of the relative weight of core versus corona depends on the particle type.

We are now going to study SPS PbPb data (158 GeV). In fig. 4 we plot the centrality...
dependence of the particle yield per participant (per unit of rapidity), for different particle species, the data [4, 5] together with the full calculation (upper diagram), and the full calculation compared to the core contribution (lower diagram). The complete calculation follows quite closely the data. Whereas central collisions are clearly core dominated, the core contributes less and less with decreasing centrality. In fig. 5 we consider the corresponding particle ratios, as a function of centrality, for the core contributions. We show the ratios of different particles, with respect to $\pi^{-}$ or $K_{s}$. The ratios are practically flat, apart of some decrease for very small participant numbers.

So our first important conclusion: after subtracting the “corona background”, the interesting part, the core contribution, shows an extremely simple behavior: there is no centrality dependence, the systems are simply changing in size. The participant number is certainly not a good measure of the volume of the core part, this is why the overall multiplicities per participant decrease with decreasing centrality. This is the same conclusion as in [2] for AuAu at RHIC. And not only the SPS core contribution is as simple as the RHIC one, it is even parameterized with the same parameters, apart of somewhat more flow at RHIC!

What makes the measured centrality dependence look complicated is the mix of core and corona, depending on the particle species. Ac-
Figure 4: Upper diagram: Particle yields per participant in PbPb scattering at 158 GeV as a function of the number of participants, for (from top to bottom): $\pi^-$, $K^+$, $K^-$, $K_s$, $\Lambda$, $\bar{\Lambda}$, $\Xi$, $\bar{\Xi}$, $\Omega$, $\bar{\Omega}$. We show data (points) \textsuperscript{5} together with the full calculation (core + corona, full line). The three upper-most curves refer to $4\pi$ results, all others to central rapidities. The leftmost points are pp calculations (colored points) and pp or pBe data (black symbols). Lower diagram: full calculations, same as in upper plot (full lines) compared to the core contributions (dotted).

Figure 5: Particle ratios as a function of centrality, from top to bottom: $K^+/\pi^-$, $K^-/\pi^-$, $\Lambda/K_s \times 0.1$, $\bar{\Lambda}/K_s \times 0.1$, $\Xi/K_s \times 0.1$, $\bar{\Xi}/K_s \times 0.1$, $\Omega/K_s \times 0.1$, $\bar{\Omega}/K_s \times 0.1$. The full lines are the calculations for the core contribution alone, the dashed lines are horizontal lines, just to guide the eye.

Finally the $\Omega$ are the simplest, since here the corona contribution is negligible. Here, all the participants which contribute to the corona (being more and more frequent with decreasing centrality) do not contribute at all to the $\Omega$ production. This is why the yields drop so strongly at small participant numbers. This also reflects the fact that the core volume is not proportional to the number of participants.

To demonstrate consistency, we check in the following $m_t$ spectra for different hadron species, for PbPb collisions at 158 GeV, see figs. \textsuperscript{6} and \textsuperscript{7}. The calculations represent the full contribution, core plus corona, whose relative contributions (at least for kaons and lambdas) can be obtained from fig. \textsuperscript{3}. So it is actually a non-trivial superposition of these two contributions, hiding the shape of the interesting part, the core.

It should be noted that NA49 \textsuperscript{8} reports much less lambda production at central rapidity than NA57, and correspondingly our calculation of $dn/dy(y=0)$ (being close to the NA57 values) is about 40% above the NA49 results (whereas the transverse mass spectra almost agree!).
Figure 6: Transverse mass spectra of $K_s$ (upper plot), $\Lambda$ (middle), $\bar{\Lambda}$ (lower) in PbPb scattering at different centralities. From top to bottom: 0-5%, 5-11%, 11-23%, 23-40%, 40-53%. Lines are full calculations, points are data [6]. The different curves are displaced by factors of 10.

Figure 7: Transverse mass spectra of $\Xi$ (upper plot), $\Xi$ (middle), $\Omega+\bar{\Omega}$ (lower) in PbPb scattering at different centralities. From top to bottom: 0-5%, 5-11%, 11-23%, 23-40%, 40-53%. Lines are full calculations, points are data [6]. The different curves are displaced by factors of 10.

In fig. 8 we show rapidity and transverse mass spectra of different hadron species for central CC and SiSi at 158 GeV. Again we just show the full calculations (core plus corona) together with the data, and we find a similar good agreement than in case of PbPb (using...
the same parameters!), with the exception of the \( \phi \) transverse momentum spectrum, which is somewhat harder in the calculations. Concerning the relative weights of core and corona, CC and SiSi is very similar to peripheral PbPb, in the sense that the corona is relatively more important than in central PbPb (the surface effect is bigger in small nuclei than in big ones).

To summarize: we have discussed the influence of the corona contribution (occurring in the periphery of nuclear collisions) in PbPb, SiSi, and CC collisions at the SPS. We provide a realistic treatment of the corona, by using a model which works excellently for pp and pA. We can provide a parametrization of the core, such that the complete calculation (core + corona) provides a good fit of the observed particle spectra in heavy ion collisions at the SPS. Our core results represent to some extent "background corrected results", removing the undesired corona contributions from the spectra. The core shows an extremely simple centrality and species dependence: actually there is no centrality dependence, all particle ratios are constant. In other words, the cores in all these different systems (CC, SiSi, PbPb at different centralities) are all identical, apart of a trivial volume difference. Even more remarkable: the SPS results (concerning core) are identical to the RHIC results, with one exception: there is 30% more radial flow at RHIC. So what really makes the experimental results complicated is the non-trivial admixture of corona contribution to the core.

All the results concerning SPS in this paper have been obtained with exactly the same procedure (and same parameters) as in a previous study of RHIC results \cite{2}, with just one exception: the radial flow parameter. All the centrality and system size dependence is purely determined by geometry.

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