# Reply to "Comment on 'Strangeness enhancement in $p+A$ and $\mathrm{S}+A$ interactions at energies near 200$A$ GeV' "

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In this Reply we argue that the factor of 4 enhancement of the local midrapidity densities of $\Lambda$ and the strong suppression of $\Lambda$ in the projectile fragmentation region in $p+\mathrm{S}$ relative to $p+p$ reactions provide strong evidence of nonequilibrium dynamics in strangeness production. Second, we show that the dramatic changes in the $\Lambda$ rapidity distributions in $pA$ cannot be attributed to nuclear baryon stopping power. [S0556-2813(96)05309-5]

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The Comment [1] of Gaździcki and Heinz challenges our recent analysis [2], where we concluded that if the NA35 data [3] on $p+\mathrm{S}$ and $\mathrm{S}+\mathrm{S}$ are correct, then strangeness enhancement in heavy ion collisions appears to be due to new nonequilibrium rather than equilibrium multiparticle production dynamics. The basic difference between our approaches is that we focus on the detailed *local* rapidity distribution of produced strange hadrons whereas Gaździcki and Heinz and Refs. [3,4] focus on the *global* integrated strangeness yields. Our emphasis on the local distributions stems from the fact that ratios of integrated yields such as $E_s=\langle \Lambda+K+\overline{K}\rangle/\langle \pi\rangle$ discard essential experimental information on the local distributions that call into question interpretations of the data based on equilibrium fireball models.

The motivation for our work was the anomalous rapidity distribution of $\Lambda$ reported by NA35 [3] for minimum bias $p+\mathrm{S}$ reactions. Our analysis used two different microscopic models, HIJING [5] and VENUS [6], to quantify the differences between $p+p$, $p+A$, and $A+A$ reactions. Gaździcki and Heinz [1] ignored the VENUS half of our analysis and argued that our analysis is problematic because our models do not account for the nuclear stopping power in $pA$.

In this Reply, we contradict two key aspects of the discussion presented in [1]. First, while we agree that the integrated strangeness yields in $p$S do not indicate global strangeness enhancement in this reaction, the factor of 4 enhancement of the local midrapidity densities of $\Lambda$ and the strong suppression of $\Lambda$ in the projectile fragmentation region relative to $p+p$ reactions provide strong evidence that novel nonequilibrium dynamical mechanisms are at work in strangeness production in $p+A$. Second, we show that the above features of the $\Lambda$ rapidity distributions cannot be attributed to nuclear stopping power in $p+A$. Other points raised in [1] are not relevant to our conclusions and will not be addressed here.

We regard the rapidity distribution of $\Lambda$'s for the *minimum bias* $p+\mathrm{S}$ reactions [3] anomalous because the central $(y\approx 3)$ rapidity density $(0.06\pm 0.01)$ of $\Lambda$'s produced in $p+\mathrm{S}$ is 4 times greater than that $(0.016\pm 0.0005)$ in $p+p$ [8]. This is very surprising since the cross section for the selected $p+\mathrm{S}$ $(n_{\mathrm{ch}}>5)$ events was 470 mb, which corresponds to a minimum bias and not the central trigger. Taking the diffuse nuclear surface into account that trigger only constrains events to have impact parameters less than 5 fm. For this weak trigger, the mean number of interacting S nucleons is only $\nu\approx 2.2$. The $p+\mathrm{S}$ reaction therefore only tests the difference between multiparticle production dynamics in two-nucleon $(\nu=1)$ and few-nucleon $(\nu=2\text{–}3)$ reactions.

From extensive $p+A\rightarrow p+X$ systematics [7] the average baryon rapidity shift in $p+A$ reactions grows slowly as $\Delta y_B\approx 1+(\nu-1)/3$. In $p+\mathrm{S}$ therefore the leading baryon rapidity shift is only a half a unit greater than in $p+p$. The leading proton stopping power of nuclei cannot therefore account for the strong suppression of $\Lambda$ production for $y>4.5$ in $p+\mathrm{S}$. Also the number of collisions $\nu$ is too small to account for the factor of 4 enhancement of the central rapidity density. In the target fragmentation region $(y\approx 1)$ there is also a factor of 4 enhancement of the $\Lambda$ density in $p$S relative to $pp$. If the $p+\mathrm{S}$ data are correct, then significant *local* strangeness enhancement already occurs in few-nucleon processes and therefore must be due to new nonequilibrium dynamics.

In stating the conclusion, we carefully pointed out, however, the fact that the NA35 data on $p+\mathrm{S}$ differ substantially from earlier data on $p$Ar by NA5 [9]. The earlier NA5 analysis [9] showed that both the dual parton and Lund models could account easily for a factor of 2 enhancement of the central $\Lambda$ rapidity densities in $p+\mathrm{Ar}$ and similar enhancement in $p+\mathrm{Xe}$ and $\overline{p}+\mathrm{Xe}$. However, the NA5 $p+\mathrm{Ar}\rightarrow\Lambda+X$ central density is a factor of 2 lower than found in $p+\mathrm{S}$ by NA35. Furthermore, the $p+A\rightarrow\Lambda+X$ systematics of Ref. [10] suggests that the enhancement of $\Lambda$ production in $p+A$ increases linearly with the number of secondary collisions in contrast to according to the anomalously enhanced NA35 central region. These discrepancies, however, are completely obscured in ratios of integrated yields. While such ratios are useful to quantify global strangeness production in case the local rapidity distributions are understood, in the present case, given the anomalous nature of the $p$S data and the unresolved discrepancies between experiments, it is best to avoid reducing the wealth of data on those distributions to a few numbers.

 

Finally, we emphasize that ratios of integrated yields mix different physics in the central and fragmentation regions. The overestimate of the fragmentation region $\Lambda$ rapidity density with HIJING in $p+p$ was used in [1] to cast doubt on our model analysis in spite of the model's ability to reproduce accurately the midrapidity yields. The fact that unlike in $p+p$ both HIJING and VENUS fit the target fragmentation $(y=1)$ peak $p+\mathrm{S}$ in Fig. 1(b) [2] provides direct evidence for conventional strangeness enhancement due to secondary reactions. That target fragmentation enhancement is consistent with NA5 [9] and Ref. [10]. However, the strong suppression of $\Lambda$ in the projectile fragmentation region $(y>4.5)$ in $p+\mathrm{S}$ is not found in either model. The Comment [1] missed entirely the significance of the VENUS model calculation. That model has been tuned to reproduce well the $p+A\rightarrow p+X$ stopping power measurements [6]. In fact VENUS also reproduces well the NA35 central $\mathrm{SS}\rightarrow pX$ distribution. HIJING is too strongly peaked about the mean rapidity loss while VENUS distributes baryons more broadly about that mean in accordance with data. The small shift of the VENUS curves in the fragmentation regions [Fig. 1(b) [2]] relative to HIJING shows that a more accurate leading baryon stopping cannot account for the strong suppression of $\Lambda$'s with $y>4.5$ in $p+\mathrm{S}$. These calculations prove that a new dynamical mechanism must be involved in leading hyperon production already in three-nucleon processes. The enhanced central rapidity $\Lambda$'s three units of rapidity away from the fragmentation regions is spectacular since unlike in $\mu+p$ and $p+p$ reactions where both leading baryon and hyperon are shifted by the same unit of rapidity, it seems that in $p\mathrm{S}$ the hyperon is shifted significantly more in rapidity than the leading nonstrange baryon. All this points to new mechanisms for hyperon production that open up when more than two nucleons collide.

Given the striking changes of strangeness production mechanisms in $pA$, conclusions [4,11] about quark-gluon plasma production based on strangeness production ratio systematics are premature. We showed in [2] that at least one nonequilibrium dynamical model (VENUS) can account for the anomalous central SS lambda production distributions as well. However, new data on $pA$ will be required to resolve experimental discrepancies and to explore more fully the onset of new mechanisms for strangeness production. The search for unambiguous signatures of quark-gluon plasma production in nuclear collisions requires untangling complex and as-yet poorly understood multiparticle dynamical effects that can forge such signatures. A better understanding of the systematics of detailed *differential* observables will be essential in that effort.

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