STRANGE BARYON PRODUCTION IN Pb–Pb INTERACTIONS AT THE CERN SPS

Ladislav Šándor
Institute of Experimental Physics, Košice

for the NA57 collaboration
Plan of talk

- The NA57 experiment
- Results on particle yields and enhancements
- Transverse mass distributions at 160 $A$ GeV/c
- Conclusions

A sketch of hyperon weak decay to charged particles and its detection in the NA57 set-up:
The NA57 experiment

NA57 – a successor of the WA97 experiment which contributed significantly to the observation of a new state of matter at the CERN SPS. NA57 utilizes the same philosophy as WA97 but significantly upgraded detectors, DAQ and software.

160 A GeV/c WA97 data at midrapidity exhibit enhancements in Pb–Pb hyperon yields with respect to p–A collisions (see E. Andersen et al., Phys. Lett. B449 (1999) 401). These enhancements increase with the strangeness content of particle (QGP prediction) reaching more than one order of magnitude for Ω.

**NA57 confirms this pattern** (V. Manzari et al., Nucl. Phys. A715 (2003) 140c) and continues the study of strangeness enhancements as a function of

- extended centrality range (down to $N_{wound} \sim 50$) in Pb–Pb at 160 A GeV/c
- beam energy (data at 40 and 160 A GeV/c)

Both 160 and 40 A GeV/c Pb–Pb samples analysed.

Analysis of the reference p–Be data at 40 A GeV/c near to completion.

The WA97 p–Be sample used as reference data at 160 A GeV/c.
NA57 experimental set-up

Y pixel plane \((3 \Omega_2 + 4 \Omega_3)\)

Z pixel plane \((4 \Omega_2 + 2 \Omega_3)\)

160 A GeV/c:
- \(d = 60\) cm \(\alpha = 40\) mrad

40 A GeV/c:
- \(d = 40\) cm \(\alpha = 72\) mrad

apparatus placed inside the 1.4 T field of the GOLIATH magnet
**Experimental procedure**

Reconstructed decay channels: $\Omega^- \to \Lambda + K^-$, $\Xi^- \to \Lambda + \pi^-$, $\Lambda \to p + \pi^-$

- Signals of hyperons and anti-hyperons extracted by geometrical and kinematical cuts with negligible level of background
- Geometrical acceptance of apparatus ($p_T$-dependent) and symmetry of Pb–Pb collision allow measurement in one unit of rapidity centered at mid-rapidity
- Data corrected for acceptance and for detector and reconstruction efficiency.

Estimate of systematic errors: $\approx 10\%$ for $\Lambda, \Xi$, $\approx 15\%$ for $\Omega$
Centrality of Pb–Pb collision

Centrality determination from charged particle multiplicity measurement $N_{\text{wound}}$ from trigger cross sections (Glauber model calculations)

$\sigma_0 = 0.95 \pm 0.03$ barn
$\sigma_I = 1.23 \pm 0.03$ barn
$\sigma_{II} = 0.88 \pm 0.02$ barn
$\sigma_{III} = 0.49 \pm 0.01$ barn
$\sigma_{IV} = 0.33 \pm 0.01$ barn

160 GeV: 56% most central events in 5 classes (bins 0 to IV),
bin IV – 5%, bins III+IV – 12% of most central collisions

40 GeV: determination of classes close to that for 160 GeV

L. Šándor (NA57) : Strange baryon production …
Quantities under study

The double–differential \((y, m_T)\) distribution parametrised as

\[
\frac{d^2 N}{d m_T \, dy} = f(y) \, m_T \exp \left(- \frac{m_T}{T_{app}} \right)
\]

assuming \(f(y) = \text{const.}\) (flat rapidity distribution) in our acceptance region. \(T_{app}\) - inverse slope of the \(m_T\) distribution, free parameter of fit.

**Particle yield** (rapidity density at mid-rapidity \(y_0\)):

\[
Y = \frac{dN}{dy} \bigg|_{y=y_0} = \int_m^\infty dm_T \int_{y_0-0.5}^{y_0+0.5} \frac{d^2 N}{dm_T \, dy} \, dy
\]

**Enhancement**:

\[
E = \left( \frac{Y}{\langle N_{\text{wound}} \rangle_{Pb-Pb}} \right) / \left( \frac{Y}{\langle N_{\text{wound}} \rangle_{p-Be}} \right)
\]

Particle yields and transverse mass spectra studied as a function of collision centrality, dividing data into 5 aforementioned classes with

\[
\langle N_{\text{wound}} \rangle = 62 \pm 4, 121 \pm 4, 209 \pm 3, 290 \pm 2, 349 \pm 1.
\]
NA57 strangeness enhancements

160 A GeV/c data

Significant centrality dependence of strangeness enhancement for all particles except for $\Lambda$. Knowledge of yields in most peripheral class 0 essential. Saturation – possibly for two most central bins ($\approx 10\%$).
Energy dependence of hyperon yields

Yields calculated for 42% most central Pb–Pb collisions (classes I–IV).
Black bars - systematic errors

Going from 40 to 160 $A$ GeV/$c$:

- particle yields for $\Lambda$ and $\Xi^-$ similar, increased by a factor 3 for $\Omega^-$
- antiparticle yields increased by factors from 5 to 7

Indication for larger baryon density at 40 $A$ GeV/$c$
Energy dependence of $\bar{Y}/Y$ ratios

STAR 130 GeV data from: J. Adams et al., nucl-ex/0211024 (submitted to Phys.Lett.B) and references therein

Centrality: 5% for $\Lambda$, $\simeq 10\%$ for $\Xi, \Omega$

$\Rightarrow$ anti-hyperon/hyperon ratios increase with energy
$\Rightarrow$ energy dependence weaker for particle with higher strangeness

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$m_T$ spectra of hyperons

Pb–Pb data at 160 $A$ GeV/$c$, full centrality region

Shapes close to single exponential, similar slopes for all hyperons

<table>
<thead>
<tr>
<th>particle</th>
<th>$\Lambda$</th>
<th>$\bar{\Lambda}$</th>
<th>$\Xi^-$</th>
<th>$\Xi^+$</th>
<th>$\Omega^-$</th>
<th>$\bar{\Omega}^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{app}$ (MeV)</td>
<td>$289 \pm 7$</td>
<td>$287 \pm 9$</td>
<td>$297 \pm 5$</td>
<td>$316 \pm 11$</td>
<td>$264 \pm 19$</td>
<td>$284 \pm 28$</td>
</tr>
</tbody>
</table>

Agreement within error limits with WA97 results
Centrality dependence of $m_T$ spectra

Weak centrality dependence of inverse slopes for all hyperons

L. Šándor (NA57): Strange baryon production...
Blast-wave analysis of $m_T$ spectra

In the framework of model based on thermalization and hydro-dynamical transverse flow description (E. Schnedermann, J. Sollfrank and U. Heinz, Phys. Rev. C48 (1993) 2462) the transverse mass spectrum of the hadron with mass $m_i$ can be approximated as:

$$\frac{dN_i}{m_T \, dm_T} \propto m_T \int_0^R r \, dr K_1 \left( \frac{m_T \cosh \rho}{T} \right) I_0 \left( \frac{p_T \sinh \rho}{T} \right).$$

The fit of $m_T$ spectra to the above function allows to disentangle the thermal freeze-out temperature $T$ and the transverse flow velocity $\beta_{\perp}$. Here $R$ is the transverse system size, $K_1$ and $I_0$ - the modified Bessel functions, $\rho = \text{atanh} \, \beta_{\perp}$ is a transverse boost,

$$\beta_{\perp} = \beta_S \left( \frac{r}{R} \right)^n, \quad \langle \beta_{\perp} \rangle = \frac{2}{2 + n} \beta_S.$$

Assumptions: kinetic freeze-out of matter at constant temperature $T$, cylindrically symmetric and longitudinally boost invariant fluid expansion
Blast-wave fit to NA57 data

Results of global fits to all strange particle spectra measured in the full accessible centrality range using different velocity profiles:

<table>
<thead>
<tr>
<th>Profile</th>
<th>n = 0</th>
<th>n = 0.5</th>
<th>n = 1</th>
<th>n = 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T$ (MeV)</td>
<td>158 ± 6</td>
<td>152 ± 6</td>
<td>144 ± 7</td>
<td>151 ± 11</td>
</tr>
<tr>
<td>$\langle \beta_\perp \rangle$</td>
<td>0.396 ± 0.015</td>
<td>0.394 ± 0.013</td>
<td>0.381 ± 0.013</td>
<td>0.316 ± 0.014</td>
</tr>
<tr>
<td>$\beta_S$</td>
<td>0.396 ± 0.015</td>
<td>0.493 ± 0.016</td>
<td>0.571 ± 0.019</td>
<td>0.633 ± 0.028</td>
</tr>
<tr>
<td>$\chi^2/ndf$</td>
<td>39.6 / 48</td>
<td>36.9 / 48</td>
<td>37.2 / 48</td>
<td>68.0 / 48</td>
</tr>
</tbody>
</table>

Separate fits for particles sharing at least one quark in common with the nucleons and for those which do not (using n = 1):

<table>
<thead>
<tr>
<th>Particles</th>
<th>$T$ (MeV)</th>
<th>$\langle \beta_\perp \rangle$</th>
<th>$\chi^2/ndf$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^0, \Lambda, \Xi^-$</td>
<td>146 ± 8</td>
<td>0.376 ± 0.015</td>
<td>18.1 / 23</td>
</tr>
<tr>
<td>$\Lambda, \Xi^+, \Omega^-, \Omega^+$</td>
<td>130 ± 28</td>
<td>0.403 ± 0.032</td>
<td>18.5 / 23</td>
</tr>
</tbody>
</table>

Fits suggest similar freeze-out conditions for the two groups.

Systematic errors of $T$ and $\beta_\perp$ are estimated to be about 10% and 3%, respectively.
Global fit to NA57 data with n = 1 profile

Common description for all strange particles satisfactory. Separate fits to individual particle spectra result in $T$ and $\langle \beta_\perp \rangle$ values which do not differ more than two standard deviations from the common scenario.
The $1\sigma$ confidence level contours in ($\langle \beta_\perp \rangle - T$) plane from fits to data samples for individual centrality classes ($n = 1$)

The suggested trend: increase of $\langle \beta_\perp \rangle$ and decrease of $T$ with increasing collision centrality
### Freeze-out parameters at SPS and RHIC

Results of fits to central NA57 160 A GeV and RHIC 130 GeV data (n = 1)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>centrality (%)</th>
<th>particles</th>
<th>$T$</th>
<th>$\beta_S$</th>
<th>$\chi^2/ndf$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA57</td>
<td>0-5</td>
<td>all strange</td>
<td>118 $\pm$ 13</td>
<td>0.67 $\pm$ 0.03</td>
<td>52.7 / 43</td>
</tr>
<tr>
<td>NA57</td>
<td>5-12</td>
<td>all strange</td>
<td>135 $\pm$ 14</td>
<td>0.62 $\pm$ 0.03</td>
<td>31.8 / 41</td>
</tr>
<tr>
<td>PHENIX</td>
<td>0-5</td>
<td>$\pi,K,p$</td>
<td>121 ± 4</td>
<td>0.70 ± 0.01</td>
<td>34.0 / 40</td>
</tr>
<tr>
<td>STAR</td>
<td>0-10</td>
<td>$\pi,K,p,\Lambda$</td>
<td>$\simeq$ 100</td>
<td>$\simeq$ 0.81</td>
<td></td>
</tr>
<tr>
<td>STAR</td>
<td>0-10</td>
<td>$\Xi,\Omega$</td>
<td>$\simeq$ 150</td>
<td>$\simeq$ 0.64</td>
<td></td>
</tr>
</tbody>
</table>

PHENIX data: nucl-ex/0307010

Preliminary STAR results (fig.)
from talk by Javier Castillo at
SQM2003 (Atlantic Beach, USA)
Different freeze-out scenario
for $\pi,K,p,\Lambda$ and multi-stranges?
Conclusions

Strangeness enhancements at 160 $A$ GeV/$c$:
- NA57 data confirm the enhancements and their hierarchy found by WA97
- significant centrality dependence of strangeness enhancement observed for all strange baryons except for $\Lambda$.

Energy dependence of hyperon yields:
- different behaviour of particles and anti-particles observed, indicating larger baryon density at lower energy

Transverse mass spectra at 160 $A$ GeV/$c$:
- inverse slopes of particle and anti-particle are the same within error limits for all hyperons
- blast-wave model with linear velocity profile describes satisfactorily the spectra of all strange particles by common freeze-out parameters $T, \beta_S$
- indication for centrality dependence of freeze-out parameters found
- evidence for the similarity of freeze-out conditions at SPS and RHIC energies