Parton String Model analysis of strange particles yields and slopes for PbPb collisions at 158A*GeV in NA57 experiment at CERN SPS

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Abstract

In this work we analyze the recent experimental data on strange and multistrange particle yields and transverse mass spectra obtained in p-Pb and Pb-Pb collisions at 158A*GeV energies by the WA97 and NA57 experiments at CERN SPS within the Parton String Model. This model assumes nucleus-nucleus collisions at the partonic level and can be applied to describe a possible non-QGP scenario that may play an essential role in earlier stages of nucleus-nucleus collisions, before the onset of the QGP. With default parameters and a simplified account of rescattering, PSM results are found in a qualitative agreement with the majority of the latest Pb-Pb data at 158A*GeV on strangeness yields, transverse mass inverse slopes and particle ratios. The deviations of the model predictions from the experiment were observed in some cases, in particular, it was obtained that the yields for $\overline{\Xi}^+$ are overestimated by the PSM by a factor of about 2 for all classes of centrality, while for $\Omega+\overline{\Omega}$ they are underestimated by a factor of about 3 for the most central collisions. For Ξ^- yields in case of p-Pb collisions results are also underestimated by the PSM (a factor of about 2). An increase of the inverse mass slopes with the collision centrality (towards central collisions) observed for Λ and $\overline{\Xi}^+$ is also not reproduced. The mentioned general agreement and the particular differences in some

model predictions and data could be stimulating for further theoretical studies. The results obtained in the framework of the PSM indicate also that future experimental studies of the event-by-event long-range correlations for strange particles could be proposed as a new method to quantify collective phenomena.

1 Introduction. Motivation of this study

The recent experimental data on strange and multistrange particle yields and transverse mass spectra obtained in p-Pb and Pb-Pb collisions at 158A*GeV energies by the WA97 [1],[2] and NA57 [3],[4] experiments at CERN SPS manifest a number of intriguing features:

- the increase of enhancements of hyperon and antihyperon production at 158 AGeV/c with the strangeness content of the particle. Strange particle yields per wounded nucleon increase with strangenes content of the particle up to factor 20 for $\Omega^{+}+\Omega-$ as compared to p-Be data[1],[3]
- inverse exponential slopes of the m_T distributions at midrapidity of different particles vs. the mass of the particles demonstrate a deviation from the linear increase [2],[4]. An increase of the inverse mass slopes with collision centrality is observed for Λ and $\overline{\Xi}^{+}$.
- the energy dependence of the hyperon production is much weaker than for the antihyperons [5],[6]. The antihyperon to hyperon ratios increase with the energy, with a stronger dependence for particles with smaller strangeness content.

These experimentally observed features could be used as a discriminating probe to validate a number of detailed Monte Carlo models describing nucleus-nucleus interactions at relativistic energies.

In this work we analyze the first two of these peculiarities within the Parton String Model (PSM) [7] that assumes nucleus-nucleus collisions at the partonic level. Thus we investigate a possible non-QGP scenario that may play an essential role in earlier stages of nucleus-nucleus collisions, before the onset of the QGP. It may be useful in understanding a possible role of a string fusion mechanism in the formation of the QGP.

2 PSM results for strange particles yields and slopes

We apply the Monte Carlo PSM event generator [7] to describe the latest detailed data [3],[4] on strange particles yields, inverse slopes and their centrality dependence obtained for PbPb collsions at 158 A GeV/c in the NA57 experiment at CERN SPS.

The details of the NA57 experimental setup and data treatment procedures could be found elsewhere [11],[12].

The description of the Parton String Model event generator can be found in [7]. It is based on the modern theory of the multiparticle production in high energy hadron collisions that describes it in a two-stage scenario [8, 9]. At the first stage a certain number of colour strings are formed, stretched between the incoming partons. At the second stage these strings decay into the observed secondary hadrons. In the simplest version the strings emit particles independently. However, due to a high density of strings in the transverse plane in the case of nuclear collision one has also to take into account the interaction between strings in the form of their fusion and/or percolation [13]-[18]. Color strings that are formed as a result of elementary parton-parton collisions are allowed to overlap producing strings in higher color representations. Thus the collective effects in nucleus-nucleus collisions are taken into account. Among the main predictions of the string fusion phenomenon are the following: (i) a strong reduction of multipicity of charged particles [13], (ii) growth of $< p_t^2 >$ [13], and (iii) an increase of baryon and strangeness production [13],[19].

We started the calculations from a conventional set of PSM parameters successfully applied previously [7],[20] to the description of the experimental data on the rapidity and transverse momentum distributions of charged particles in heavy ion collisions at SPS and RHIC. Various options of model calculations were tried including cases with and without fusion and rescattering, some variations of the PSM parameters were also investigated.

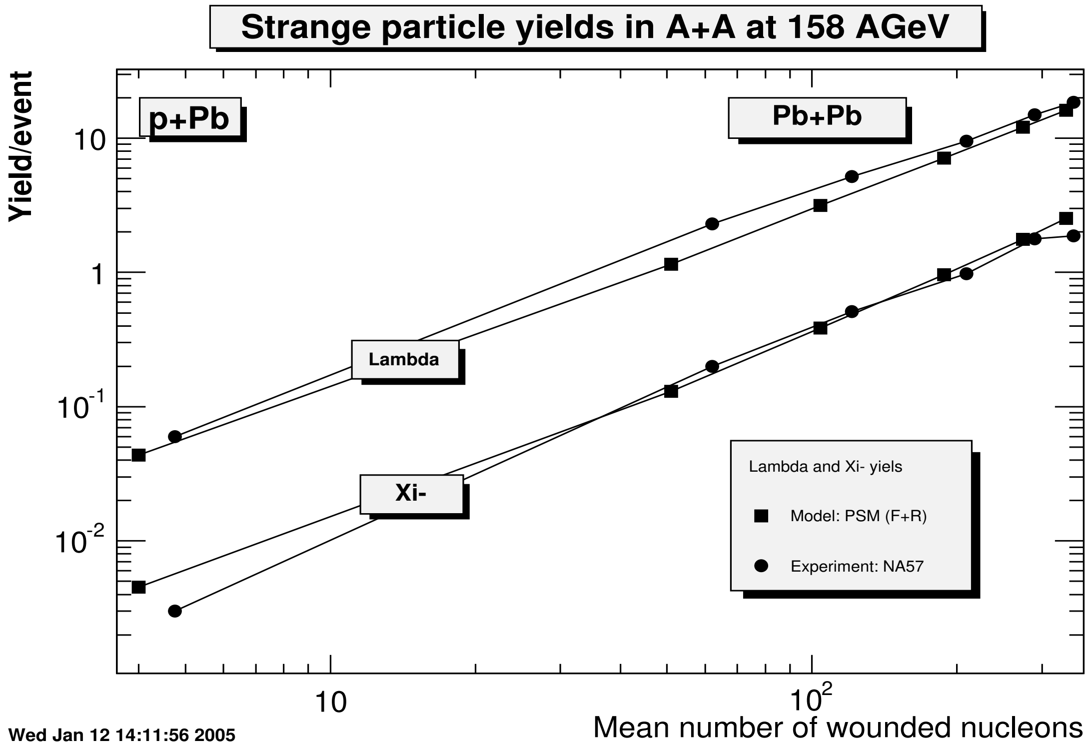

Figure 1: Strange particles yields per event vs. collision centrality:
Circles - experiment (statistical errors are within the data points);
Squares - PSM calculations

As a final result we obtained that with the default parameters and a simplified model for rescattering of secondaries, PSM shows a good qualitative agreement with the majority of data:

(i) it was found that the general trends of the centrality dependence of strange particles yields at mid-rapidity as well as the inverse slopes parameters of spectra of charged particles are reasonably well reproduced only if both string fusion and rescattering are considered. (This confirms previuos results [20] where the inclusion of string fusion was also found to be crucial for the agreement with the RHIC data);

(ii) good agreement is obtained (within 1-2 error bars) for strange particles yields at 158 A GeV/c calculated for PbPb collisions with the standard set of parameters for Λ and Ξ^- yields/event vs. centrality of collision (see Fig.1) and within 3-4 error bars for $\overline{\Lambda}$ (see Fig.2).

(iii) a qualitative agreement is achieved for $\overline{\Xi}^+$ (a factor of about 2) and $\Omega + \overline{\Omega}$ (a factor about 3 for the most central data) yields/event vs. centrality of collision), see Fig.2.

It was found in the framework of the PSM that the rescattering of string fragmentation products in the final state (i.e. secondaries) in PbPb collisions brings at CERN SPS energy a factor of about 2 for $\Omega + \overline{\Omega}$, adds about 30% to $\overline{\Xi}^+$ yields and decreases at the same time the $\overline{\Lambda}$ yields also by about 30%. The last fact mentioned for $\overline{\Lambda}$ is due to annihilation, (it was also found that for antiprotons annihilation decreases the yield by more than a factor 2).

The importance of rescattering was also stressed by our observation that the variations of the PSM parameters near the default values failed to account for the experimental yields and slopes unless the rescattering is included.

At the same time, we see from the Fig.2 that the yields for $\overline{\Xi}^+$ are overestimated (a factor of about 2) and for $\Omega + \overline{\Omega}$ are still underestimeted (a factor of about 3 for the most central collisions) by the PSM. We can guess here, that this discrepancy could be either a result of the simplified rescattering used in the model [7] or an indication on a possible contribution of some other mechanisms of $\overline{\Xi}^+$ and $\Omega + \overline{\Omega}$ production, e.g. fusion of more than two strings. This suggestion is based on the reasonable agreement

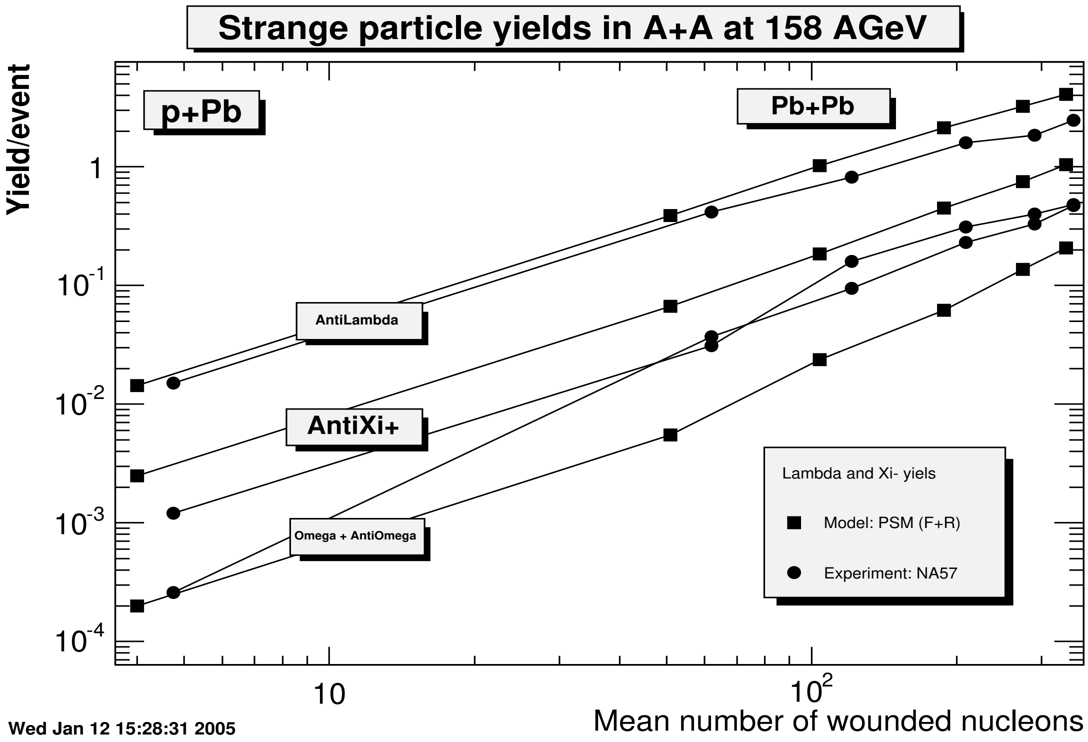

Figure 2: Strange particles yields/event vs. collision centrality:
Circles - experiment (statisyical errors are within the data points);
Squares - PSM calculations

of the previous PSM results to the available data on total multiplicties, transverse momentum spectra and strange particle yields in a wide energy range from SPS to TeVatron obtained earlier [7],[20]. The presently observed particular discrepancies could point to the necessity of further theoretical studies.

In our PSM calculations the string fusion phenomenon was found to be the most influential on the strange particles yields:

- String fusion phenomenon gives about 3 fold increase (as compared to the calculations without fusion) for Λ yields.
- It appeares to be the most important (bringing about 10 fold increase) for $\overline{\Lambda}$, $\overline{\Xi}^{+}$ and $\Omega + \overline{\Omega}$, and about 15 fold increase for Ξ^{-}.

One has to comment that the previuos results of our VENUS and RQMD analysis of NA57 data [10] showed that both models predicted the enhancement increasing with the strangeness content of the particles but they were not able to reproduce the measured values of strange particles yields at central rapidity. This fact is also confirmed by the results of the present work: it was found that only the inclusion of the string fusion process has provided the needed increase of yields mentioned above.

The overal agreement of the PSM results obtained with the account of string fusion and rescattering processes was achieved with the experimental data on inverse m_T slopes (temperatures) (see Tables 1 and 2). In particular, the deviation from the linear increase of inverse exponential slopes of the m_T distributions at midrapidity vs. the mass of the particles is obtained (a decrease of the corresponding temperatures is obtained for multistrange hyperons in a qualitative agreement with the experiment). It was found that in case of the most central collisions (40%) the inverse m_T slope parameters for all strange hyperons (except Λ) in PSM are not very sensitive to the string fusion (a slight decrease at the level of 10% from the values obtained without string fusion was observed in PSM calculations bringing a better agreement with the experiment).

However, the centrality dependence of the inverse m_T slope parameters shows that the PSM is dramatically overestimating the inverse slopes for Λ and for Ξ^- for the peripheral case (classes 0 and 1, see Table2). This effect was observed previously also in our calculations using the VENUS model, so it looks like that the inverse slopes description for peripheral events (i.e. those that should be free from any nuclear matter involvement) are, probably, the common drawbacks for both models (VENUS and the PSM).

The following general conclusion could be obtained here from the comparison of PSM calculations to the experimental results: in the framework of the Parton String Model both fusion and rescattering processes are found to play a crucial role in the description of strange particles yields and slopes at the SPS energies.

Table 1: Experimental inverse m_T slopes (MeV) parameters of strange particles in PbPb ($\sqrt{s}$=17.3 GeV) at mid-rapidity ($|\Delta y^*|$ 0.5), see [4]. (Definition of the NA57 event centrality classes for PbPb at 158 A GeV/c could be found elsewhere [12]. 0 - refers to the most peripheral collisions, class 4 - to the most central).

Centrality class	0	1	2	3	4
Λ	237±19	274±13	282±12	315±14	305±15
$\overline{\Lambda}$	277±19	264±11	283±10	313±14	295±14
Ξ	290±20	290±11	295±9	304±11	299±12
$\overline{\Xi}$	232±29	311±23	294±18	346±28	356±31
$\Omega + \overline{\Omega}$		274±34	274±28		268±23

Table 2: PSM calculated m_T inverse slopes (MeV) parameters of strange particles in PbPb ($\sqrt{s}$=17.3 GeV) at mid-rapidity ($|\Delta y^*|$ 0.5).

Centrality class	0	1	2	3	4
Λ	522	438	378	349	334
$\overline{\Lambda}$	298	325	321	319	308
Ξ	391	343	311	297	283
$\overline{\Xi}$	278	280	300	308	261
$\Omega + \overline{\Omega}$	271	225	217	245	234

3 Long-range correlations for strange particles as a method to quantify collective phenomena

Results of the present study indicate a new possibility to quantify the collective phenomena within a string fusion mechanism.

As it was already mentioned, color strings that are formed as a result of elementary parton-parton collisions could overlap (or fuse), producing strings of higher color representations. At the same time, the hypothesis of color string fusion has clear predictions which could be tested experimentally. It is the so called long-range correlations, i.e. event-by-event study of observables obtained in a sufficiently separated different rapidity windows (see [21]) and references therein as well as [22], [23], [24]), that could be a signature of the basic new phenomenon, i.e. of the formation of emitters with higher color density.

Such phenomenon is expected to occur at large string density values reached in the high energy nucleus-nucleus collisions [14, 23, 21]. The search of long-range correlations was started using the available SPS experimental data[25]. Noticeable long-range correlations are found between event mean p_t and charged particle multiplicty in NA49 experimental data obtained in two separated rapidity intervals in 158 A GeV/c PbPb collisions at the CERN SPS[25].

The results of the present study confirm the substantial increase of strange particles yields from the overlapped strings. Therefore, this could be an indication that the event-by-event studies of long-range correlations for strange particles produced in heavy-ion collisions could be capable to bring a new experimental insight into the heavy-ion collison process. The main benefits expected from the new experimental investigations based on the string fusion hypothesis with involvment of strange particles are:

- to obtain a new experimental evidence of collectivity at SPS energies
- to get a clear indications on the directions of the further upgrade of the PSM and of the other models of multiparticle production,
- to predict and to search for experimental long-range correlation effects at other energies and for other colliding nuclei
- to provide new observables to quantify collective phenomena in heavy-ion nuclear collisions

4 Conclusions

The recent experimental data on strange and multistrange particle yields and transverse mass spectra obtained in p-Pb and Pb-Pb collisions at 158A GeV/c energies by the WA97 and NA57 experiments at CERN SPS are analysed within the Parton String Model.

With default parameters and a simplified model for rescattering of secondaries, PSM shows a qualitative agreement with the majority of the latest Pb-Pb data at 158A GeV/c including the increase of hyperon and antihyperon production at 158 AGeV/c with the strangeness content of the particle and with the collision centrality.

Our calculations confirm that in the framwork of the PSM both fusion and rescattering play a crucial role in description of strange particles yields and slopes at the SPS energies. We found that inclusion of a string fusion phenomenon in the PSM gives about 3 fold increase (as compared to the calculations without fusion) for Λ yields, although it appeares to be the most pronounced (bringing about 10 fold increase) for $\overline{\Lambda}$, $\overline{\Xi}^+$ and $\Omega + \overline{\Omega}$, and about 15 fold increase for Ξ^- yields. Data on yields are spanning about 3 orders in magnitude vs. centrality of collision in all cases mentioned above.

At the same time, it is important to stress that some dicreapancies are observed in comparison of the model predictions and experiment. It was obtained that the yields for $\overline{\Xi}^+$ are overestimated by the PSM by a factor of about 2 for all classes of centrality, while for $\Omega + \overline{\Omega}$ they are still underestimated by a factor of about 3 for the most central collisions. For Ξ^- yields in case of p-Pb collisions results are also underestimated by the PSM (a factor of about 2). The mentioned particular differences in the model prediction and data could point to the necessity of further theoretical studies.

The experimentally observed deviation from the linear increase of inverse exponential slopes of the m_T distributions at midrapidity of different particles vs. the mass of the particles (lower temperatures for $\Omega + \overline{\Omega}$ as compared to the $\overline{\Xi}^+$) is qualitatevly described by the PSM for the central collisions. The overal agreement of the PSM with the experimental data on the inverse slopes centrality dependence is achieved for all classes of collision centrality and particles, with the exception of Λ and Ξ^- for the most peripheral cases. An increase of the inverse mass slopes with the collision centrality (towards central collisions) observed for Λ and $\overline{\Xi}^+$ is also not reproduced, pointing at the necessity of more studies for a possible modification of the PSM.

The future studies may involve the investigations of the event-by-event long-range correlations for strange particles in heavy-ion collisions, and the NA57 experimental data could be an important test for the PSM event generator with the purpose to develop a sensitive method to quantify the collective phenomena.

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References

[1] E.Andersen, et al.,Phys.Lett.B449(1999)401
[2] F.Antinori, et al., Eur.J.Phys.C14(2000)633; CERN-EP-200-001, 03 January 2000
[3] V.Manzari, et al., Nucl.Phys.A715(2003)140-150
[4] F.Antinori, et al, J.Phys.G:Nucl.Part.Phys.30(2004) 823-840
[5] F.Antinori et al., Phys.Lett.,B595(2004)68-74
[6] D.Elia, J.Phys.G:Nucl.Part.Phys.30(2004)S1329-S1332
[7] N.S.Amelin, N.Armesto, C.Pajares, D.Sousa, Eur.Phys.J. C22(2001)149-163
[8] A.Capella, U.P.Sukhatme, C.–I.Tan and J.Tran Thanh Van, Phys. Lett. B81(1979)68; Phys. Rep.236(1994) 225.
[9] A.B.Kaidalov, Phys. Lett.B116(1982)459; A.B.Kaidalov K.A.Ter-Martirosyan, Phys. Lett.B117(1982)247.
[10] F.Antinori et al. (NA57 collaboration), Eur.Phys.J.C11(1999)79-88.
[11] R.Caliandro, et al., NA57 Proposal, CERN/SPSLC 96-40, SPLC/P300
[12] V.Manzari et al.,J.Phys.G:Nucl.Part.Phys.25(1999)473; V.Manzari et al.,Nucl.Phys.A661(1999)716c;
[13] M.A.Braun and C.Pajares, Phys. Lett.B287(1992)154; Nucl. Phys.B390(1993) 542, 549; N.S.Amelin, M.A.Braun and C.Pajares, Phys. Lett. **B306** (1993) 312; Z.Phys.C63(1994)507.
[14] N.S.Amelin, N.Armesto, M.A.Braun, E.G.Ferreiro and C.Pajares, Phys. Rev. Lett.73(1994)2813.
[15] N.Armesto, M.A.Braun, E.G.Ferreiro and C.Pajares, Phys. Rev. Lett.77(1996)3736.
[16] M.Nardi and H.Satz, Phys. Lett.B442(1998)14; H.Satz, Nucl. Phys.A661(2000)104c.
[17] M.A.Braun, C.Pajares and J. Ranft. Int. J. of Mod. Phys.A14(1999)2689.
[18] M.A.Braun and C.Pajares, Eur. Phys. J.C16(2000)349.
[19] N.Armesto,M.A.Braun,E.G.Ferreiro and C.Pajares, Phys.Lett.B334(1995)301;E.G.Ferreiro,C.Pajares and D.Sousa, Phys.Lett.B422(1998)314.
[20] N.Armesto,C.Pajares, D.Sousa, Phys.Lett.B527(2002)92-98
[21] M.A.Braun,R.S.Kolevatov,C.Pajares.V.V.Vechernin, Eur.Phys.J.C.32.535-546(2004)
[22] N.Armesto,M.A.Braun.E.C.Ferreiro.C.Pajares, Z.Phys.C.67(1995)489-493
[23] M.A.Braun,C.Pajares, Phys.Rev.Let,85(2000)4864-4867
[24] M.A.Braun,C.Pajares, Eur.Phys.J.C16(2000)349-359
[25] NA49 Collaboration at CERN and G.Feofilov, R.Kolevatov, V.Kondratiev, P.Naumenko, V.Vechernin,"Long-Range Correlations in PbPb Collisions at 158 A GeV/c", Abstracts of the XVII International Baldin Seminar on High Energy Physics Problems, Dubna, Russia, September 27-October 2 (2004), p.59, (to be published).