JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin Laboratory of High Energy Physics

FINAL REPORT ON THE STUDENT PROGRAM

Selection of lambda hyperons

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Abstract

In the present report, we considered data on Au-Au collisions at the STAR detector at energies of 200 GeV and An algorithm for searching for particles decaying into pairs of oppositely charged pions and protons was constructed. Lambda hyperons were found by searching for invariant mass.

Contents

1 Introduction

Experiments with collisions of high-energy heavy ions make it possible to study the properties of nuclear matter. under extreme conditions and its transition from hadrons to the state of deconfinement quarks and gluons, called quark-gluon plasma. To analyze the properties of QGP, it is necessary to recognize particles by type.

1.1 STAR detector

One of the main RHIC detector complexes is the Solenoidal Tracker At RHIC (STAR). The STAR detector is designed to detect charged and neutral particles resulting from the interaction of relativistic heavy ions. The scheme of the STAR detector complex is shown in fig. 1.

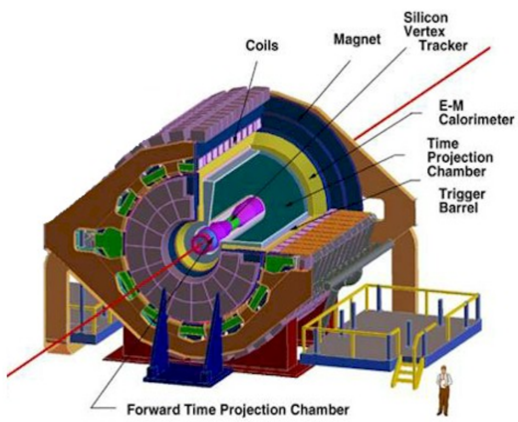

Figure 1: The scheme of the STAR detector complex

To reconstruct the trajectories of secondary hadrons formed as a result of a collision, the core of the STAR detector complex, the TPC (Time Projection Chamber) fig. 2, is used. The time projection camera is a combination of drift and proportional cameras. When charged particles fly through the volume, they ionize the gas, forming ionization clusters, each with 1 to 5 electrons. Thus, the track of a relativistic charged particle crossing the chamber volume consists of a chain of such clusters.

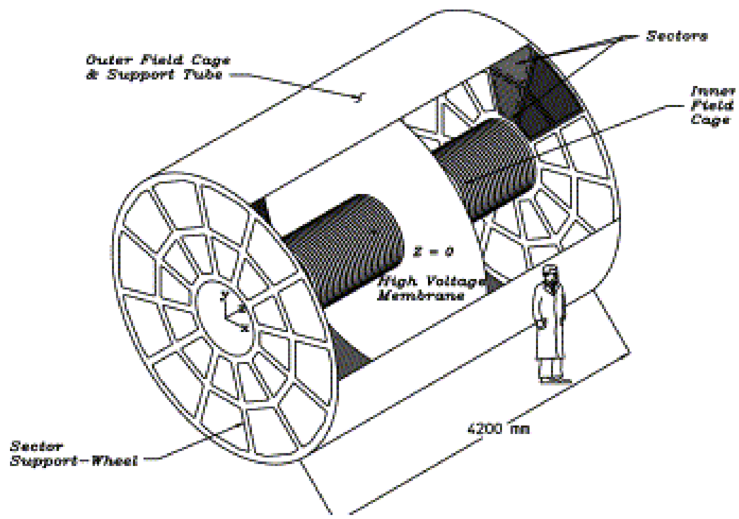

Figure 2: STAR time projection chamber

Particle identification capabilities have been increased by using the camera's Time-of-flight (TOF) detector. A cylindrical segmented TOF detector surrounds the TPC. Identification occurs with the help of time-of-flight information, i.e. the time between the occurrence of an event and the particle hitting a certain segment of the TOF system. The track information from the TPC makes it possible to determine the momentum of the particle and the length of the trajectory from the point of interaction to the point of registration. Thus, for each track, the speed is determined by the length of the trajectory and the time of its flight, and, knowing the momentum, the mass is determined. This makes it possible to carry out identification in a noticeably larger range of pulses than with only one time-projection camera.

1.2 V0 candidates

During the collision, particles are formed that the detectors do not directly register, but we can see traces of their decay. V0's : those particles (Λ, K_s^0) decay into two particles $(\Lambda \longrightarrow p\pi^-, K_s^0 \longrightarrow \pi^+\pi^-)$.

According to the parameters of a pair of tracks, the expected trajectories in the form of a helix are built, then the distance at which these helices are closest to each other is checked. The expected point of decay of V0 will be the point between the helices.

Also it is important that the tracks are not primary, i.e., located at some distance from the primary vertex. The condition that the particles fly in the same direction is verified by the scalar product of the vectors of the total momentum of two particles at the point of the minimum distance between the tracks by the vector directed from the primary vertex to decay point V0.

The decay length L is determined by constructing a segment connecting the points of the decay site V0 of the candidate and the position where the distances between the primary vertex and the line extended from the vector of the total momentum of the decay particles. The fig. 3 schematically shows the required parameters V0 of the candidate.

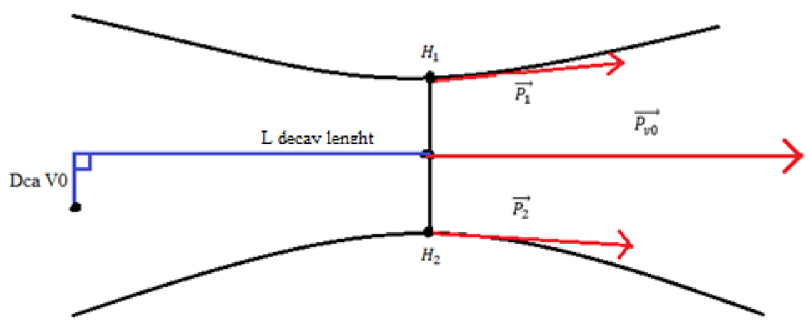

Figure 3: V0 candidate

2 Main results of the practice

In this work we focus on the Au + Au collisions at energy 200 GeV. The point at which the Au-Au beams collided is called the primary vertex, its position is an important parameter, since events that occurred at a great distance are poorly displayed in the detector, or do not fall into its working area at all.

Particles with a weak momentum are also not suitable for analysis, because their trajectories are twisted in the detector and it is impossible to single out particles of secondary decays from them. Also, the particle must have enough hits in the detector. Conditions [3] presented in fig. 4 were applied to the selection of events and tracks.

Cut	Particle
DCA of 0 to primary vertex XY	< 2 cm
DCA of 0 to primary vertex Z	< |38| cm
DCA p	> 0,2 GeV
nHits	> 15
nHits / nProbablyHits	> 0,52

Figure 4: Criteria for selecting events and tracks

The histograms of the distribution of the position of the primary vertex in the XY and Z axes are shown in fig 5 and 6.

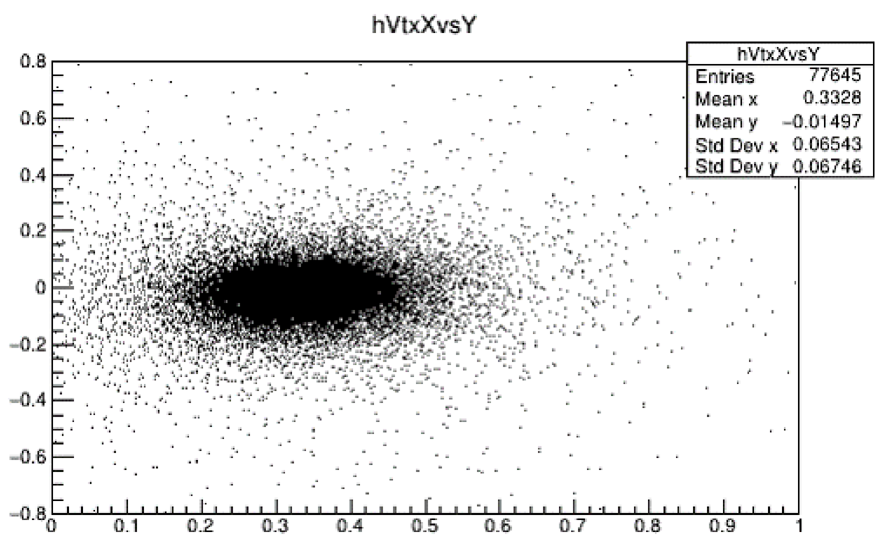

Figure 5: Two-dimensional histogram of the distribution of the position of the primary vertex in the XY axes

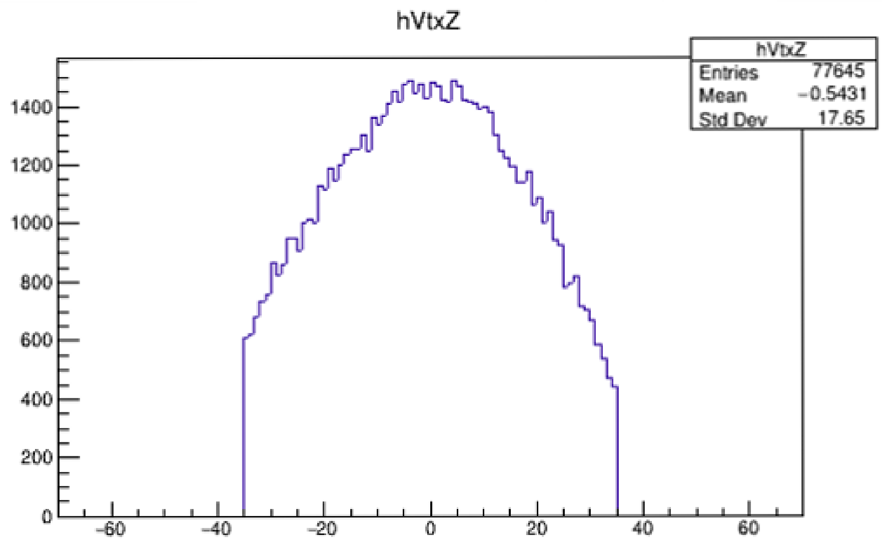

Figure 6: histogram of the distribution of the position of the primary vertex on the axis Z

2.1 Particle identification

For further analysis and selection of lambda hyperons, it is necessary to distinguish particles by type. For this, ionization losses are used. According to the two-dimensional histogram of the distribution of ionization losses depending on the momentum of the particle fig. 7, using the Beta-Bloch formula [1], the lines belonging to electrons, pions, kaons and protons are selected.

$$-\left(\frac{dT}{dx}\right) = \frac{4\pi n_e z^2 e^4}{m_e u^2}\left(ln\frac{2m_e u^2}{I} - ln(1-\beta^2) - \beta^2 - \delta - U\right) [1]$$

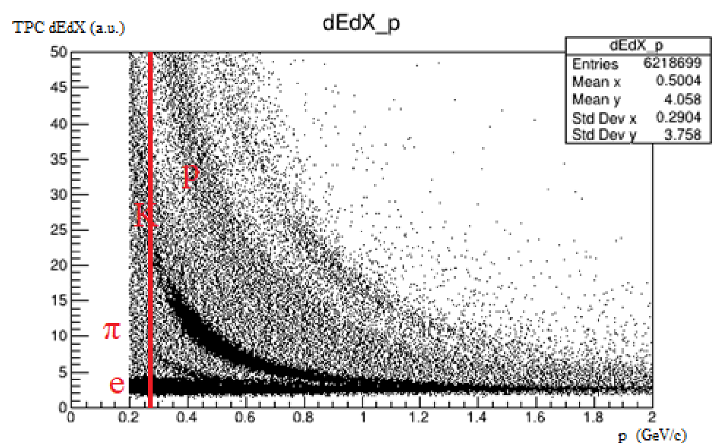

Figure 7: Two-dimensional histograms of the ionization losses of particles depending on the momentum with projection line fig. 8.

In order to determine the type of particle with an accuracy of $n\sigma$, the histogram is cut into a projection of 50 MeV and approximated by a multi-gaussian function fig. 8.

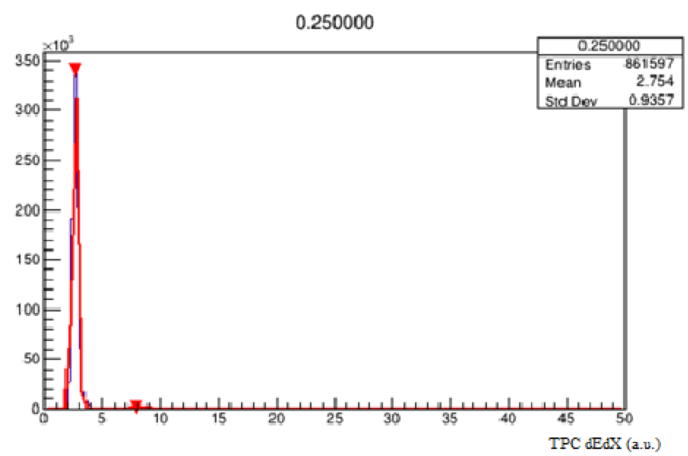

Figure 8: Projection of a two-dimensional histogram onto the Y-axis in the range from 25 to 30 MeV

The figure shows that several peaks stand out, the first belongs to electrons, the second to pions. The same is done with the data from the TOF detector. After extracting the B particle from the detector, 1/B distribution is plotted depending on the momentum of the particle 9. The histogram shows the lines belonging to the particles.

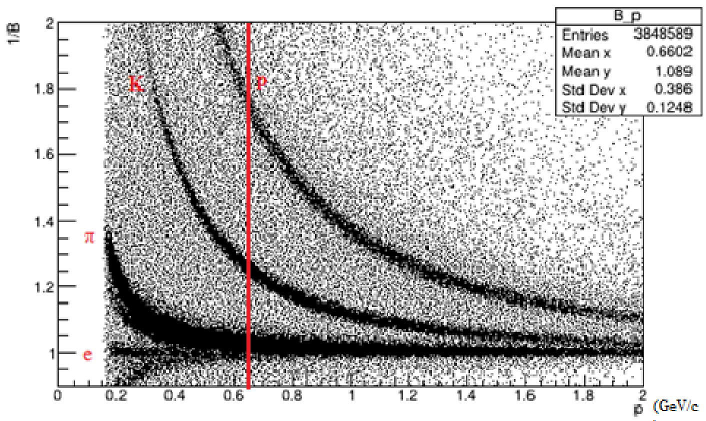

Figure 9: Two-dimensional histogram of the distribution of 1/B taken from the TOF depending on the momentum with projection line fig. 10

In fig. 10 peak lines belonging to pions, kaons and protons are visible.

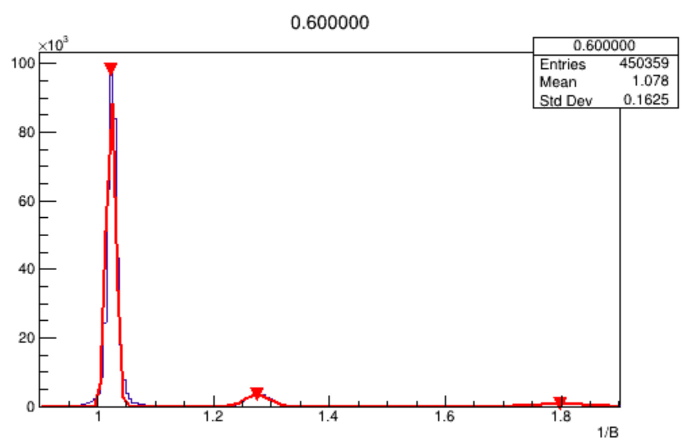

Figure 10: Projection of a two-dimensional histogram onto the Y-axis in the range from 60 to 65 MeV

2.2 V0 and Λ identification

In addition to determining the type of particles, an important step in the selection of Λ is the correct selection of V0 candidates. By changing the range of selected values of the decay length, the distance between the track helices, DCA V0 to the primary peak, the optimal conditions for the selection of V0 candidates were selected, the following cuts are selected fig. 11 [4].

Cut	Λ
DCA of V0 to primary vertex	< 0,8 cm
DCA of daughters to primary vertex	> 1 cm
DCA between daughters	< 1,5 cm
V 0 decay length	> 3 cm
$(\vec{r}_{V0} - \vec{r}_{PV}) \cdot \vec{p}_{V0}$	> 0

Figure 11: Criteria for selecting V0

In order to single out lambda hyperons from V0 candidates, pairs of pion-proton were selected. After selection, the invariant mass is found by the formula:

$$M_{inv}^2 = (E_p + E_n)^2 - (\overrightarrow{p_p} + \overrightarrow{p_n})^2$$

The constructed distribution of the invariant mass is shown in fig. 12.

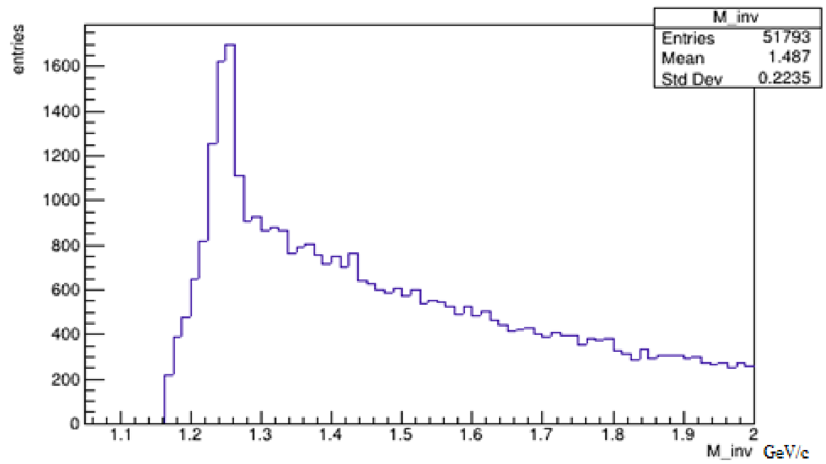

Figure 12: Histogram of invariant mass distribution

Noise is removed to clearly highlight the peak. To do this, V0 candidates from different events are selected and their invariant mass is also calculated. The constructed distribution of the invariant masses of mixed events in fig. 13.

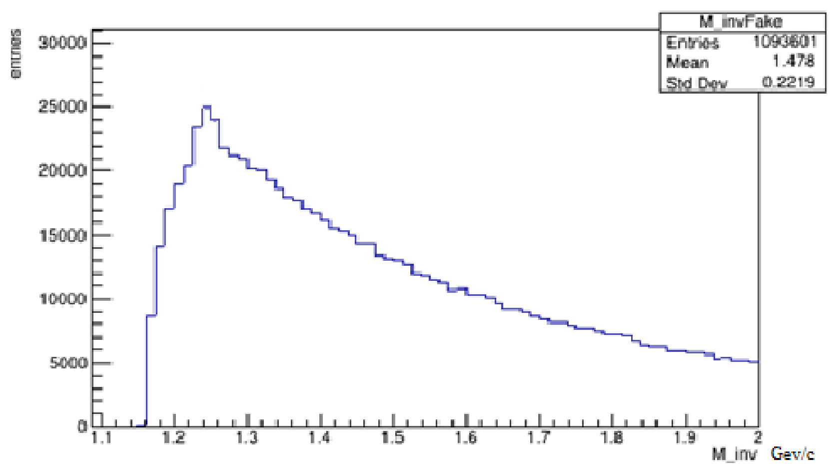

Figure 13: Histogram of invariant mass of mixed eventы distribution

Comparing the histograms, it can be seen that the lambda hyperon peak is clearly visible.

3 Summary

In this paper, the distributions of the yields of charged particles of various types in Au-Au collisions on the STAR detector at energies 200 GeV were analyzed. An algorithm for searching for V0 candidates was written and the distributions of invariant masses for protons and pions determined with an accuracy of no more than 2nσ were constructed.

- An algorithm was built to search for lambda hyperons .
- Histograms of the distribution of invariant masses for protons and pions from one event and mixed ones were constructed.

4 Acknowledgment

I would like to express my gratitude to the committee of JINR Student Program for giving me an opportunity to try myself in such amazing event. I would like to thank my supervisors Artem A. Korobitsin, Alexey A. Aparin for their support, patient attitude and proposed phenomena for investigation, which turned out to be interesting.

References

[1] THE EUROPEAN PHYSICAL JOURNAL C. Particles and Fields. Zietschrift fur Physik C v.15, No.1-4, 2000. Springer.

[2] https://www.star.bnl.gov/

[3] STAR Collaboration, "Measurement of interaction between antiprotons", nature15724 (2015)

[4] STAR Collaboration, "Strange hadron production in Au+Au collisions at sNN=7.7, 11.5, 19.6, 27, and 39 GeV", physrevc.102.034909 (2020)