Λ, Ξ and Ω production at mid-rapidity in Pb-Pb and p-Pb collisions at 158 A GeV/c

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Abstract. Λ, Ξ and Ω yields and transverse mass spectra measured at central rapidity in Pb-Pb and p-Pb collisions at 158 A GeV/c are presented. The yields in Pb-Pb interactions are given as a function of the collision centrality and compared with those obtained from p-Pb collisions. The dependence of hyperon yields on the centrality of the impact and on the strangeness content of the hyperon are discussed.

1. Introduction

In collisions of heavy nuclei at relativistic energies nuclear matter is compressed and significantly excited. In such extreme conditions novel physical phenomena can arise, and it is believed that the quarks confined in hadrons can "dissolve", forming a macroscopic space time region filled with free quarks and gluons: the quark gluon plasma state of matter (QGP).

One of the sensitive signatures for a phase transition to a QGP state is the enhanced yield of strange particles in nucleus-nucleus reactions with respect to proton-nucleus interactions [1]. It is expected, in particular, that the enhancement should be more pronounced for multi-strange baryons and especially anti-baryons, since hadronic production of such particles is strongly suppressed due to high mass thresholds [2].

Three heavy ion experiments dedicated to the study of strangeness production were performed at the CERN Omega spectrometer: WA85, WA94 and WA97. The WA85 and WA94 experiments utilised the 200 A GeV/c SPS sulphur beam. WA85 investigated strangeness production in S-W and p-W collisions, whereas WA94 studied S-S and p-S interactions. Both experiments showed evidence for enhanced production of Λ ($|S| = 1$) and Ξ ($|S| = 2$) in nucleus-nucleus with respect to proton-nucleus collisions [3, 4]. The WA97 experiment has extended this study to the heavier Pb-Pb system using the 158 A GeV/c SPS lead beam and has allowed the measurement of the rare Ω ($|S| = 3$) signal.

2. The WA97 experiment

The WA97 experiment is designed to study strange particle production at central rapidity in Pb-Pb, p-Pb and p-Be collisions as a function of the strangeness content of the particles and of the number of nucleons taking part in the collisions.

The WA97 set-up is shown schematically in fig. 2. The 158 A GeV/c lead beam from the CERN SPS was incident on a 1% interaction length lead target. An 8% interaction length target was used for the p-Pb run.

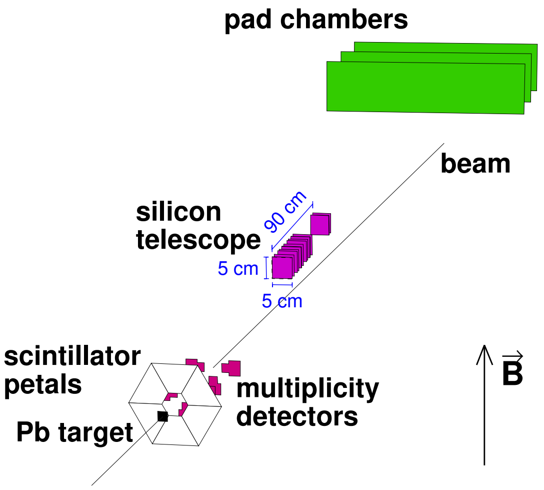

Figure 1. The WA97 set-up.

Scintillator petal detectors behind the target provided an interaction trigger selecting the most central ($\sim$ 40%) Pb-Pb collisions. Two planes of microstrip multiplicity detectors, covering the pseudorapidity region $2 \leq \eta \leq 3$ and $3 \leq \eta \leq 4$ respectively, provided information for detailed off-line study of the centrality dependence of particle ratios and spectra.

The silicon telescope was the WA97 tracking device, consisting of 7 planes of silicon pixel detectors with pixel size 75×500 μm^2, and of 10 planes of silicon microstrips with a 50 μm pitch [5]. The telescope had $5{\times}5$ cm^2 cross section and contained $\approx 0.5{\times}10^6$ channels. It was placed 60 cm downstream from the target (90 cm for the p-Pb reference run) slightly above the beam line and inclined so as to point to the target, in order to accept particles at central rapidity and medium transverse momentum.

The target and the silicon telescope were placed inside the homogeneous 1.8 T magnetic field provided by the CERN Omega magnet. Three MWPC's with a cathode pad readout (pad chambers), placed immediately outside the magnet, improved the momentum resolution of fast tracks.

In the proton reference run at 158 GeV/c the protons were selected using two Cherenkov CEDAR detectors [6] and a trigger was applied to select events with at least two tracks in the telescope, as required to find V^0s.

3. Analysis of the signals

The Λ, Ξ^-, Ω^- hyperons and their antiparticles were identified by reconstructing their decays into final states containing only charged particles:

$$
\begin{array}{lll}
\Lambda & \rightarrow & \mathrm{p} + \pi^- \\[1ex]
\Xi^- & \rightarrow & \Lambda + \pi^- \\
 & & \hookrightarrow \mathrm{p} + \pi^- \qquad\qquad + \ c.\ c. \\[1ex]
\Omega^- & \rightarrow & \Lambda + \mathrm{K}^- \\
 & & \hookrightarrow \mathrm{p} + \pi^-
\end{array}
$$

The hyperon signals were obtained using particle specific identification criteria based on geometric and kinematic constraints, as discussed in [7]. The resulting invariant mass spectra show very clear peaks with a resolution of about 2 MeV and negligible backgound.

The data have not been corrected for feed-down from cascade to Λ. In the geometry of our experiment the feed-down for weak decays is expected to be of minor importance. It is estimated to be less than 5% for Λs and less than 10% for $\overline{\Lambda}$s in the Pb-Pb configuration.

Each reconstructed Λ, Ξ and Ω has then been corrected for geometrical acceptance and reconstruction efficiency using the following method:

- Monte Carlo particles were generated and traced through the apparatus by GEANT [8] with the tranverse momentum, rapidity and position of the primary vertex measured for each observed particle;
- background tracks and electronic noise were simulated by embedding the hits of the Monte Carlo tracks into a real event. Detector efficiencies, measured for every read-out chip of the pixel planes, were taken into account;

- the mixed events were processed by the same analysis programs as were used for real data and a weight was calculated as the ratio of the number of generated Monte Carlo particles to the number selected by the analysis programs.

Up to now only a fraction of the available data sample on tape has been fully corrected for acceptance and reconstruction losses. The results presented here are based on the analysis of two data samples taken in Pb-Pb (200 million events) and p-Pb (120 million events) interactions. Table 1 shows the hyperon samples used for the present analysis and the expected increase in statistics after processing and correcting all collected data. Present statistics are twice those presented in [9] and [10].

Table 1. Hyperon statistics used in the present analysis and expected increase in the statistics after processing all available data.

	p-Pb		Pb-Pb	
Particle	Present	Expected	Present	Expected
Ω^-	15	–	145	$\times 2.5$
$\overline{\Omega}^+$	4	–	58	$\times 2.5$
Ξ^-	275	–	1346	$\times 2.5$
$\overline{\Xi}^+$	101	–	339	$\times 2.5$
Λ	1056	$\times 100$	1868	$\times 350$
$\overline{\Lambda}$	243	$\times 100$	669	$\times 150$

The acceptance windows for Λ, Ξ and Ω from Pb-Pb and p-Pb collisions are shown in fig. 2.

4. Results

The momentum spectra $d^2N/dm_{\mathrm{T}}dy$ of hyperons were fitted in their respective acceptance windows using the expression

$$\frac{d^2N}{dm_{\mathrm{T}}dy} = f(y)\, m_T^{\alpha}\, \exp\left(-\frac{m_T}{T}\right) \tag{1}$$

where $m_T = \sqrt{p_T^2 + m^2}$ is the transverse mass, T is the inverse slope parameter and α is an exponent discussed below.

The fit was performed using the method of maximum likelihood. For the present analysis with limited statistics we have assumed the rapidity distributions to be flat in the considered interval (about one unit of rapidity around mid-rapidity) i.e. $f(y) = constant$ in expression (1). This assumption can introduce systematic errors, expecially in the case of Λ produced in p-Pb collisions, whose rapidity distribution shows a strong backward peak. The systematic errors can be estimated from existing data for p-Au collisions [11]. It is found that using a flat rapidity distribution instead of one obtained from an exponential fit to the data of [11] gives a difference of less than 10% on the inverse slope parameter and less than 7% on the extrapolated yield in the case of Λ from p-Pb collisions.

4.1. Transverse mass distributions

Transverse mass distributions have been fitted using expression (1), where the values $\alpha = \frac{3}{2}$ and $\alpha = 1$ [12] were used, in order to facilitate the comparison with other

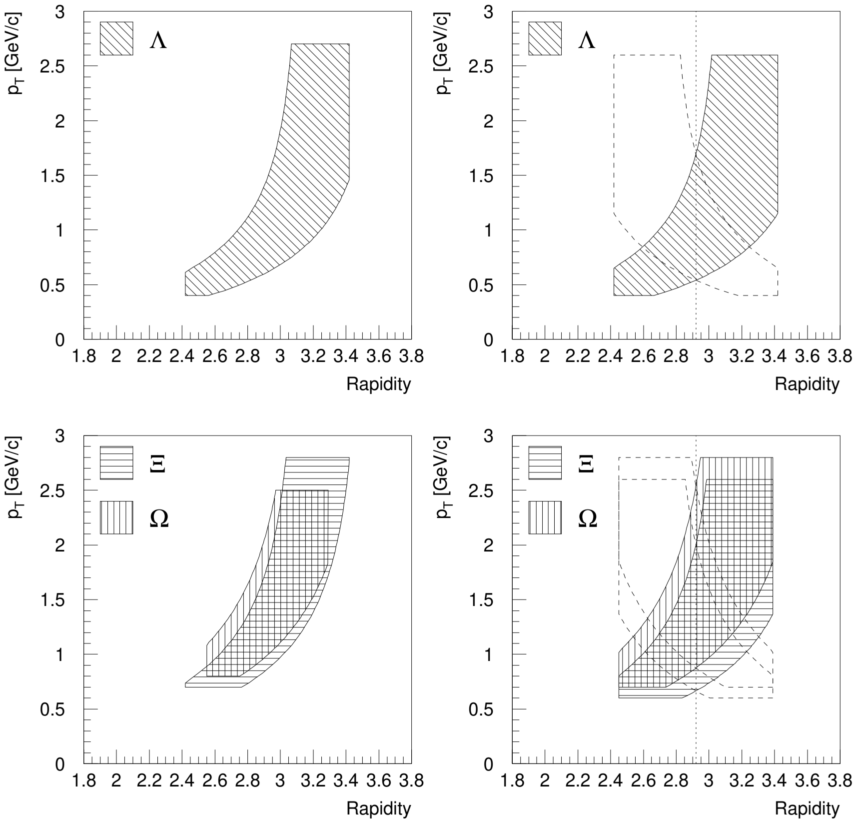

Figure 2. Acceptance windows for Λ, Ξ and Ω hyperons for p-Pb (left) and Pb-Pb (right) interactions. For Pb-Pb collisions, the symmetry of the system allows to symmetrize the acceptance windows by reflection around y_{cm}. The reflected windows are drawn as dashed lines.

experiments. The inverse slope parameters T for Λ, Ξ and Ω measured in p-Pb and Pb-Pb collisions are given in Table 2. Quoted errors are statistical only; data on Ω^- and $\overline{\Omega}^+$ were considered due to the limited statistics.

Table 2. Inverse m_T slope parameters T in MeV for Pb-Pb and p-Pb interactions.

	p-Pb		Pb-Pb	
Particle(s)	$\alpha = 3/2$	$\alpha = 1$	$\alpha = 3/2$	$\alpha = 1$
Λ	184± 5	196± 6	266± 7	289± 8
$\overline{\Lambda}$	172± 10	183±11	264± 11	287±13
Ξ^-	222± 12	235±14	266± 8	286± 9
$\overline{\Xi}^+$	211± 19	224±21	265± 15	284±17
$\Omega^-+\overline{\Omega}^+$	312± 86	334±99	238± 17	251±19

The inverse slope parameter increases from p-Pb to Pb-Pb for Λ and Ξ; the large error on T for p-Pb precludes firm conclusions for the Ω inverse slope.

In fig. 3 the inverse slope parameters for Λ and Ξ and their antiparticles are compared with previous WA85 [13] and WA94 [14] results. As a common feature, the inverse slope parameters have similar values for proton induced reactions, while they show a clear increase with the size of the collision system for nucleus-nucleus reactions.

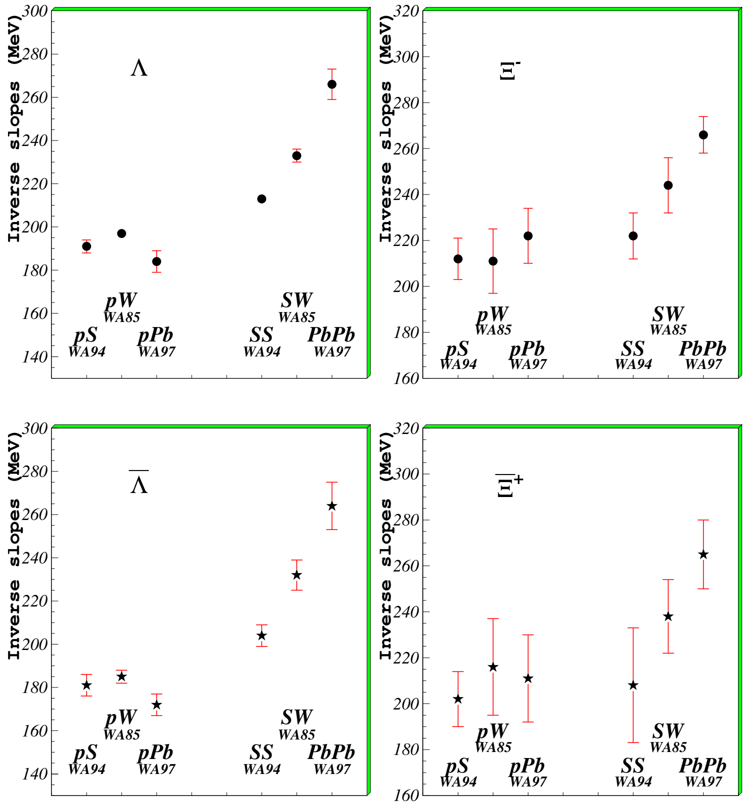

Figure 3. Inverse slopes of Λ, Ξ^-, $\overline{\Lambda}$ and $\overline{\Xi}^+$ for different colliding systems. The $\alpha = \frac{3}{2}$ value has been used.

Furthermore, in fig. 4, the inverse slope parameters for different hadrons in the Pb-Pb system are shown as a function of their mass. The present results on Λ, Ξ and Ω are superimposed on recent results from the NA49 experiment [15]. It can be noted that strange and multi-strange baryons deviate from the steady increase of the parameter T with the particle mass.

4.2. Particle ratios

To obtain particle yields in a well defined kinematic region, they were extrapolated to the common window $|y - y_{cm}| < 0.5$ and $p_{\mathrm{T}} > 0$ GeV/c according to expression (1), where y_{cm} is the centre-of-mass rapidity for the nucleon-nucleon system. The resulting particle ratios for Pb-Pb collisions are given in table 3. Quoted errors are statistical only and do not include systematics from feed-down or from the assumption of a flat rapidity distribution in our acceptance window. These extrapolated ratios are fully

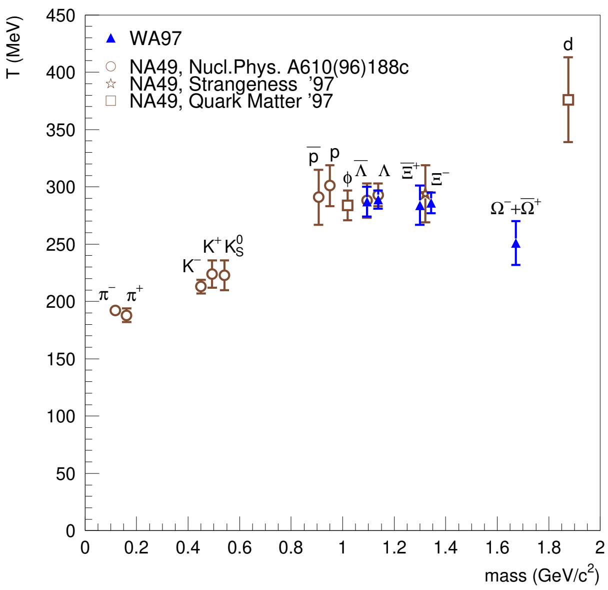

Figure 4. Dependence of inverse slope parameter T versus the particle mass. The $\alpha = 1$ value has been used.

compatible with those calculated in the overlap of the acceptance windows of Λ, Ξ and Ω in Pb-Pb collisions, shown in fig 2.

4.3. Hyperon yields

Hyperon yields were calculated as a function of the centrality of the collision. As a measure of the centrality we used the number of participant nucleons. From the multiplicity detector measurements we estimated the number of participants in the collision using a Glauber model for Pb-Pb interactions, together with the assumption of proportionality between the number of participants and the multiplicity. The two multiplicity detector stations provide independent measurements of the number of participants which allows us to estimate the detector resolution. In fig. 5 the model calculation, modified to account for the multiplicity detector resolution, is compared with the experimental multiplicity distribution.

For multiplicities above 400 the model gives an excellent description of the multiplicity spectrum with only one free parameter, which fixes the proportionality between the charged particle multiplicity and the number of participants. To obtain the hyperon yields in Pb-Pb as a function of the number of participants, the multiplicity spectrum is divided into four bins (fig. 5), and in each bin the average number of participants is calculated from the model. In bin I, where the trigger selection introduces a discrepancy with the model, the average number of participants is estimated by weighting the multiplicities with the ratio of the measured multiplicity to the Glauber calculation. The above analysis is done in analogy with that presented in ref. [17]. For p-Pb interactions, the estimated number of participants corresponds to minimum bias collisions.

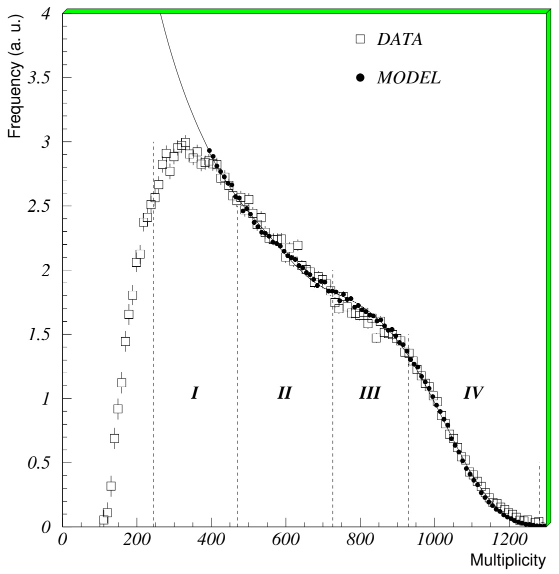

Figure 5. Charged particle multiplicity spectrum (squares) compared with a Glauber model calculation (line).

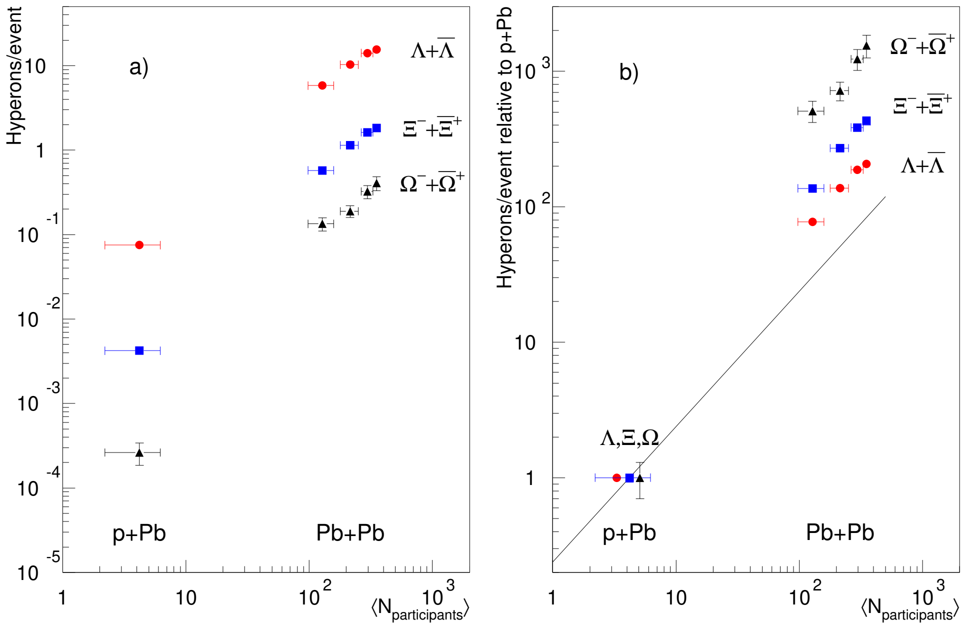

Figure 6. a) Λ, Ξ and Ω yields as a function of the number of participants. b) Yields as a function of the number of participants expressed in units of yields observed in p-Pb collisions. The line refers to a yield proportional to the number of participants.

Table 3. Particle ratios in Pb-Pb collisions in the window $|y - y_{cm}| < 0.5$ and $p_{\mathrm{T}} > 0$ GeV/c.

Ratio	Pb-Pb
$\frac{\Omega^-}{\Xi^-}$	0.182 ± 0.022
$\frac{\overline{\Omega}^+}{\overline{\Xi}^+}$	0.281 ± 0.053
$\frac{\Omega^- + \overline{\Omega}^+}{\Xi^- + \overline{\Xi}^+}$	0.202 ± 0.021
$\frac{\Xi^-}{\Lambda}$	0.100 ± 0.004
$\frac{\overline{\Xi}^+}{\overline{\Lambda}}$	0.188 ± 0.016
$\frac{\Xi^- + \overline{\Xi}^+}{\Lambda + \overline{\Lambda}}$	0.110 ± 0.004
$\frac{\overline{\Lambda}}{\Lambda}$	0.133 ± 0.007
$\frac{\overline{\Xi}^+}{\Xi^-}$	0.249 ± 0.019
$\frac{\overline{\Omega}^+}{\Omega^-}$	0.383 ± 0.081

Fig. 6a shows the Λ, Ξ and Ω yields per event for p-Pb and Pb-Pb interactions as a function of the number of participants. Yields are extrapolated to the window $|y - y_{cm}| < 0.5$ and $p_{\mathrm{T}} > 0$ GeV/c according to expression (1) and the effect of the two tracks trigger in the p-Pb sample has been taken into account. All hyperon yields show a steady increase with centrality, from p-Pb to very central Pb-Pb collisions. In fig. 6b the hyperon yields are presented, rescaled so that each value for p-Pb is set to one. The hyperon yields, expressed in units of the corresponding yields per p-Pb interactions, are then compared to a yield curve (full line) proportional to the number of participants, drawn through the p-Pb common point. It is observed that the Λ, Ξ and Ω yields increase with centrality from p-Pb to Pb-Pb interactions faster than the number of participants. The Ω yield, for example, increases by one order of magnitude with respect to what can be expected from simple scaling with the number of participants. Moreover, this increase is greater for Ω than for Ξ and for Ξ than for Λ, so that the enhancement increases with the strangeness content of the hyperon. The observed enhancement is not an effect of the extrapolation to the full $y - p_T$ window, since it is still present if the yields are calculated in the overlap windows between Pb-Pb and p-Pb acceptances shown in fig. 2. A more detailed discussion of these results is given in [16], in which data on K^0_s and negatives are added.

5. Conclusions

An analysis of current results on Λ, Ξ and Ω production in Pb-Pb and p-Pb collisions has shown that inverse slope parameters for $\Lambda\,(\overline{\Lambda})$ and Ξ^- $(\overline{\Xi}^+)$ increase as a function of the size of the collision system. Moreover, multi-strange inverse slopes for the Pb-Pb collision system deviate from a linear increase with particle mass. In ref. [18] it is suggested that such linear increase would be a consequence of radial flow in nucleus-nucleus collisions.

We have also observed a strong increase in the production at mid-rapidity of Λ, Ξ and Ω hyperons and anti-hyperons in Pb-Pb collisions with respect to p-Pb collisions. This enhancement is more pronounced for multiply strange particles, and is one order of magnitude in the case of the Ω. The yields increase with centrality faster than the number of participants. However, is shown in [16], presented at this conference, that in the participant range $N_{part} > 100$, corresponding to our Pb-Pb data, all yields are found to increase linearly with N_{part}, thus suggesting that all the reported enhancements reach their maximum for values of N_{part} below 100 and then remain constant.

Two questions arise from these observations:

- How yields behave at lower values of N_{part}, i.e. are they smooth or is there a sudden change ?
- How does this pattern depend on the collision centre of mass energy ?

Both questions will be addressed by the forthcoming NA57 experiment [19].

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