COMMENTS ON SYSTEMATIC EFFECTS IN HEAVY IONS EXPERIMENTS*

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Comments on the comparison between results from two CERN-SPS heavy-ion experiments studying the production of strange particles.

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1. Introduction

After sixteen years of activity, the field of high energy heavy ions physics has now reached maturity. At the CERN-SPS, the experiments have provided strong evidence [1] of a new state of matter that behaves as predicted for long-sought plasma of quarks and gluons. At the BNL-RHIC collider, a wealth of new results is being obtained [2] in the study of such a new state, at center of mass energies up to about 10 times larger than those available at the SPS. Finally in a few years the ALICE experiment at the CERN-LHC collider, will pursue these studies at even higher energies, about 400 times larger than at SPS. More and more attention needs now to be given to measurement precision and hence to systematic effects — an issue clearly less urgent for first generation experiments. The main experimental difficulty stems from the need to unravel the interesting signals from the host of particles produced in the collision: a few thousands in a head-on collision between two lead nuclei at the top SPS beam energy of 160 GeV/c per nucleon. Needless to say, such a task becomes more difficult when looking for relatively rare processes such as the production of Ω^- or J/ψ particles. Under these conditions, systematic errors on a given observable are not easy to estimate if one wants something more than an educated guess. Independent analyses of the data are certainly useful to spot systematic effects in the software. In the end, however, one would really need to have more than one experiment looking at the same observable.

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To illustrate this point, in what follows I shall describe what we have learnt by comparing two CERN-SPS experiments studying strangeness production in the interaction between lead nuclei. The two experiments, named WA97 and NA57, took data in the period 1995–1996 and 1998–2001 respectively. Both studied the production of $K^0_{\rm s}$, Λ, Ξ^- and Ω^- *i.e.* of particles and antiparticles carrying one, two and three units of strangeness respectively. Their interest stems from the prediction that strange particle abundances are enhanced if a quark–gluon plasma is produced in the interaction; the enhancement increasing with the strangeness content. Negative particles, mainly pions, were also recorded to compare strange *versus* non-strange enhancements. Both experiments were similar in conception, but otherwise quite distinct. WA97 was located in the West and NA57 in the North Area. Beam lines, spectrometer magnets and on-line software were completely different as were most of the detectors and of the off-line software.

2. The first experiment: WA97

The WA97 set-up [3] is shown schematically in Fig. 1. The core of the apparatus is a tracking telescope, 90 cm long with a 5 cm×5 cm cross section, made of silicon pixel and microstrip detectors (5×10^5 channels) and placed in a 1.8 Tesla magnetic field. An array of pad chambers are used as lever arm detectors to improve momentum resolution on fast tracks. Masses and momenta of $K^0_{\rm s}$, Λ, Ξ^- and Ω^- are obtained from the tracks that their decay products leave in the telescope, as sketched in Fig. 2 Two planes of

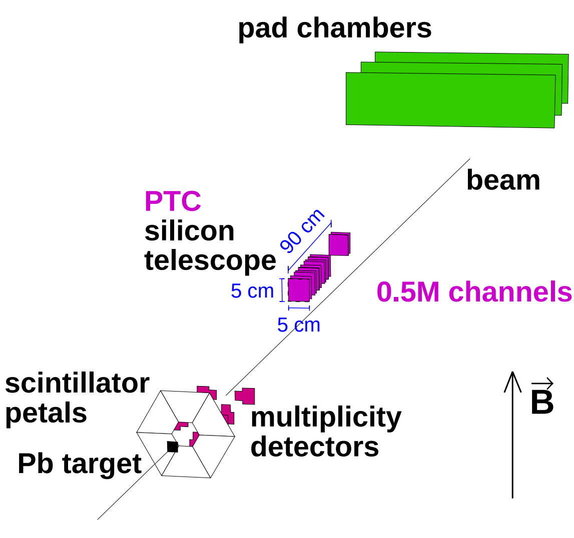

Fig. 1. A schematic view of the WA97 layout in the CERN-OMEGA Spectrometer.

multiplicity detectors, located between the target and the telescope, provide the information to calculate the event centrality, defined as N_{wound}, the number of wounded nucleons *i.e.* nucleons taking part in the collision [4, 5].

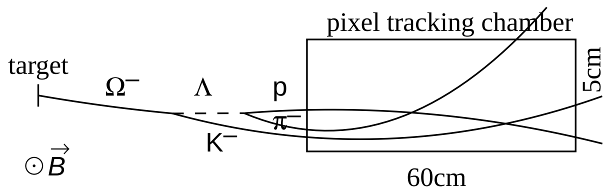

Fig. 2. Sketch of the trajectories in the WA97 silicon tracker, of the particles from the decay of Ω^- into $K^- + \Lambda$, and from the subsequent decay of the Λ into a proton and a π^-.

The type of collisions and the particles studied are summarized in Table I together with the phase space window and the centrality range covered.

TABLE I

WA97 (data in 1995–1996)

Collisions	Pb–Pb at 158 A GeV/c beam momentum p–Pb at 158 A GeV/c " " p–Be at 158 A GeV/c " "
Detection of	Λ, Ξ^-, Ω^- & antiparticles K^0_{s} and $-ve$ particles h^- (mainly pions)
Phase space window	$-0.5 \leq$ c.m.s. rapidity ≤ 0.5 transverse momentum ≥ 0.3 GeV/c for Λ's 0.7 GeV/c for Ω^-
Pb–Pb collision Centrality range	$100 \leq N_{\mathrm{wound}} \leq 416$

For each observed particle species one determines the double differential inclusive cross section:

$$\frac{\mathrm{d}^2 N(m_{\mathrm{T}}, y)}{\mathrm{d}m_{\mathrm{T}}\mathrm{d}y},$$

where y stands for longitudinal rapidity and m_{T} for transverse mass, and the yield:

$$Y = \int_m^{\infty} \mathrm{d}m_{\mathrm{T}} \int_{y_{\mathrm{cm}}-0.5}^{y_{\mathrm{cm}}+0.5} \mathrm{d}y \frac{\mathrm{d}^2 N(m_{\mathrm{T}}, y)}{\mathrm{d}m_{\mathrm{T}}\mathrm{d}y}.$$

The main WA97 contribution to the evidence for quark–gluon plasma at the SPS, has been the measurement of the mid-rapidity particle enhancements E, when going from proton–beryllium to lead–lead collisions as a function of the strangeness carried by the particle:

$$E = \left(\frac{\langle Y\rangle}{\langle N_{\rm wound}\rangle}\right)_{\rm Pb-Pb} \Bigg/ \left(\frac{\langle Y\rangle}{\langle N_{\rm wound}\rangle}\right)_{p-{\rm Be}} ,$$

where Y and $N_{\rm wound}$ are averaged over the centrality range covered by the experiment.

The values of E obtained for various particle species [6] are displayed in Fig. 3. Particles which have at least one common valence quark with the nucleon *i.e.* negatives (mainly pions), Λ, Ξ^- (Fig. 3(a) are kept separate from those with no common valence quark with the nucleon *i.e.* $\bar{\Lambda}$, $\bar{\Xi}^-$, Ω^- and $\bar{\Omega}^-$ (Fig. 3(b), since the two groups are known to exhibit different production features. In both cases we note that the enhancement increases dramatically with the strangeness content, up to a factor of about 15 for Ω, as expected if strange quarks are equilibrated in a deconfined quark–gluon plasma. In Fig. 4 the enhancements are displayed *versus* the collision centrality — $N_{\rm wound}$- [3]. No significant dependence of the enhancements on centrality is observed in the range $N_{\rm wound} \geq 100$ covered by the experiment.

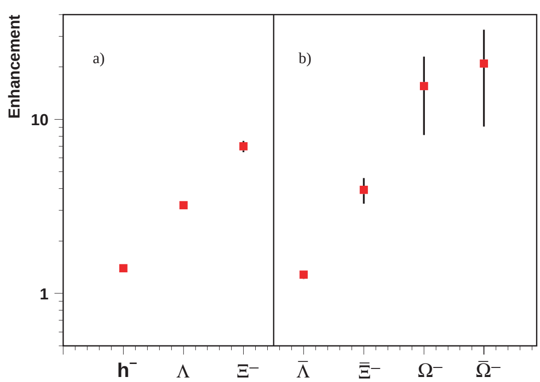

Fig. 3. Enhancements E of particle production in lead–lead *versus* proton–beryllium collisions, for various particles.

Two methods have been used to extract the particle inclusive distributions and correcting for acceptance and reconstruction losses; the first based on individual weighting of each reconstructed particle and the other on the deconvolution of measured spectra [7]. All the spectra obtained with the two methods were found to be compatible. Lifetimes for $K^0_{\rm S}$, Λ and $\bar{\Lambda}$ were found to be in agreement with table values.

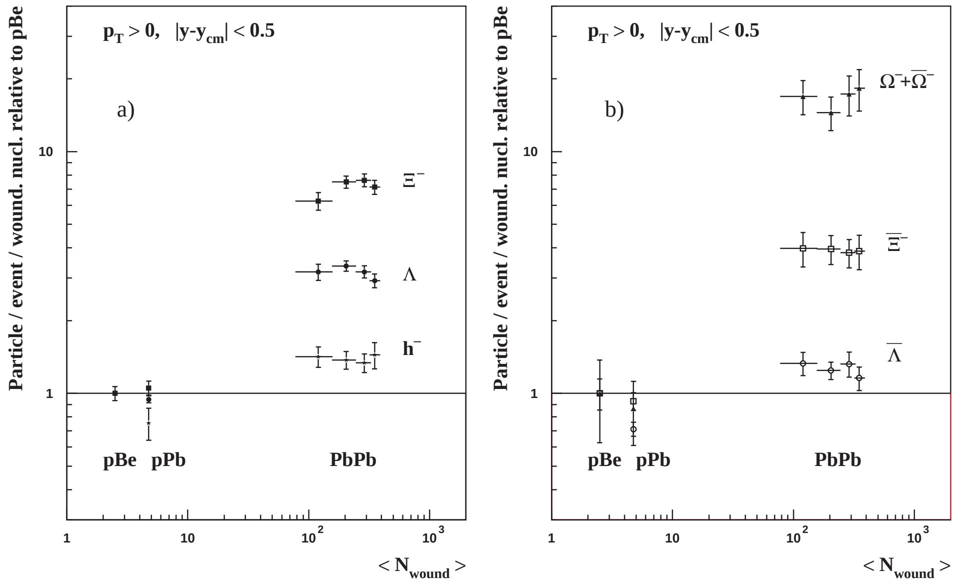

Fig. 4. Enhancements *versus* the number of nucleons taking part in the lead–lead collision $N_{\rm wound}$.

The experiment ended in 1996 with the closure of the West Hall. The results obtained however, warranted a follow-up to study the onset of the observed enhancements. In other words, how do these depend on the interaction volume *i.e.* on the number of participants — $N_{\rm wound}$-? How do they depend on the energy available in the collision center of mass? To try and answer these questions, it was decided to start in the North Area an experiment, similar to WA97, which took the name of NA57.

3. The NA57 experiment

The NA57 set-up is shown in Fig. 5. The main changes with respect to WA97 are [8]

(i) a new beam line,

(ii) a new telescope layout, fully based on silicon pixel detectors,

(iii) a new spectrometer magnet and

(iv) a new data acquisition system.

As a result the detector alignment procedure and the track finding and event reconstruction software packages had to be substantially different from those used for WA97. The NA57 experiment has been taking data at two beam momenta: at 160 A GeV/c and at 40 A GeV/c. A special effort has been made to extend the centrality coverage towards more peripheral events, by reducing various background sources. For Pb–Pb collisions at 160 GeV/c per nucleon, NA57 is able to identify interactions with only 50–60 participating nucleons, *i.e.* about half of the WA97 lower limit.

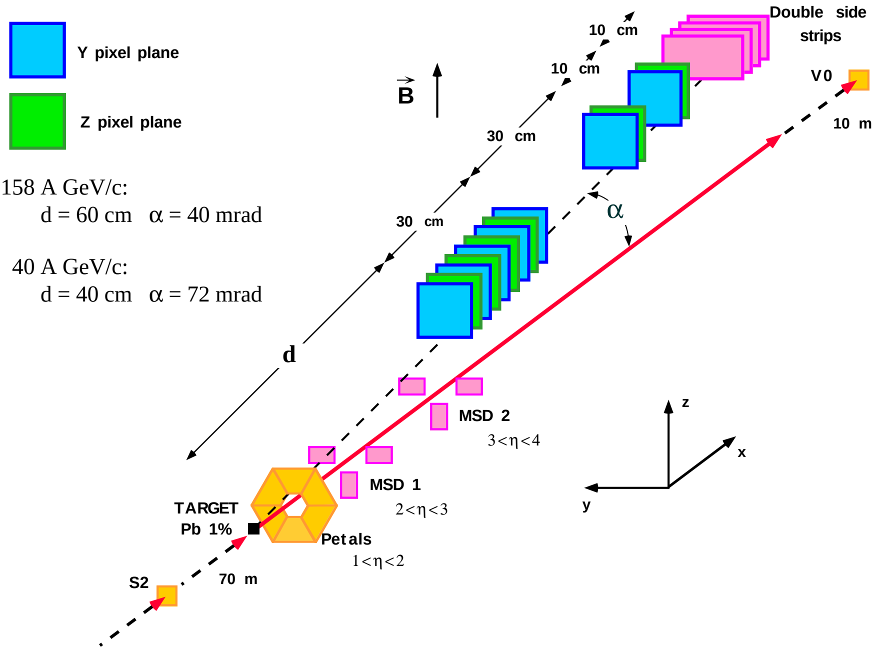

Fig. 5. A schematic view of the NA57 layout (not to scale).

The type of collisions and the particles studied are summarized in Table II, together with the phase space window and the centrality range covered.

TABLE II

NA57 (data in 1998–2001)

Collisions	Pb–Pb at 158 A GeV/c beam momentum Pb–Pb at 40 A GeV/c " " p–Be at 40 A GeV/c " "
Detection of	Λ, Ξ^-, Ω^- & antiparticles K^0_s and $-ve$ particles h^- (mainly pions)
Phase space window	$-0.5 \leq$ c.m.s. rapidity ≤ 0.5 transverse momentum ≥ 0.3 GeV/c for Λ's 0.7 GeV/c for Ω^-
Pb–Pb collision Centrality range	$50 \leq N_{\text{wound}} \leq 416$

4. The comparison

The results obtained by the two experiments for lead–lead collisions at 160 A GeV/c are compared here in their common centrality range, *i.e.* for $N_{\rm wound} \geq 100$, while the NA57 results over the full centrality will be presented at Quark Matter 2002 by Manzari [9]. Fig. 6 shows the WA97 enhancements (presented in Fig. 4) with the corresponding values found by NA57 superimposed.

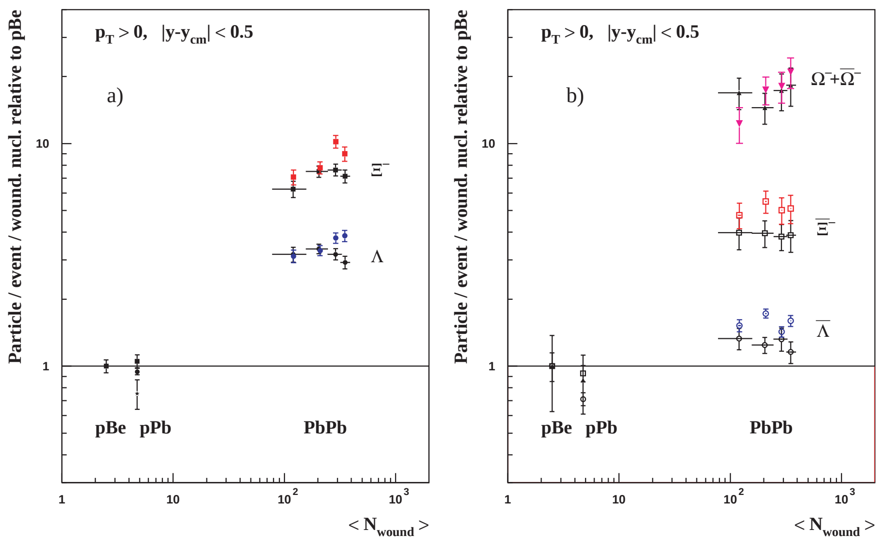

Fig. 6. NA57 *versus* WA97 enhancements *versus* $N_{\rm wound}$, in the common centrality range $N_{\rm wound} \geq 100$. The p–Be and p–Pb reference data are from WA97.

The new data generally confirm the enhancements and their hierarchy as found by WA97. The new yields, however, are larger than the old ones by 10%–20% and, at least for Λ's and Ξ's, show a significant centrality dependence. Other observables *e.g.* the transverse distributions, are found to be compatible between the two experiments. The observation of the difference in yields triggered an intensive analysis effort. The bulk of the difference was traced to the WA97 interaction vertex reconstruction. An instability in the lead beam extraction to the West Area made the beam spot move during the spill. The technique adopted to cope with this movement for each event, introduced a spread in the position of the reconstructed vertices, which was not accounted for. The small dimensions of the detector set-up, together with tight selection criteria, made this effect influence, by 10–15%, our estimate of the apparatus acceptance and therefore also the calculated yields. The NA57 data instead were not affected by this problem since the beam line in the North Area was very stable, thus allowing a precise determination of the acceptance corrections. The WA97 proton–beryllium reference data at 160 GeV/c were also unaffected since the beam was stable and each beam track was accurately measured by a set of silicon microstrips. As examples of the quality of our understanding of the NA57 setup, Fig. 7, 8 and 9 show a comparison between simulated and real data for several quantities from the decay $\Xi^- \rightarrow \Lambda + \pi^-$.

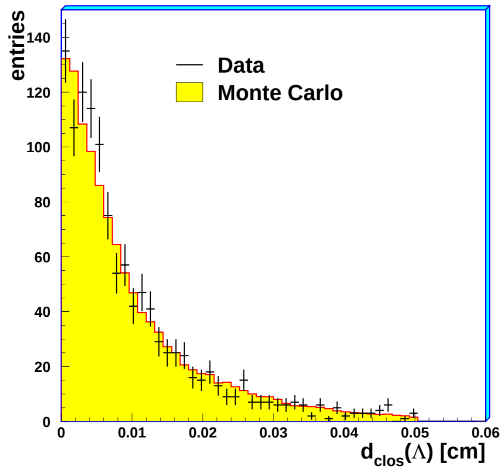

Fig. 7. $\Xi^- \rightarrow \Lambda + \pi^-$ and subsequent $\Lambda \rightarrow$ proton + π^- decays. Comparison between data and Monte Carlo simulation for the distance of closest approach d_{clos} between the two tracks from the Λ decays.

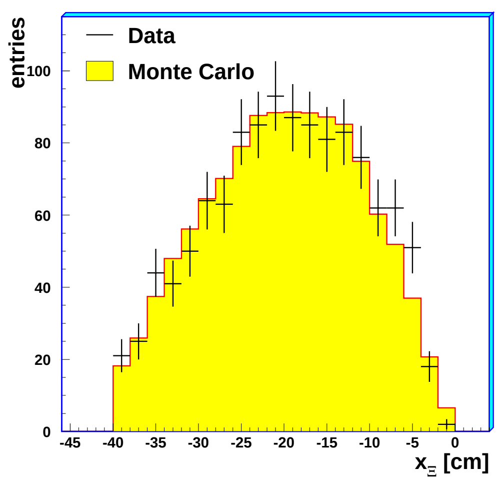

Fig. 8. $\Xi^- \rightarrow \Lambda + \pi^-$ and subsequent $\Lambda \rightarrow$ proton + π^- decays. Comparison between data and Monte Carlo simulations for the x-position (see Fig. 5) of the Ξ^- decay vertex. The target is located at $x = -60$ cm, and the first plane of the detector is at $x = 0$.

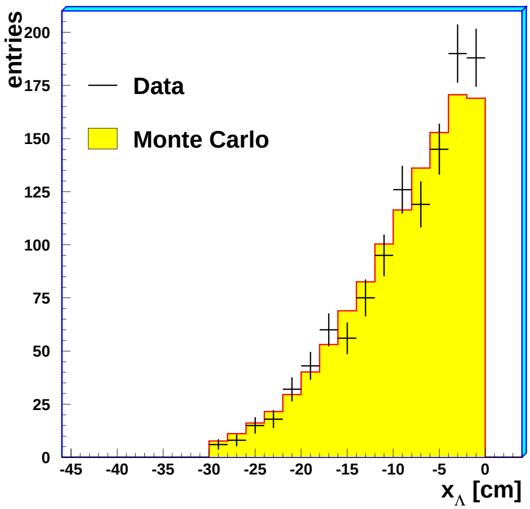

Fig. 9. $\Xi^- \to \Lambda + \pi^-$ and subsequent $\Lambda \to$ proton $+ \pi^-$ decays. Comparison between data and Monte Carlo simulations for the x-position of the Λ decay vertex.

The outcome of all these studies gives us confidence in the correctness of the NA57 data [10, 11]. It seems reasonable to conclude that without this second experiment, the 10–20% systematic error on the yields would probably have gone uncorrected.

5. Conclusions

Comparing results from different experiments is clearly indispensable in order to reveal systematic effects. It is not always easy, however, or possible to have more than one experiment for each observable. For example, at SPS, RHIC and LHC some of the interesting observables are only studied by one experiment. How are people coping with this situation? Since all experiments need to correct the raw data for losses due to limited acceptance and to reconstruction inefficiency, repeated independent analyses of the same data are becoming common practice. In future, such a type of cross-checking will certainly become more frequent and more sophisticated. In addition, all known physical quantities which can be extracted from the data need to be examined, since deviations from table values may point to a problem.

For strange particles, one usually checks the reconstructed masses and, for those decaying weakly, their average lifetimes. In future experiments where statistics of tens of thousands of reconstructed Ξ^- (Ω^-) decays into Λ and π^-(K^-) may be expected, (*e.g.* ALICE [12]), other physics constants could be checked, namely the products of weak decay constants $\alpha_\Lambda \cdot \alpha_\Xi$ and $\alpha_\Lambda \cdot \alpha_\Omega$ that are expected to be (-0.293 ± 0.007) and (-0.017 ± 0.015), respectively [13]. As well known, these products can be obtained from the measurement of the longitudinal polarization of the decay Λ's. The parent $\Xi^-(\Omega^-)$ polarization, if any, does not need to be known, provided that the acceptance of the detector is left–right symmetric with respect to the beam axis [14].

In conclusion, upon due consideration and bearing in mind the examples that I have outlined above, I would humbly suggest that the best recipe for avoiding systematic effects is just to keep worrying about them!

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[14] The author wishes to thank Maurice Jacob for a clarifying discussion on this issue.