DIRAC note 10-08

Determination of the ratio between proton-antiproton pairs and $\pi^+\pi^-$ pairs in DIRAC experimental data

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December 6, 2010

Abstract

In this paper is presented the measurement of the ratio between $p\bar{p}$ and $\pi^+\pi^-$ pairs. Determination of this ratio is important for $\pi^+\pi^-$-atoms-lifetime measurement and for checking prediction of models. Data, which were analysed, were taken in 2001 on nickel targets.

1 Introduction

The lifetime τ of the $\pi^+\pi^-$ atom $A_{2\pi}$ is related to relevant scattering length $1/\tau \sim |a_0 - a_2|^2$. The lifetime of the ground state is predicted by ChPT to be $\tau = (2.9 \pm 0.1) \cdot 10^{-15}$s[2].

The direct measurement of $A_{2\pi}$ lifetime is due to its very small value practically impossible. Therefore an indirect method based on the determination of $A_{2\pi}$ breakup probability P_{br} is used.

A value of the brake-up probability established from DIRAC experiment includes statistic and systematic errors. One of sources of systematic error is a presence of unrecognised $p\bar{p}$ pairs which fulfilled all selection criteria. These $p\bar{p}$ pairs evoke decreasing of the brake-up probability. The abundance of $p\bar{p}$ pairs among $\pi^+\pi^-$ pairs is estimated to be around 0.15%. In this work we analyse data from year 2001 to find out the real abundance of these pairs which is important for knowing the right affect of $p\bar{p}$ pairs to the brake-up probability.

2 DIRAC experimental setup

2.1 General layout description

DIRAC detector is designed like a double-arm spectrometer with the main task to detect close $\pi^+\pi^-$ (or $K^-\pi^+$ or $K^+\pi^-$) pairs with high resolution. The DIRAC apparatus, as mentioned above, consists of a target station, a secondary vacuum channel, a spectrometer magnet and detectors which are placed upstream and downstream of the magnet.

The secondary particle channel is positioned at an angle 5.7° upwards with respect to the primary beam. The horizontal and vertical acceptance of the channel is $\pm 1°$. The upstream part consists of the following detectors : Microstrip gas chamber (MSGC), Scintillating fibre detector (SFD) and Ionization Hodoscopes (IH). The downstream part splits into two identical arms for the detection and identification of positive and negative secondary particles. The angle between the arms is $2 \times 19°$. There are Drift chambers (DC), Vertical and Horizontal hodoscopes (VH and HH), Cherenkov counters (CH), Preshower detector (PSH) and Muon counters (MU) (Figure 1) along each arm.

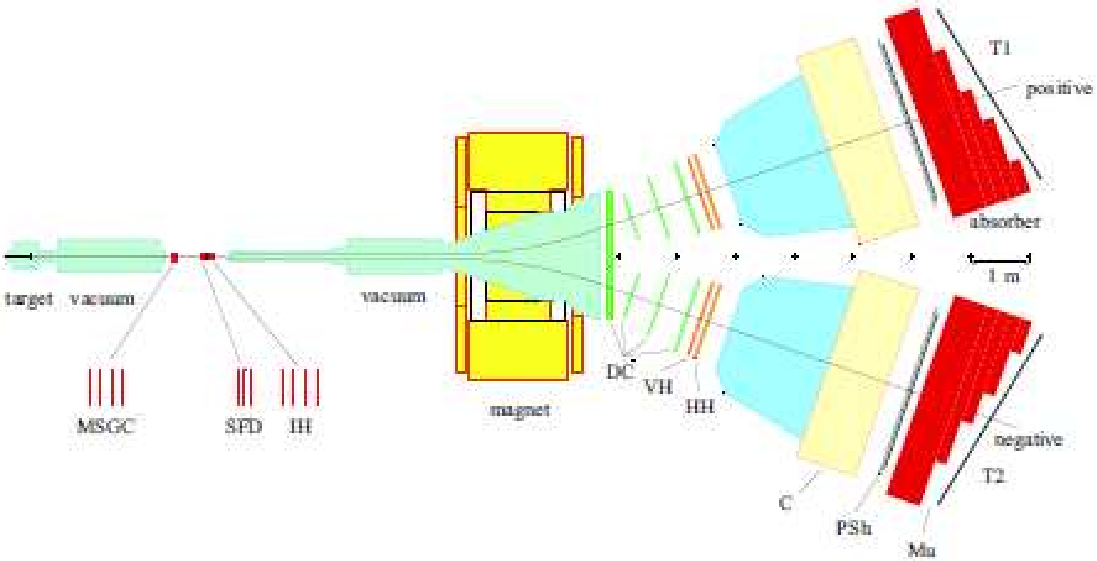

Figure 1: Top view of the setup. Detectors: Microstrip Gas Chambers (MSGC), Scintillating Fiber Detector (SFD), Ionization Hodoscope (IH), Magnet, Drift Chambers (DC), Vertical Hodoscopes (VH), Horizontal Hodoscopes (HH), Cherenkov detectors (C, or CH), Preshower detectors (PSH) and Muon counters (Mu).

2.2 Proton beam and target station

Protons are extracted from PS to the T8 beam line in a slow extraction mode with the spill duration between 400 and 500ms. The intensity can be varied from 0.5×10^{11} to 3×10^{11} protons per spill. Nickel target data were measured in 2001 and at the time the beam intensity was about 1×10^{11}.

2.3 Detectors and Trigger

DIRAC detectors are divided to the upstream and downstream detectors. The upstream detectors are placed close to the target. The main task of upstream detectors is a precision measurement of close particle tracks with high detection rate and efficiency. MSGC, SFD and IH are used for improving the precision of the relative momenta of pairs, for TOF measurement and time resolution. SFD and MSGC are used in particle tracking and are essential to provide the coordinates of the effective beam position used in the momentum reconstruction. IH is used to identify the very closed two particle tracks.

The downstream detectors have several tasks: the measurement of space parameters of track behind magnet (DC), rejection of electrons, positrons and muons (CH, PS and MU), the fast triggering and the time measurement (Vertical and Horizontal Hodoscope - VH and HH).

The DIRAC experiment has a very sophisticated multilevel trigger which is used for coincidence between the positive and the negative arm.

In our data analysis we use information from SFD, IH and VH; therefore, a best description of these detectors is given below.

Scintillation fibre detector

The scintillation fibre detector is used for the tracking upstream of the magnet. The detector is placed at a distance of 2.95m from the target. It consists of 2 perpendicular planes (X and Y) separated by 2.5cm. Each plane has 240 channels. Since 2002 the third inclined U plane with 340 channels was added. The U plane is rotated with respect to the X axis by an angle of 45°. SFD covers an active area of $105 \times 105\text{mm}^2$.

Ionisation hodoscope The recognition of close tracks is crucial for the DIRAC experiment. The dedicated ionization hodoscope was built to separate single track hits from double close-lying tracks by take to account their ionization energy losses.

It is placed at a distance of 3.05m from the target. The detector consists of two X and Y planes with a sensitive area of $110 \times 110\text{mm}^2$.

Vertical hodoscope The vertical hodoscope is designed to achieve a high resolution to be able to distinguish between the particle pairs from one primary proton interactions and the particles produced at two different primary interactions. Each of hodoscopes consists of 18 vertical scintillation slabs with dimensions 400mm×72.3mm and 20mm thick. Two VH (one per arm) are placed at a distance of 11.6m from the target and downstream of the DC system. Their sensitive area is $0.4 \times 1.3\text{m}^2$.

The VH single-hit detection efficiency was estimated to be 99.5% for the positive arm and 98.8% for the negative one. The intrinsic absolute time resolution per slab is around of 127ps[5].

3 Data cuts and conditions

Pairs of oppositely charged pions are identified by signal absent of CH and MU. Through the measurement of the time difference between VH signals of the two arms, time correlated (prompt) events can be distinguished from accidental events[4] (Figure 2). The three components of the relative momentum Q of two particles, transverse and longitudinal to the c.m. full momentum direction. The components Q_x, Q_y and Q_L are calculated for π^+ and π^- and all other particles combinations($\pi^- p, \pi^+ \bar{p}, p\bar{p}$) are rejected. If it was not possible, they were analysed as π^+ and π^-.

The following cuts and conditions are applied[4]:

- at least one track candidate per arm with a confidence level better than 1% and a distance to the beam spot in the target smaller than 1.5 cm in x and y;
- prompt events are defined by the time difference Δt of VH in the two arms of $|\Delta t| \leq 0.5$ ns;
- accidental events are defined by time intervals $-15 \leq \Delta t \leq -5$ns and $7 \leq \Delta t \leq 17$ns, determined by the read-out features of SFD (time dependent merging of adjacent hits) and exclusion of correlated πp pairs (the corresponding graph is in Figure 2);
- $\mu^{\pm}$ are rejected by appropriate cuts on the MU information;
- only events with two preselected hits per SFD plane are accepted. This provides the cleanest possible event pattern;
- at least hits in two planes of IH for each track and two separated hits in SFD are demanded;
- for TOF measurements, pairs with Q_x and Q_y less then 4 MeV/c are rejected to make unique identification of positive and negative tracks (i.e. region of atomic signal is not analysed);
- criterion on Q_L is not used in preliminary stage of selection.

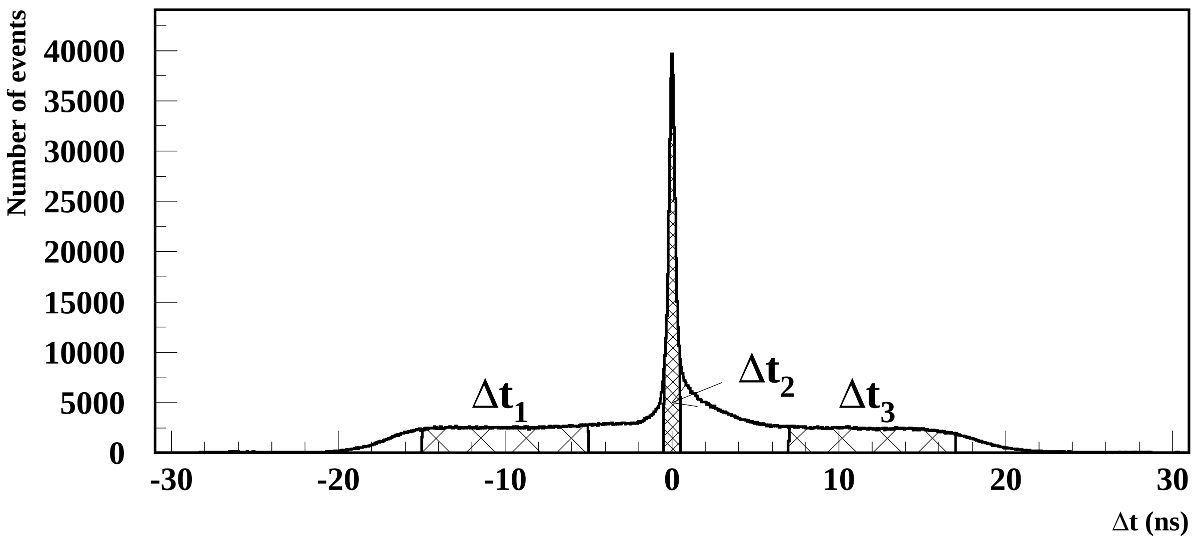

Figure 2: Time difference for the particle pairs measured by the vertical hodoscope planes in the positive and negative arms of the spectrometer with old electronics. The resolution of the vertical hodoscope moves from 175 till 193 ps. Δt_2 area corresponds to the prompt events signal with background and the tail on the right side of the peak is due to the π^-p pairs.

4 Total number of $p\bar{p}$ pairs

This section estimates a number of $p\bar{p}$ pairs in the analysed data. The analysis is based on a data separation into discrete momenta intervals and is done for each momentum interval separately. This is due to the fact that the difference between measured proton-, antiproton-, π^+- and π^--time depends on momenta(the higher momentum, the more are protons(antiprotons) close to $\pi^+(\pi^-)$).

For this analysis the momentum interval $p = (1600, 2600)$MeV/c was selected. It is not possible to analyse higher momenta in data collected in 2001, because for these higher momenta the proton peak (the antiproton peak) has very large overlap with the π^+ peak (the π^- peak). The momentum interval, where we made the analysis, was divided into 5 intervals with a width of 200MeV/c.

4.1 The used variables

For each event the following information is available:

- momentum of positive and negative particle ,
- measured time by Vertical Hodoscope (using mean-timer), by all planes of Scintillation Fiber Detector and Ionisation Hodoscope (using amplitude correlations) for the positive and the negative particle ,
- a length of track from the target to the plane of Vertical Hodoscope ,
- an angle of upstream track for negative and positive particle.

The momentum of particles and trajectory is known with very high precision. Therefore, if we know the mass of particles, is also exactly determined velocity of particles.

Because Scifi and IH are close together, it is essential to use their average time. This average time is calculated for each 200MeV/c momentum interval separately and used time resolution (trigger-plane resolution) of each plane of Scifi and IH in this appropriate momentum interval and distance between these planes. This time is related to the fourth plane of IH.

The time resolutions of individual planes are determined from RMS values. Some of results are mentioned in Table 1. It is evident that higher momentum means worse time resolution.

Mom. interval [MeV/c]	**SCIFI**				**IH**							
	positive		**negative**		**positive**				**negative**			
	1	**2**	**1**	**2**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1600-1800	706	762	707	742	712	903	658	668	714	907	649	663
1800-2000	718	786	712	758	722	918	660	677	718	914	657	663
2000-2200	735	790	717	758	736	947	666	679	712	916	660	673
2200-2400	744	808	717	761	749	981	680	683	715	926	657	673
2400-2600	762	806	715	761	781	1037	698	702	712	929	659	674

Table 1: RMS values in *ps* for individual momenta intervals and detector planes.

Now we establish new variables:

- $T_{\pi/P,-/+}$, *time difference between expected and measured time of flight in case of pion or proton between Vertical Hodoscope and the average time from upstream detectors (SFD and IH). The first index means the kind of particle (π-pion and P-proton) and the second one means the charge ($-$ negative and $+$ positive).*
- $\Delta t_\pi(\Delta t_P)$, *a difference between outgoing time from the target for positive and negative particle in case those particles are π^+(proton) and π^-(antiproton).*
- Length1(2), *a length of track from the target(upstream detectors) to the plane of Vertical Hodoscope.*

In Figures 3, 4, 5, 6 we can see histograms of $T_{\pi/P,-/+}$ for the whole momentum interval p=(1600,2600)MeV/c. In these histograms, anti/protons-, π^+- and π^--peak are obviously visible.

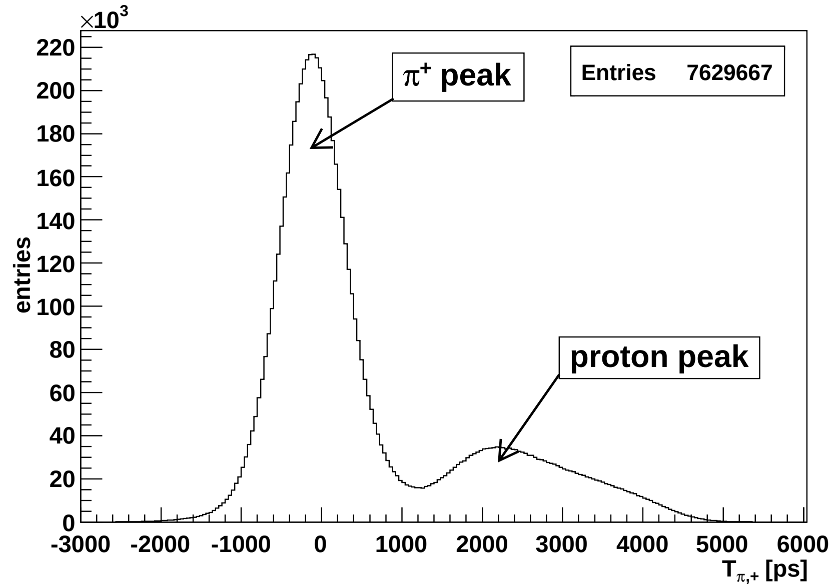

Figure 3: Distribution of dependence $T_{\pi,+}$ for a momentum interval of p=(1600,2600)MeV/c.

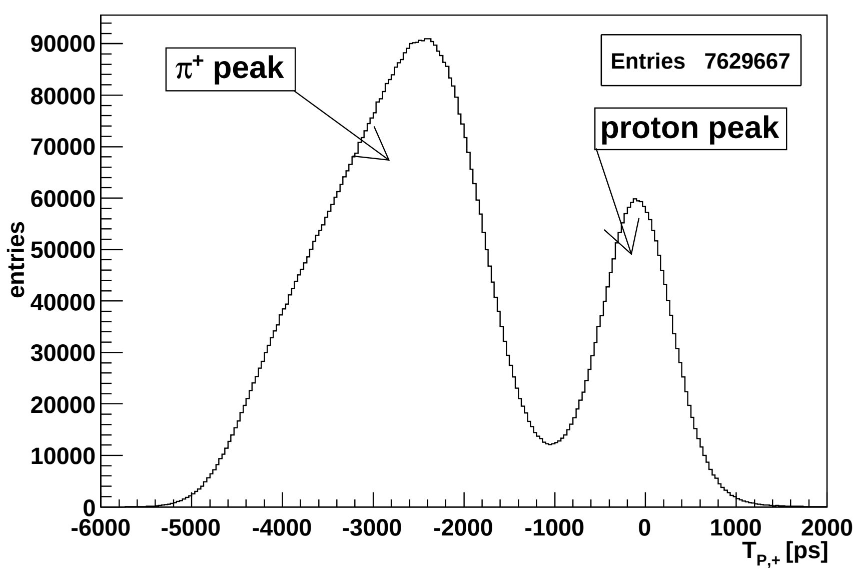

Figure 4: Distribution of dependence $T_{P,+}$ for a momentum interval of p=(1600,2600)MeV/c.

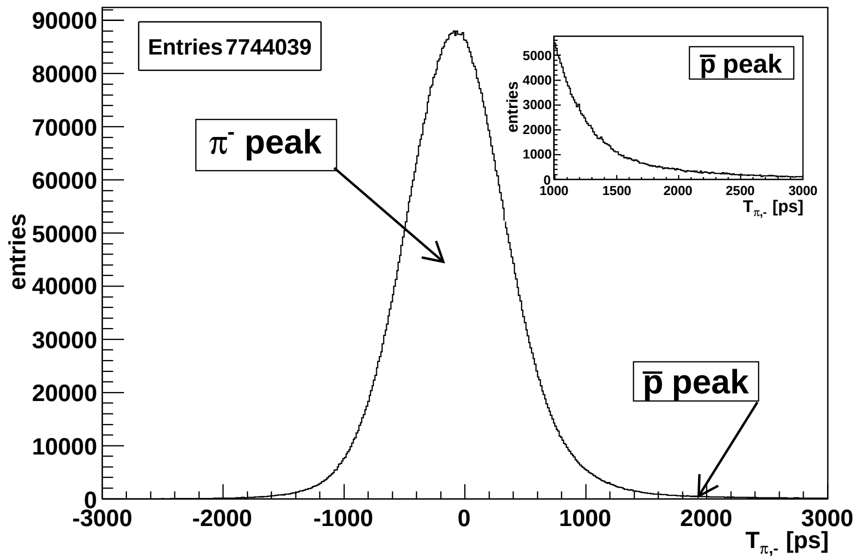

Figure 5: Distribution of dependence $T_{\pi,-}$ for a momentum interval of p=(1600,2600)MeV/c.

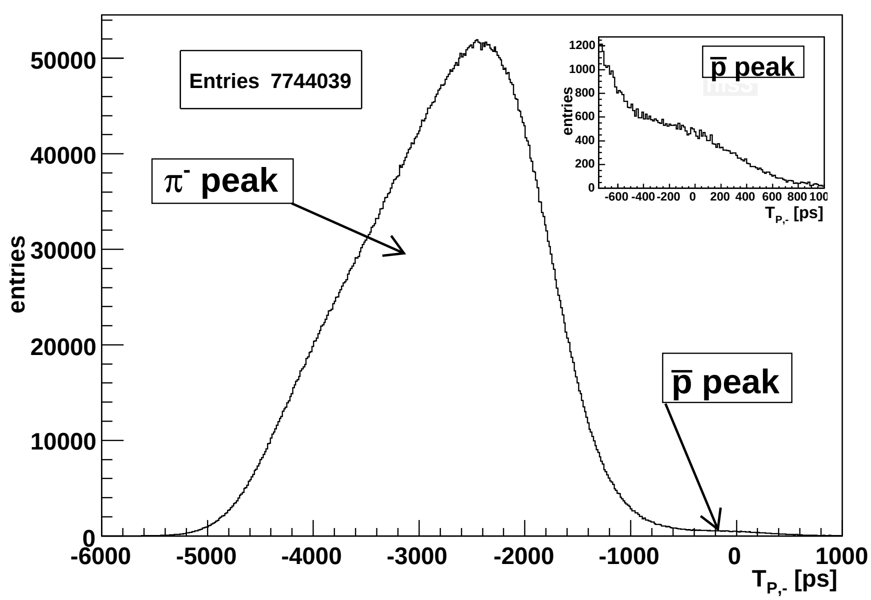

Figure 6: Distribution of dependence $T_{P,-}$ for a momentum interval of p=(1600,2600)MeV/c.

4.2 The main analysis

For investigation of $p\bar{p}$ pairs we used 2-dimensional histograms of dependence $T_{P,+}$ on $T_{P,-}$. Such histogram (for a momentum interval of p=(1600,1800)MeV/c) is shown in Figure 7. Four various zones are located here. The small upper right corresponds to $p\bar{p}$ pairs. The others are from the smallest till the largest $\pi^- p$ pairs, $\pi^+\bar{p}$ pairs and $\pi^-\pi^+$ pairs.

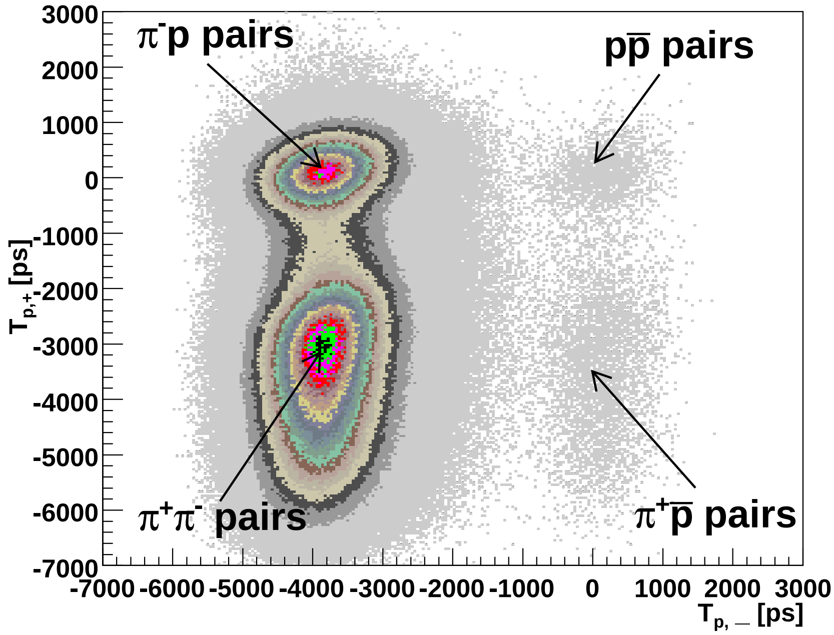

Figure 7: The distribution of dependence $T_{P,-}$ (time difference between measured and expected time of flight in case of protons between Vertical Hodoscope and upstream detectors for the negative arm) and $T_{P,+}$ (time difference between measured and expected time of flight in case of protons between Vertical Hodoscope and upstream detectors for the positive arm) for a momentum interval of p=(1600,1800)MeV/c with four various zones corresponding to different particles pairs.

To select only prompt [2] $p\bar{p}$ pairs, it is essential to apply some conditions. A condition $|\Delta t_P| <500$ ps (3σ) is used to determine number of prompt $p\bar{p}$ pairs in all measured data and a condition $|\Delta t_\pi| <500$ ps (also 3σ) is used to determine an admixture of prompt $p\bar{p}$ pairs in prompt $\pi^-\pi^+$ pairs.

The value 500 ps is used by reason that this is the value for the standard analysis of prompt $\pi^-\pi^+$ pairs in DIRAC experiment.

The statistic decreases and the shape of the distribution slightly transforms after applying this conditions as it is shown for a momentum interval of p=(1600,1800)MeV/c in Figures 8, 9.

[2] Prompt pairs are pairs which origin from the same proton nuclei collisions.

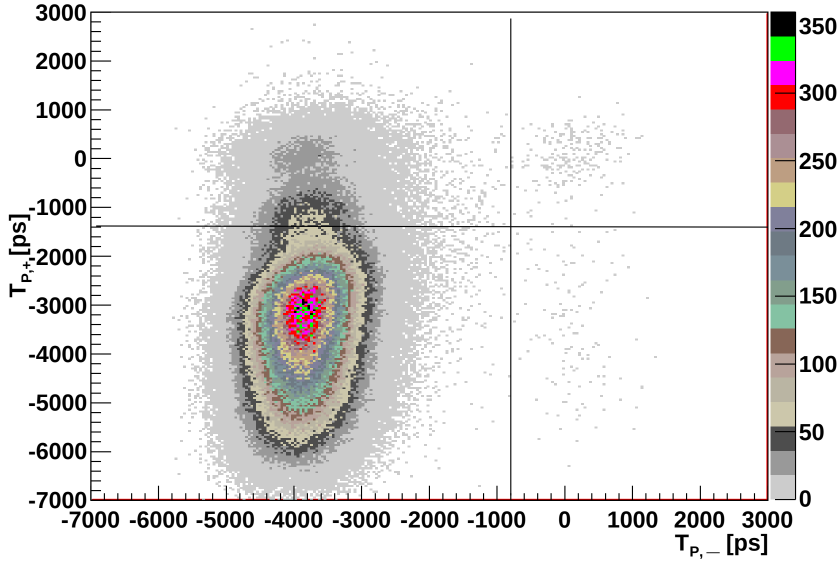

Figure 8: Distribution of dependence $T_{P,-}$ and $T_{P,+}$ for a momentum interval of p=(1600,1800)MeV/c with the condition $|\Delta t_\pi|$ <500ps and corresponding time cuts.

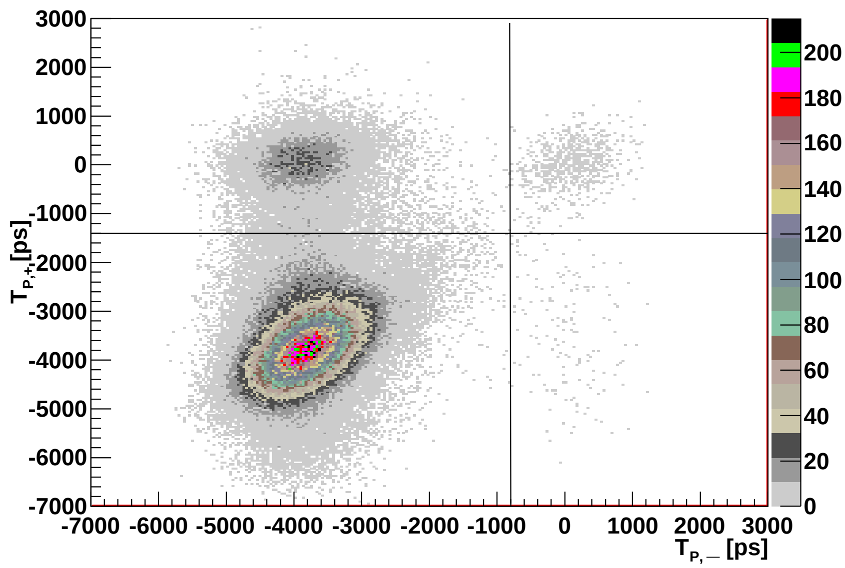

Figure 9: Distribution of dependence $T_{P,-}$ and $T_{P,+}$ for a momentum interval of p=(1600,1800)MeV/c with condition $|\Delta t_P|$ <500ps and corresponding time cuts.

The next step is selecting the area, where $p\bar{p}$ pairs are located, and calculating their total numbers with the help of time cuts. These time cuts are different for each momentum interval and are also drawn in Figures 8 and 9.

This procedure is made for each momentum interval and limitation of Δt_π or Δt_P separately. Results with corresponding cuts are mentioned in Table 2.

Momentum interval [MeV/c]	**cut1 [ps]**	**cut2 [ps]**	**entries1**	**entries2**
1600-1800	-800	-1400	253	790
1800-2000	-800	-1400	465	1254
2000-2200	-600	-1400	946	1834
2200-2400	-600	-1000	1597	2481
2400-2600	-500	-700	2216	2973

cut1 time limitation in the negative arm
cut2 time limitation in the positive arm
entries1 a number of $p\bar{p}$ pairs with condition $|\Delta t_\pi|$ <500ps
entries2 a number of $p\bar{p}$ pairs with condition $|\Delta t_P|$ <500ps

Table 2: Total number of $p\bar{p}$ pairs in individual momenta intervals with time cuts.

4.3 Systematic and statistic errors

Systematic errors in this analysis rise from time cuts in 2-dimensional histograms. Cuts in $T_{P,+}$ evoke that some protons are cut off and some π^+ are added, cuts in $T_{P,-}$ evoke that some antiprotons are cut off and some π^- are added.

Percent of cut off protons or antiprotons and percent of added π^+ or π^- are calculated with the help of 1-dimensional histograms (the projection of 2-dimensional histograms to x and y axes) for the positive and the negative arm with momenta intervals which correspond to $p\bar{p}$ pairs-intervals. An illustration of this method for momentum interval p=(2200,2400)MeV/c for the positive and the negative arm is shown in Figures 10 and 11.

In Figure 10 is the illustration of the calculation of the number of added π^+ and cut-off p. For the calculation of the number of added π^+, we assume the π^+ peak symmetry. By the Gauss function, we determine the mean of the π^+ peak. Then the left part of this peak is turned around the mean. The number of added π^+ is calculated from the turned part of the π^+ peak(the yellow curve) which lies beyond the time cut(the blue line). The procedure for finding the number of cut off protons is almost the same. By assumption of the proton peak symmetry and by using of the Gauss distribution, we found the mean of the proton peak. Now the right part of the proton peak is turned around the mean. The number of cut-off protons is calculated from the turned part of the proton peak(the black curve) which lies beyond the time cut(the blue line). We can not use for the analysis the right part of the π^+ peak and the left part of the proton peak, because this region includes an admixture of K^+ and there also exists the π^+ peak asymmetry.

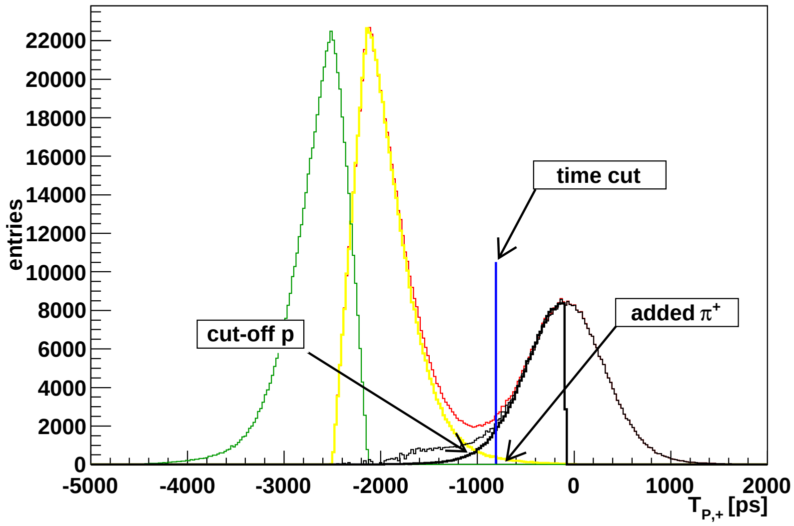

Figure 10: The illustration of the calculation of the number of added π^+ and cut-off p for momentum interval p=(2200,2400)MeV/c.

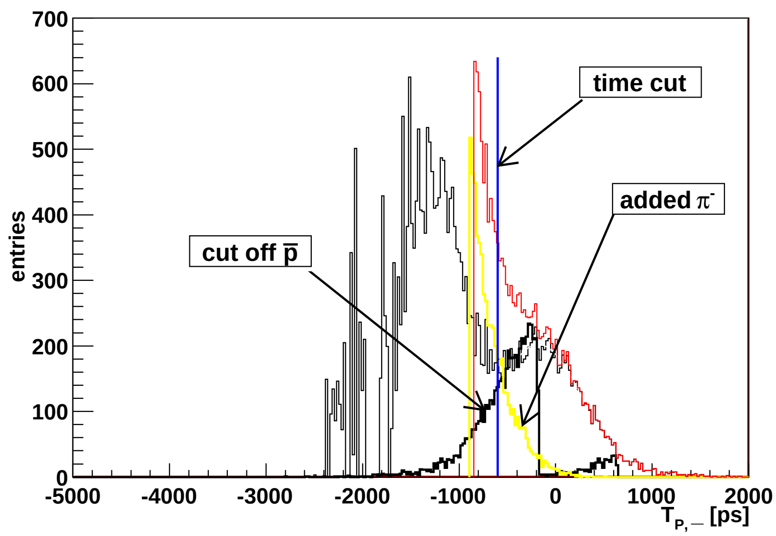

Figure 11: The illustration of the calculation of the number of added π^- and cut-off $\bar{p}$ for momentum interval p=(2200,2400)MeV/c.

In Figure 11 is shown the illustration of the calculation of the number of added π^- and cut off $\bar{p}$. The number of added π^- is calculated from part of π^- peak(the green curve) which occurs above the corresponding time cut(the blue curve) and the number of cut off $\bar{p}$ is calculated from the part of $\bar{p}$ peak(the black curve) which occurs below the corresponding time cut(the blue curve).

Percent of cut off protons or antiprotons and percent of added π^+ or π^- are calculated for each momentum interval. From these results are calculated corresponding percent of cut off $p\bar{p}$ pairs and percent of added other pairs (as $\pi^- p$ pairs, $\pi^+\bar{p}$ pairs or $\pi^+\pi^-$ pairs). It is done with the assumption that the production of positive and negative particles is independent, which is a good approximation. For the calculation a probability formula is applied for independent events.[3]. Statistic error is taken as the square root of total number of $p\bar{p}$ pairs in individual momenta intervals. Results are presented in Table 3 and Figure 12. Because in the first two momenta intervals are pion- and anti/proton-peak good separate, value of cut off and added pairs are zero.

Mom. intervals [MeV/c]	**entries1**	**sse1**	**ratio1** [%]	**entries2**	**sse2**	**ratio2** [%]	**added** [%]	**cut off** [%]
1600-1800	253	±16	0.04	790	±28	0.02	0.01	0.00
1800-2000	465	±22	0.06	1254	±35	0.03	0.00	0.00
2000-2200	946	±31	0.12	1834	±43	0.04	0.08	0.02
2200-2400	1597	±40	0.21	2481	±50	0.06	1.21	0.22
2400-2600	2216	±47	0.32	2973	±55	0.08	8.60	0.82
total	**5477**	**±74**	**0.15**	**9332**	**±97**	**0.05**		

entries1 a number of $p\bar{p}$ pairs with condition $|\Delta t_\pi| <$500ps
entries2 a number of $p\bar{p}$ pairs with condition $|\Delta t_P| <$500ps
sse1 standard statistic error for entries 1
sse2 standard statistic error for entries 2
ratio1 percent of $p\bar{p}$ pairs in $\pi^+\pi^-$ pairs
ratio2 percent of $p\bar{p}$ pairs in all pairs of appropriate interval
cut off percent of cut off $p\bar{p}$ pairs
added percent of added additional pairs

Table 3: Statistic and systematic errors of number of $p\bar{p}$ pairs in individual momenta intervals.

5 Conclusion

Data which were collected in 2001 on nickel targets were analysed in this work. We ascertain the admixture of $p\bar{p}$ pairs in $\pi^+\pi^-$ pairs and in all data.

For obtaining the number of $p\bar{p}$ pairs are applied 2-dimensional histograms where we combined together informations from the negative and positive arms. Time conditions in the negative

[3]If two events, A and B are independent then the joint probability is

$$P(A\,\text{and}\,B) = P(A \cap B) = P(A)P(B) \tag{1}$$

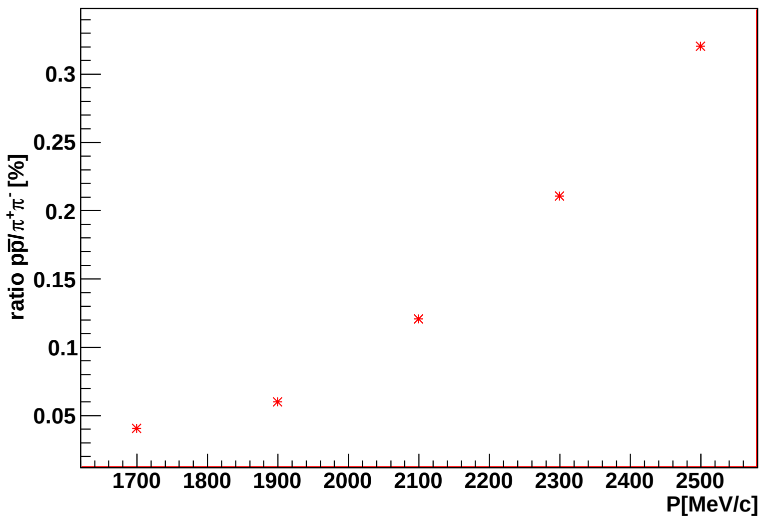

Figure 12: Ratio between $p\bar{p}$ pairs and $\pi^+\pi^-$ pairs depending on momentum.

and the positive arm and conditions of $\Delta t_{\pi,p}$ are used for separation the admixture of $p\bar{p}$ pairs in total number of pairs and the admixture of $p\bar{p}$ pairs in $\pi^+\pi^-$ pairs. Received results with errors are presented in Table 3.

Total number of $p\bar{p}$ pairs is about 9300 which is approximately 0.05% from total number of all pairs and total number of $p\bar{p}$ pairs in $\pi^+\pi^-$ pairs is about 5500 which is approximately 0.15%.

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