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Addendum 1 to the NA57 Proposal (P300)

EXTENSION TO INDIUM OF THE NA57 PROGRAMME

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Abstract

In the present document we summarize the status of the NA57 programme and we propose to complete it with a study of the *A* dependence of the enhancements using the full energy indium beam scheduled to be available in 2003.

1. Introduction

The NA57 experiment has been designed to study the onset of the strange baryon and antibaryon enhancements in Pb-Pb with respect to p-Be collisions, first observed by the WA97 experiment at 160 *A* GeV/*c* beam momentum [1,2]. The two main physics goals of NA57 are the studies of the dependence of these enhancements on the interaction volume and on the interaction energy.
In the present document we first summarize the status of our programme. The main additions with respect to our last memo to the SPSC [3] are

i) the Ω^- and $\overline{\Omega}^+$ yields in Pb-Pb at 160 *A* GeV/*c* with final statistics and

ii) the Ξ^-, $\overline{\Xi}^+$, Ω^- and $\overline{\Omega}^+$ yields for central Pb-Pb collisions at 40 *A* GeV/*c*.

We then propose to complete the programme with a study of the *A* dependence of the enhancements using the full energy indium beam scheduled to be available in 2003.

In section 2 we recall the available NA57 data sets. We then present the status of the study of the dependence of the enhancements on the interaction volume (in section 3) and on the interaction energy (in section 4). The case for an Indium run of NA57 is presented in section 5, while the expected event rates are discussed in section 6.

2. NA57 data sets

NA57 has collected Pb-Pb data both at 160 and at 40 *A* GeV/*c* beam momentum. The centrality range was enlarged with respect to the one accessible to WA97. The centrality selection is based on the multiplicity signal from a set of scintillator "petals". In order to allow an extension of the trigger multiplicity range towards more peripheral events, particular care was taken in the design of the beam line, so as to minimize the contamination from interactions upstream of the target.
Two samples of p-Be reference data at 40 GeV/*c* were also collected. As proton reference data at 160 *A* GeV/*c*, NA57 is using the WA97 p-Be (180 10^6 events) and p-Pb (290 10^6 events) samples.

An overview of the available NA57 data sets is given in Table 1. The event reconstruction procedure has now been completed for all samples.

Table 1: NA57 Data Sets

System	Beam momentum	Sample size	Run
Pb Pb	160 A GeV/c	230 M events	November 1998
p Be	40 GeV/c	60 M events	July 1999
Pb Pb	40 A GeV/c	290 M events	November 1999
Pb Pb	160 A GeV/c	230 M events	October 2000
p Be	40 GeV/c	110 M events	September 2001

3. Status of the physics analysis: enhancements versus interaction volume

The NA57 results on the hyperon enhancements at 160 GeV/*c* per nucleon are shown in Figure 1 as a function of the number of participant (wounded) nucleons (N_{wound}) for p-Be collisions, p-Pb collisions and for five centrality bins in Pb-Pb collisions. The statistics for Ω^- and $\overline{\Omega}^+$ is now final, while an increase by a factor two for Ξ^- and

$\overline{\Xi}^+$ is forthcoming. Enhancements, defined for each particle species as the yield per wounded nucleon relative to p-Be, are plotted separately for particles with (left) and without (right) valence quarks in common with the nucleons. The statistical (segment bars) and systematic (bracket bars) errors are shown separately. The horizontal line indicates the expectation in the case that the yields per wounded nucleon were to stay constant from p-Be all the way to central Pb-Pb collisions (i.e.: no enhancement). As can be seen, while the p-Pb points lie close to the no enhancement prediction, in Pb-Pb collisions there is a substantial enhancement for all the particle species under consideration. The effect is progressively more pronounced for particles of higher strangeness content. The maximum enhancement is about a factor 20 for ($\Omega^- + \overline{\Omega}^+$) in central Pb-Pb collisions. Such a pattern of strangeness enhancement was predicted twenty years ago [4] as signature for a phase transition to Quark-Gluon Plasma in ultrarelativistic nucleus-nucleus collisions. The enhancements increase with the number of wounded nucleons within the accessible centrality range for all the particles except the $\overline{\Lambda}$. The effect is particularly striking for the $\overline{\Xi}^+$: the $\overline{\Xi}^+$ enhancement jumps up by a factor 2.6 (a 3.5 σ effect) around $N_{wound} = 100$.

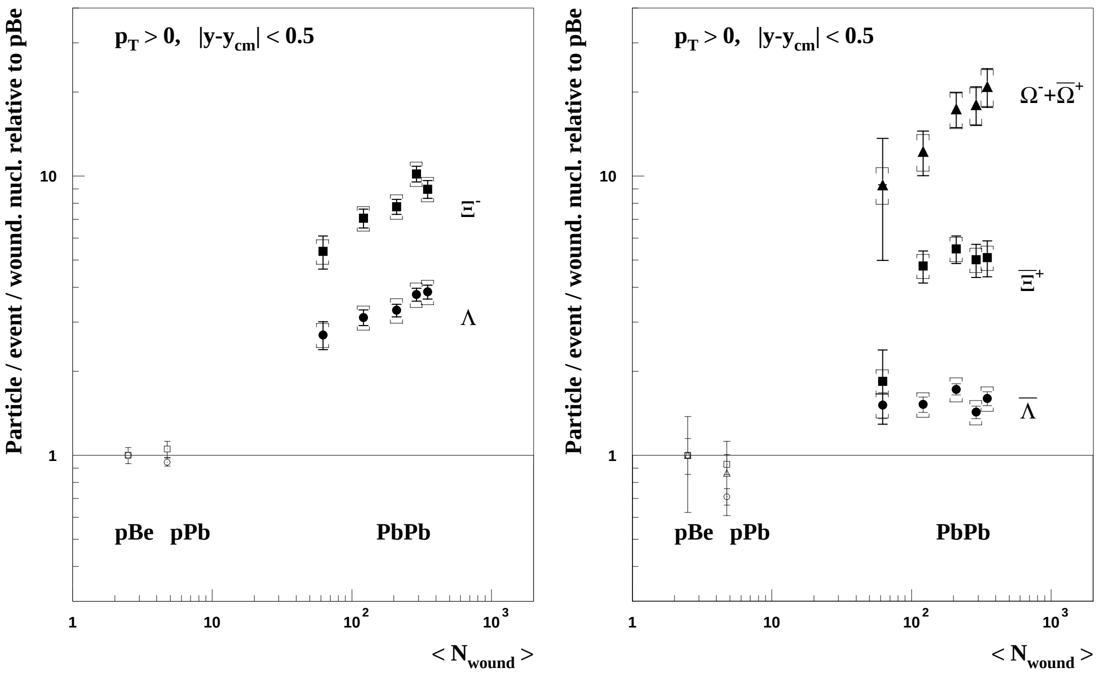

Figure 1: Yields per participant (wounded) nucleon relative to the p-Be yields. Statistical errors are indicated by vertical bars. Systematic errors are indicated by bracket bars.

As discussed in [3], the Λ and Ξ yields measured in NA57 were found to be up to 20% larger than the corresponding ones from WA97. This is shown in Fig. 2, where the results of the two experiments are compared in the common centrality range (only the systematic errors are shown). The bulk of the discrepancy has been understood as due to a bias introduced in WA97 by the vertex reconstruction procedure. Instability in the lead beam extraction to the West Area H1 beam line caused the beam spot to move during the spill, leading to a large (a few mm) spread in the transverse position of the primary interaction vertex. Therefore, it was necessary to compute the acceptance and efficiency corrections according to the position of the primary vertex, as measured event by event. The spread in the position of the reconstructed vertices was not completely accounted for in the simulation. This effect, combined with the use of tight geometrical selection criteria, had an influence of 10-15% on our estimate of the acceptance of the apparatus and therefore on the calculated yields. The NA57 data are not affected by such problems: the North Area H4 beam is very stable, allowing a precise determination of the acceptance corrections. As for the WA97 p-Be reference data at 160 GeV/*c*, they are not affected by such problems either, since the H1 proton beam was stable and each beam track was accurately measured by a set of silicon microstrips. In [3] we presented a series of checks of the Ξ systematics. Examples of the quality of our understanding of the NA57 set-up were also shown. Such checks have now been extended to the Λ with similarly positive results, thus strengthening our confidence in the NA57 results.

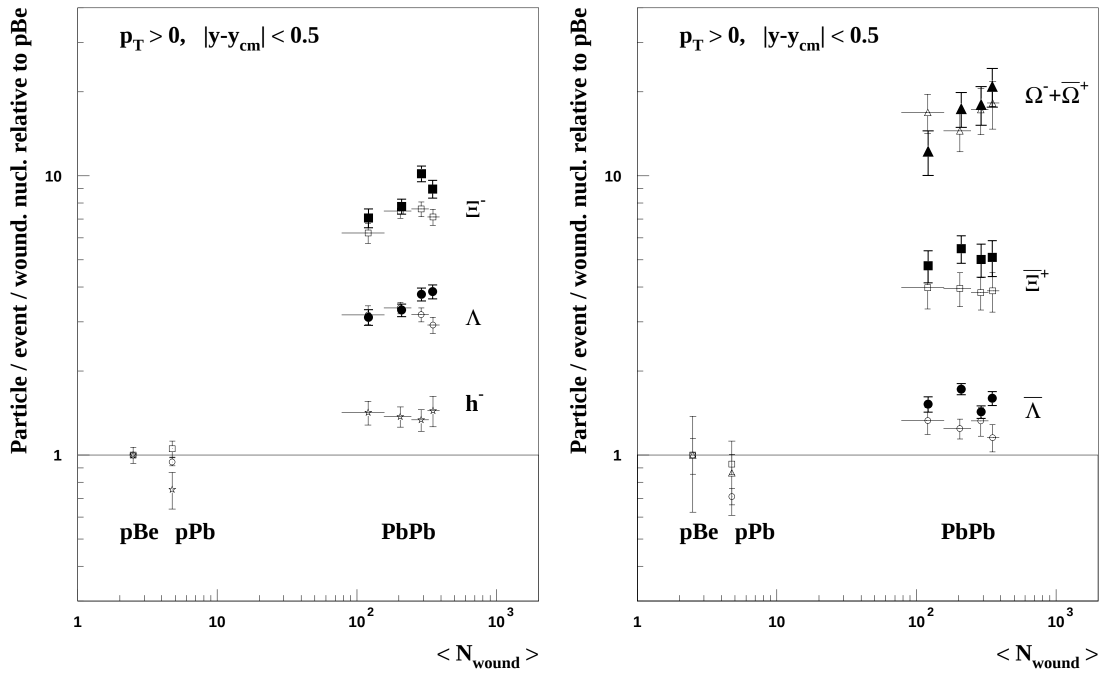

Figure 2: Comparison of the values of the enhancements measured by NA57 (closed symbols) and WA97 (open symbols) in the common centrality range. Only the statistical errors are shown.

4. Status of the physics analysis: enhancements versus interaction energy

The Ξ and Ω yields at 40 *A* GeV/*c* are compared with those measured at 160 *A* GeV/*c* in figure 3. For this comparison, the hyperon samples at 160 *A* GeV/*c* have been restricted to the three most central classes, corresponding to the same fraction of cross section (25%) as for the 40 *A* GeV/*c* sample . While the Ξ^- yields at 40 and 160 *A* GeV/*c* are similar, $\overline{\Xi}^+$, Ω^- and $\overline{\Omega}^+$ are produced less abundantly at the lower beam energy.
In Figure 4 the NA57 Ξ and Ω yields at both energies are compared with preliminary results from the STAR experiment at RHIC [5]. The STAR sample corresponds to the most central 14% of the inelastic cross section. For comparison, the NA57 particle yields at both energies have been computed for the two most central classes, which correspond to the most central 12%. The Ξ and Ω yields display

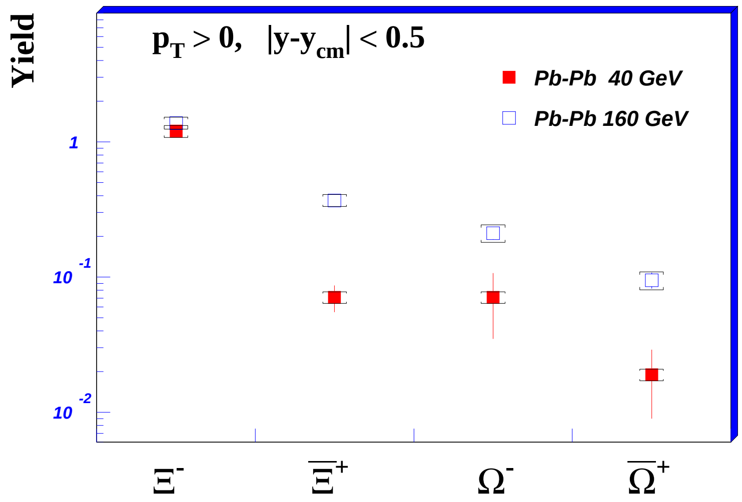

Figure 3: Ξ and Ω yields for the most central 25% of the inelastic Pb-Pb cross section at 40 (closed symbols) and 160 (open symbols) *A* GeV/*c*.

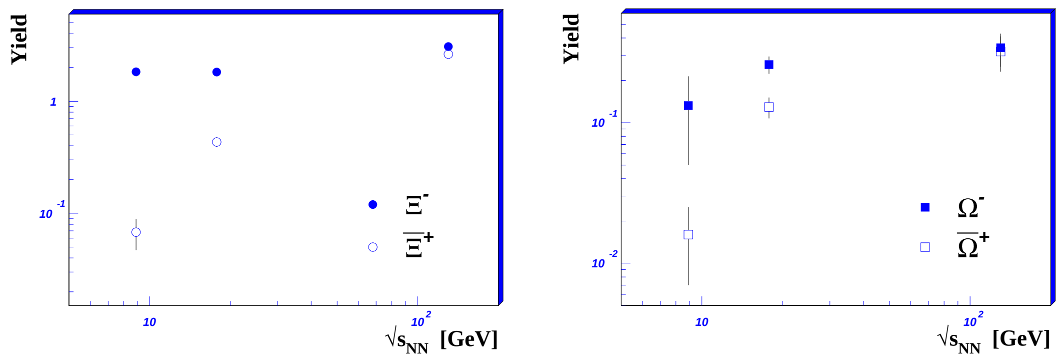

Figure 4: Comparison of Ξ and Ω yields from NA57 and STAR.

a much weaker energy dependence than those of their anti-particles. At RHIC, the production rates for hyperons and anti-hyperons are very similar.

In Figure 5 the anti-hyperon/hyperon ratios are shown as a function of $\sqrt{s}$ from NA57 to STAR energies. The $\overline{\Lambda}/\Lambda$ ratio at 40 *A* GeV/*c* is also shown. This last ratio is not corrected for acceptance and efficiency, but we know that such corrections are very small for anti-particle/particle ratios, due to the left/right symmetry of the NA57 apparatus and to the fact that we collect about one half of our samples with each of the opposite magnetic field polarities. In order to increase the statistics, the NA57 ratios are computed at both energies over the most central 25% of the inelastic cross section.

All ratios increase with energy, approaching 1 at RHIC. The energy dependence is weaker for particles with higher strangeness (lower light quark) content. These results indicate a progressive decrease of the baryon density at central rapidities as the energy is increased.

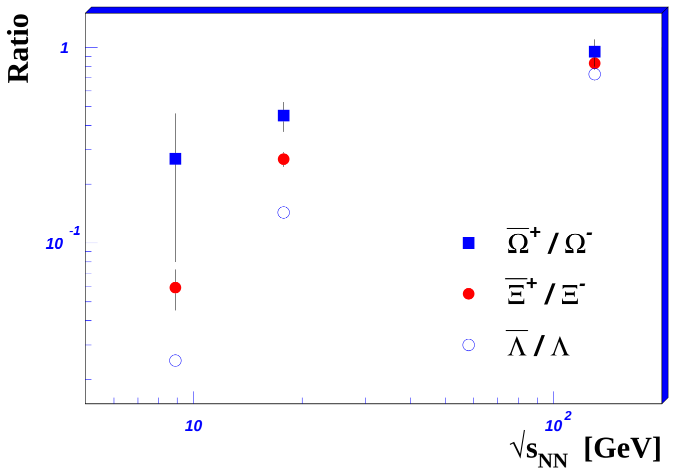

Figure 5: Comparison of anti-hyperon/hyperon ratios from NA57 and STAR.

In order to establish whether hyperon production is already enhanced at 40 *A* GeV/*c* and by how much, we need to compare with p-Be reference data collected at the same beam energy. The collection of p-Be reference data by NA57 was completed in 2001 (see Table 1). The whole reference sample has now been processed through the event reconstruction software chain. The analysis is currently ongoing. We expect results on the energy dependence of the enhancements in the coming months.

5. The case for an In run

As discussed in the previous sections, the original NA57 Pb-Pb programme at both 40 and 160 *A* GeV/*c* is nearing completion. The bulk of the analysis is expected to be over by the summer of 2003. On the theoretical side, work is under way to understand and interpret the behaviour with N_{wound} of the hyperon yields. As for the behaviour of the $\overline{\Xi}^+$ around $N_{wound} = 100$, which has aroused considerable interest since it could signal the onset of deconfinement when the collision involves more than 100 nucleons, as discussed above the precision of the Ξ^- and $\overline{\Xi}^+$ points will soon be improved when the analysis of the remaining 50% of the Ξ statistics is completed.

In order to understand the physics behind the increase with N_{wound} of the hyperon enhancements, we could take great advantage from exposing the existing NA57 apparatus to the indium beam scheduled for 2003. Until now, we have collected Pb-Pb events with a wide centrality trigger and calculated N_{wound} from the observed multiplicity. This approach, the only one possible so far, does not take into account that as N_{wound} decreases, the shape of the system created in the collision changes at the same time, becoming more and more asymmetric and deformed as one moves away from central, head-on collisions. Ideally, the clean way to study the dependence on the number of participants would be to measure the hyperon enhancements on very central collisions for various mass numbers of the two (identical) colliding nuclei, i.e. to measure the *A* dependence of the enhancements.

Experimentally, it has been shown [6] that for kaon production, for the same value of N_{wound} central collisions of a lighter system are more effective than peripheral collisions of a heavier system. The availability of a high energy In beam in 2003 offers us the only opportunity to extend such measurements to multiply-strange particles at SPS energy. Exposing the NA57 apparatus to the scheduled In beam would provide us with meaningful statistics for such a study. In particular, we should collect enough statistics to check the puzzling behaviour of the $\overline{\Xi}^+$ at N_{wound} around 100.

6. Event rates

The amount of hyperon statistics which can be collected with In-In collisions depends on the value of the enhancement for each hyperon. In the following, we estimate the raw yields in the two extreme hypotheses of no enhancement (assuming the yields per wounded nucleon to be the same as in p-Be collisions) and of full enhancement (assuming the yields per wounded nucleon to be the same as in central Pb-Pb collisions), for two classes of centrality. We define a *peripheral* class where $N_{wound} <$ 100 (below the second centrality bin of NA57) and a *central* class where $N_{wound} > 100$. Table 2 shows the upper and lower limits for the yields in each class of Λ, $\overline{\Lambda}$, Ξ^-, $\overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$ expected in the NA57 set-up from a 36-day run with a 170 *A* GeV/*c* beam of 10^6 In nuclei/spill on a 2% interaction length In target. We expect to collect 3000 events per spill at 60% centrality, 4000 spills per day and a global efficiency of 0.7. While, depending on the amount of enhancement, such statistics may not be enough for the $\Omega^- + \overline{\Omega}^+$, it would certainly allow us to check the behaviour for In-In collisions of the Λ, $\overline{\Lambda}$, Ξ^- and $\overline{\Xi}^+$ enhancements at $N_{wound} < 100$. The $\overline{\Xi}^+$ statistics in the peripheral class, for instance, should be comparable to the statistics in the most peripheral NA57 Pb-Pb bin collected in 1998 (50% of the total statistics collected by NA57 at 160 *A* GeV/*c*) even in the case of no enhancement, allowing us to measure a variation of the $\overline{\Xi}^+$ enhancement around $N_{wound} = 100$ with a precision comparable to that of the measurement shown in Figure 1. In addition, the statistics for peripheral events may be increased by specifically selecting events with lower centrality at trigger level.

Table 2: Lower and upper limits on the hyperon statistics in two centrality classes expected in NA57 for a 36-day In-In run at 170 *A* GeV/*c* (see text for assumptions)

	Peripheral		**Central**	
	Min. yield	**Max. yield**	**Min. yield**	**Max. yield**
Λ	35,000	100,000	70,000	200,000
$\overline{\Lambda}$	11,000	14,000	23,000	29,000
Ξ^-	100	430	200	850
$\overline{\Xi}^+$	40	115	85	230
$\Omega^- + \overline{\Omega}^+$	7	70	14	140

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