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Project "Thermalization"

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Project "Thermalization" is aimed at multiparticle production study in interactions of the beam energy protons E_{lab}=70 GeV of IHEP (Protvino) with hydrogen and nucleus targets in the region of high multiplicity: $n > 20$. The experiment is carried out on modernized installation SVD - a Spectrometer with Vertex Detector supplied with the trigger system to register rare high multiplicity events. The physical programme of the project and basic equipment are reported.

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1. Introduction

The multiparticle dynamics study at high energies is one of the fundamental problems of strong interactions physics. Different theoretical approaches to describe and explain a plenty of experimental phenomena are developed. The latest experiments on Quark-Gluon Plasma (QGP) search have shown the evidence of complicated problems emerged in the modern picture of hadron and nucleus interactions [1]. We consider that the study of multiparticle production (MP) in hadron and nucleus interactions at lower energies may help to solve these problems.

The purpose of the proposed experiment "*Thermalization*" [2] is to investigate the collective behavior of particles in the process of multiparticle production in proton or proton-nucleus interactions

$$p + p(A) \to n_\pi \pi + 2N \tag{1}$$

at the proton energy $E_{lab} = 70$ GeV. We use a modernized setup SVD-2 - Spectrometer with a Vertex Detector (SVD). It was constructed to study production and decay of charm particles, but has basic components necessary to perform the physical programme of the *Thermalization* project.

At present the multiplicity distribution at this energy is measured up to the number of charged particles $n_{ch} = 18$ ([3]-[4]). The kinematics limit is $n_{\pi,thr} = 69$. Here $n_{\pi,thr}$ is the

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maximum number of all charged and neutral pions allowed by the energy-momentum conservation. In the region of high multiplicity (HM) $n_{ch} > 20$ we expect [5]: formation of high density thermalized hadronic system, transition to pion condensate or cold QGP, increase of partial cross section $\sigma(n)$ is expected in comparison with the commonly accepted extrapolation and enhanced rate of direct soft photons. We will continue searching for new phenomena: Bose-Einstein condensate (BEC), events with ring topology (Cherenkov gluon radiation), pentaquarks. The available multiparticle production models and MC codes (PYTHIA) are distinguished considerably at the HM region. We also study the hadronization mechanism and related issues.

This review is organized as follows: section 2 presents a description of setup SVD-2, section 3 – explains the statement of alignment problem and gives the results, section 4 – informs about searching for a new state θ^{+} pentaquark. Section 5 summarizes all the above.

2. Experimental setup

2.1. Setup schematic

The physical programme determines parameters of the installation. The layout of the SVD installation at $U - 70$ accelerator is shown in Figure 1.

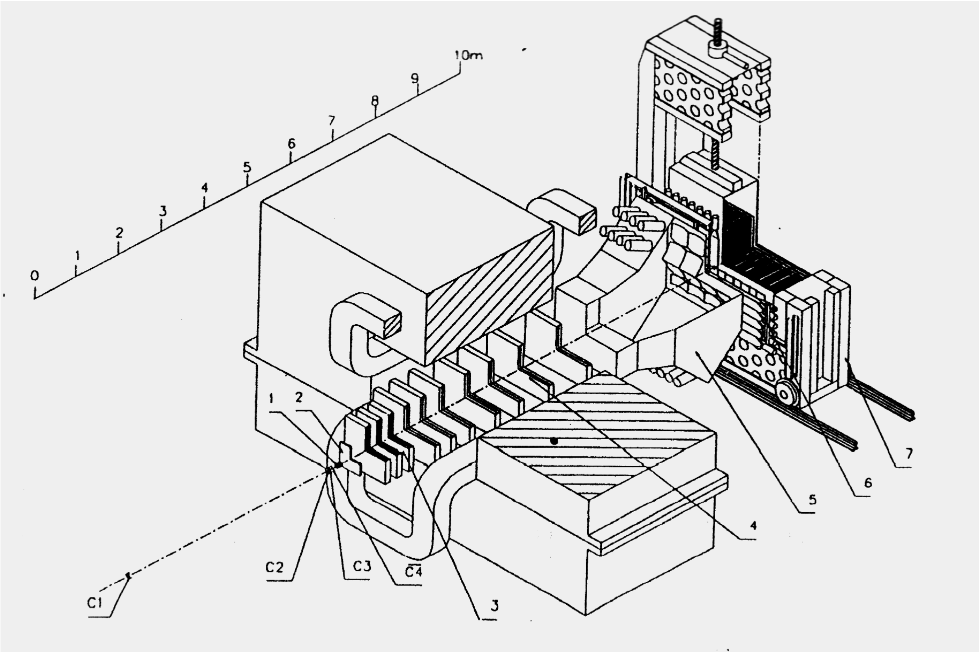

FIG. 1. Schematic of the SVD installation at U-70. C1,C2 - beam scintillation and Si-hodoscope; C3,C4 - target station and vertex Si-detector; 1, 2, 3 - the drift tubes track system; 4 - magnetic spectrometer proportional chambers; 5- threshold Cherenkov counter; 6 - scintillation hodoscope; 7 - electromagnetic calorimeter.

The basic requirements to the equipment consist in the following:
∗ The study is carried out on the extracted beam of protons with the energy of 70 GeV and intensity $\sim 10^7$ in a cycle of the accelerator.
∗ The liquid hydrogen target is used.
∗ Installation is capable to detect events with HM of charged particles and γ quanta. Multiplicity of photons makes up to ≤ 100. The lower energy threshold of the photon registration is 50 MeV.
∗ The HM trigger system selects rare events with multiplicity $n_\pi = 20 \div 30$. The suppression

factor of events with low multiplicity $n_\pi < 20$ is 10^4.
$\ast$ The magnetic spectrometer has the momentum resolution $\delta p/p \approx 1.5\%$ in the interval $p = 0.3 \div 5.0$ GeV/c. The VD schematic is shown in Figure 2. The generator was developed at the beginning of the experiment and subsequent data analysis. It is based on the assumption that in the HM region the particles in c.m.s. should have an isotropic angular distribution and their energy distribution is of the Maxwell or Bose-Einstein type [5].

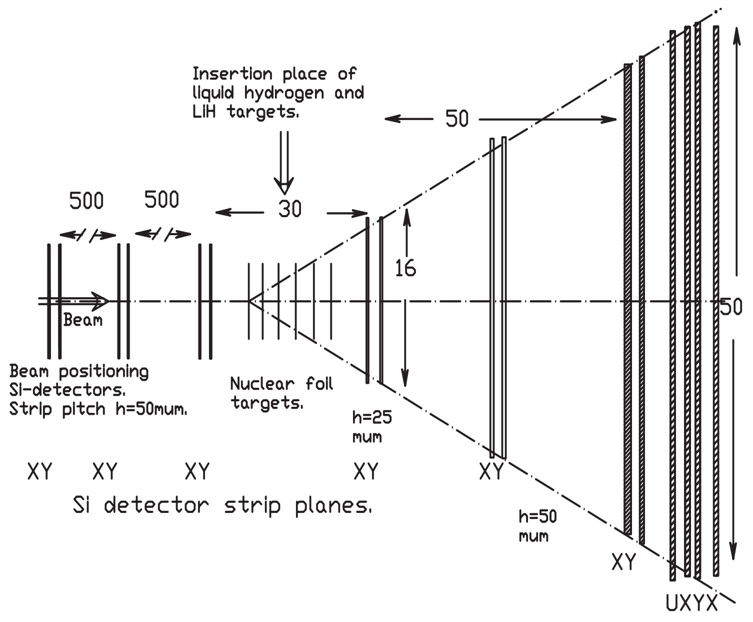

FIG. 2: The silicon vertex detector.

2.2. Liquid hydrogen target

For a target accommodation in the design of the installation there is a space along the beam of only 7 cm. The design and manufacture of the liquid hydrogen target is under the full JINR responsibility. A team under the leadership of L. Golovanov has a unique experience to develop a very reliable, easy maintained and low helium consuming. The target is the liquid hydrogen vessel and has 7 cm thick and 3.5 cm in diameter (Figure 3). The thermostat is equipped with thin (200 μm) lavsan windows to suppress background scattering. Successful tests of the

FIG. 3: Liquid hydrogen target.

whole target system have indicated to advanced reduction an helium consumption in which the resulting factor is expected at the order of 1.5.

2.3. Straw tube chambers

The straw tube chamber system is a new addition of the SVD setup. This detector has been designed at LPP of JINR (Figure 4). It implements front end boards with preamplifiers produced in Minsk (NC PHEP BSU) and TDC modules produced in Protvino (IHEP) allowing to detect several pulses, consequently coming from the anode on each trigger signal. Typical plane dimensions are 70 x 70 cm^2. The total number of channels is about 2400. In December 2004 and November 2005 the assembly of the straw tubes and readout system has been tested in U-70 beam. A resolution of 200 μm was found, efficiency was better than 99.9 % and some shortcomings were eliminated before the future to future November run, 2006. At beam intensity of 10^7 the trigger rate should be 100, less than the scattering rate in the target.

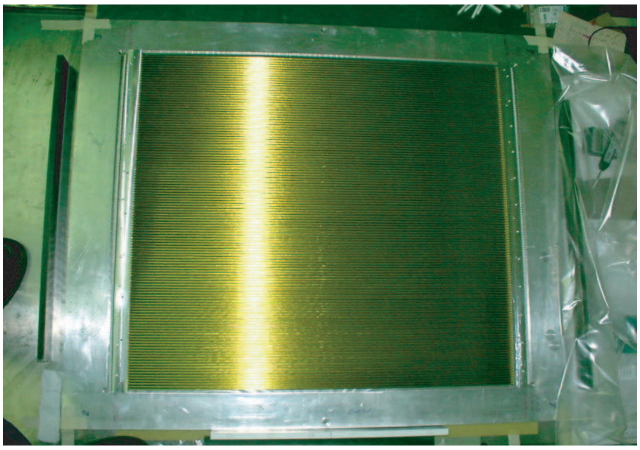

FIG. 4: Drift tube tracker.

2.4. HM trigger

Suppression of low multiplicity events by a trigger is an urgent request for our experiment. The slowest readout system of SVD (magnet spectrometer proportional chambers) takes only 150 events per second. For this purpose our collaboration had designed and manufactured a scintillation hodoscope (Figure 5) or HM trigger. It is expected to suppress interactions with track multiplicity below 20. Beyond this it should be thin not to distort an angular and momentum resolution of the setup to any kind of a fake signal. The scintillator counter array can operate at higher counting rate and be more resistant to many kinds of noise. Its schematic concept is shown in Figure 6, where TS is a trigger signal. The HM events registration is realized under the following conditions: the sum amplitude $A_\Sigma \geq n \times mip$. The detector was made of plastic scintillator 1.5 mm thick, has 20 elements in the form of triangle with h=18 mm, thickness of 1.8 mm connected to PMT FEU-137-3. It was studied in Dubna (LPP) and Protvino (IHEP). This assembly gives 250 mV output voltage for minimum ionizing particle and 25 mV for one electron emission (signal/noise is equal to 10). The total pulse width is shorter than 20 ns. These nice parameters not have been achieved in any silicon system. At present the modification of the vertex detector box to accommodate the new HM detector is finishing. Together with the mentioned above modules it provides a reliable and efficient trigger system for HM events.

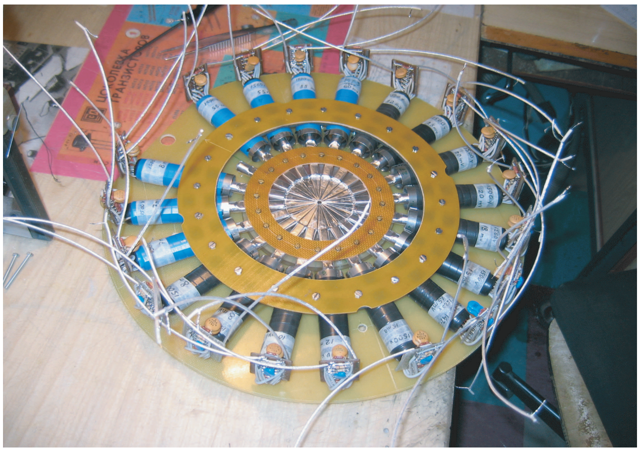

FIG. 5: Scintillator hodoscope (HM trigger).

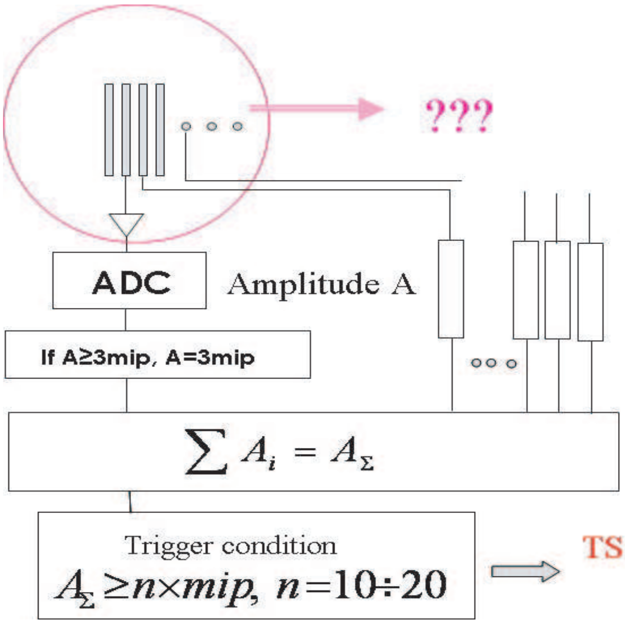

FIG. 6: HM trigger concept.

2.5. Vertex detector

Vertex detector (VD) is a necessary identify the constituent of SVD setup because it allows to vertex position. VD team from SINP MSU has produced new high quality detectors with the average number of dead channels below 3%. Vertex front-end uses an integrated circuit called GASSIPLEX. As the GASSIPLEX is a 16-channel design, only 1280 channels of detector may be placed on one board. For the 50 μm pitch detector the largest sensitive area dimension is 64 mm. To overcome this restriction, the Collaboration has made up a decision to use the integrated 128-channel circuit VIKING. JINR provides important technical support of this development. Now we had purchased a requisite consignment of these circuits which are installing in VD.

2.6. Magnetic spectrometer

The magnet MC-7A having length of 3 m on the beam is used in the spectrometer. The magnetic field in the center is equal to 1.1 T at the current of 4000 A. The detection system of the spectrometer includes 18 planes of proportional chambers (PC). The data analysis has given the following characteristics of the spectrometer: average PC efficiency is 80%; coordinate accuracy on the reconstructed tracks is 1 *mm*; the momentum resolution on beam tracks (p=70 GeV/c) is 3 %; the momentum resolution on the secondary tracks is ∼1 %. The magnetic spectrometer electronics allows one to register up to 1.5 thousand events per 1 accelerator cycle. Some of PC have been repaired, anode wires in the beam region have been covered with insulator to make them insensitive to beam particles. This modification has improved efficiency of the central part of the chamber at high beam intensity 10^7 required for *Thermalization* project.

2.7. Cherenkov counter and Gamma-detector

The threshold Cherenkov counter has 32 channels of the signal registration from the photomultiplier (PMT). PMTs are supplied with active magnetic field protection. The efficiency of pion registration in the momentum interval of $3 \div 30$ *GeV* is 70 %. It is revealed with insufficient magnetic field compensation and possible leak of air in the radiator filled with freon. The gamma-detector consists of 1536 full absorption Cherenkov counters. Radiators made of lead glass , have the following sizes: $38 \times 38 \times 505$ mm^3 and are connected with PMT-84-3. The total fiducial area of the detector is 1.8×1.2 m^2. The energy resolution on 15 *GeV* electrons is 12%. The accuracy of the γ quantum coordinate reconstruction is ~ 2 *mm*.

3. Alignment

The important task of any experiment is to provide reconstruction of charged particle tracks. Spatial characteristics and geometric position of detector modules can differ from its design values. Possible reasons of detector misalignments are the limited accuracy of initial hardware, inaccuracies in placing of detectors and their internal dimensions. The alignment procedure intends to compensate this misalignment in a mathematical way. Three ordinary types of misalignment are distinguished: planar translation Δx, Δy; planar rotation around axis z by angle α, out-of-plane translation Δz. At present experiment we realize global alignment which is correction of the placement of detectors as a whole without a division into parts. In Figure 7 we illustrate the misalignment problem: what we have (on the left) and what we want to get (on the right) - aligned detectors. The alignment task is solved in high energy physics by different standard methods. One of them is based on residuals (the deviations between the

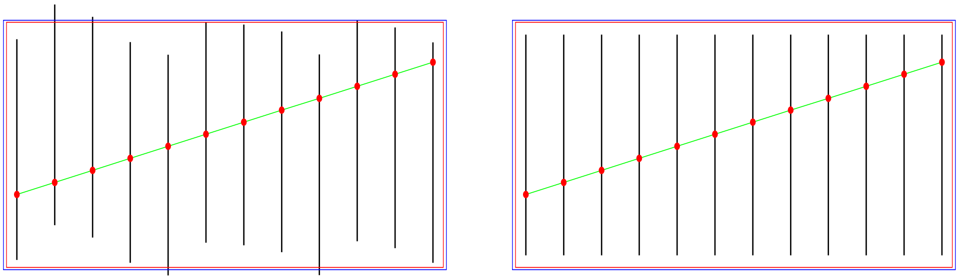

FIG. 7. Alignment problem. Left: unknown detector position, right: aligned position taking into account misalignment parameters (shifts).

measured and fitted data) [6]. Straight line fits, plot histograms of residuals for all planes, determined in all histograms, mean residuum and obtain misalignment values.

For alignment procedure we have used a more robust, efficient and high precision method based on the Linear Least Squares (LLS) with a linear model

$$\mathbf{u} = \mathbf{A}\mathbf{a} + \mathbf{r}, \tag{2}$$

where $\mathbf{u}$ is a vector of measured data, $\mathbf{A}$ - matrix, $\mathbf{a}$ - vector parameters and $\mathbf{r}$ - vector residuals. The solution of (2) $\mathbf{a} = \mathbf{C^{-1}A^{T}Wy}$ requires inversion of the symmetric matrix $\mathbf{C} = \mathbf{A^{T}WA}$. V.Blobel [7] had designed and applied LLS for calibration and alignment tasks. His approach allows to resolve a problem with a lot of parameters. Their number may reach thousands and hundred thousands. V. Blobel had solved this mathematical puzzle task and put a general program package **MILLEPEDE** [7] into practice into for the efficient solution.

The known equation of a straight line for a charged particle track in space (without magnetic field) is

$$u_{i,j} = (x_0 + t_x z_j)\cos(\alpha_j) + (y_0 + t_y z_j)\cos(\alpha_j), \tag{3}$$

where $u_{i,j}$ - the j-detector measuring coordinate for i-track or the called hit, x_0, t_x and y_0, t_y (parameters for i-track) - straight line parameters in space which are defined by projections on planes XOZ and YOZ, z_j - j-detector position on z-axis (beam line), α_j -angle detector. Our setup disposes of detectors with four types of angles: 0, $\pi/2$ and $\pm 10.5^o$. We call coordinates of these detectors x, y, u $(+10.5^o)$ and v (-10.5^o), respectively. The expression (3) helps to determine the coordinate the same way as the concrete detector measures.

If the detector disposition is known, the then alignment problem is absent. But we could not know it. So into misalignment (3) we introduced parameters related with uncertain location:

$$u_{i,j} \rightarrow u_{i,j} + \Delta u_j, \tag{4}$$

$$\alpha_j \rightarrow \alpha_j + \Delta\alpha_j, \tag{5}$$

$$z_j \rightarrow z_j + \Delta z_j. \tag{6}$$

In (4) misalignment parameters Δu_j are named also shifts. It is known that restriction to this single this parameter leads to a linear LLS task. Taking into account all three parameters (4)-(6) makes the task a nonlinear one and it is solved few iterations.

Mathematical alignment formulation can be illustrated with the following simple examples. Let us have the number of detectors $N_{det} = 10$, they are placed at the same angle (equation of straight line has 2 parameters, e.g. x_0 and t_x), also introduce 10 shifts for every detector plane Δu_j (4) and let us obtain 10 hits for one track. In this case the number of measured values is equal to 10 (the number of hits), and the number of unknown parameters is equal to $2 + 10 = 12$, more than the number of the hits (10). In this case the task has no solution.

If the number of tracks increases, e.g. to $N = 100$, then the number of measured values is $N \times N_{det} = 10 \times 100 = 1000$ and the number of track parameters and shifts $2 \times N + N_{det} = 2 \times 100 + 10 = 210$. For a matrix solution of this task by LLS it is necessary to remove the singularity rank defect 2: the uncertainty relatively overall shift and rotation of detector system as a whole. This has been resolved by means of the assumption that a location of two left and two right detectors on the axis Z is known. We describe the space track with 4 parameters (3). In this case the number of tracks is about hundred thousands or millions for the alignment task. The following [6] alignment parameters are called *global* parameters. These parameters are corrections to default values and are small. Usually the value zero is taken as the initial approximation. Track parameters are called *local*. Taking into account misalignment parameters in first order of smallness the expression (3) transforms to the following one:

$$u = (x_0 + t_y z)\cos(\alpha) + (y_0 + t_y z)\sin(\alpha) + \Delta u +$$

$$+((-x_0 - t_x z)\sin(\alpha) + (y_0 + t_y z)\cos(\alpha))\Delta\alpha +$$

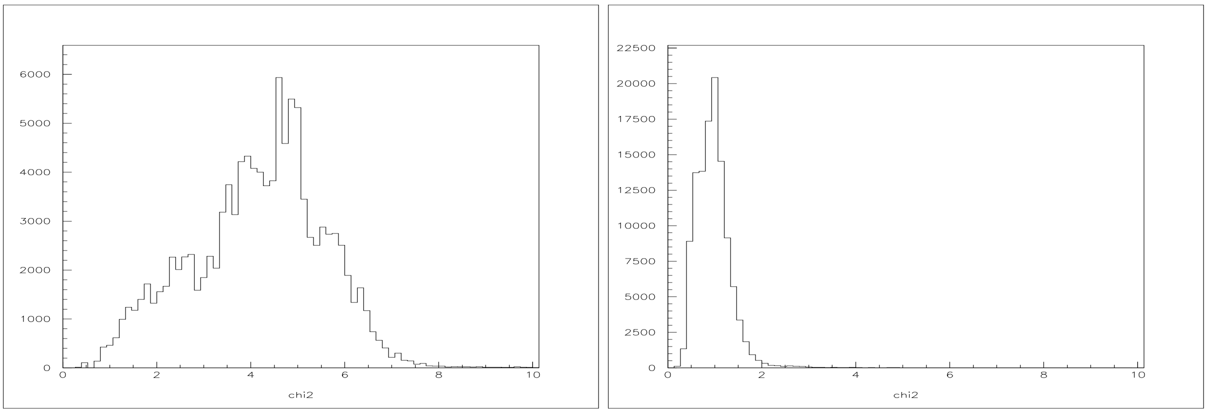

FIG. 8. χ^2/n_{df} for 114769 tracks in magnetic spectrometer. Left: before alignment, right: after alignment.

$$+(t_x\cos(\alpha)+t_yz\sin(\alpha))\Delta z, \tag{7}$$

The size of matrices in the LLS scheme can be large – of the order of $10^4\times10^4$ or $10^6\times10^6$. With ordinary methods this solution is impossible. A special method of solution for this problem was realized in the programme **MILLEPEDE**. Due to a special structure of matrix with one set of global parameters and many sets of local parameters, the task is reduced to a solvable size without any approximations. Since we are interested only in global parameters, the huge matrix C in MILLIPEDE is divided into sub matrices related to the global and local parameters and can be reduced to a system of equations for the global parameters only and no iterations are required. Iterations are necessary due the presence of outliers (bad tracks) or a nonlinear task with three global parameters. We have produced packets based on the **MILLEPEDE** programme and applied them to determine misalignment in two cases: with one (shifts) and with three (shifts, planar rotations around axis z and out-of-plane translations) misalignment parameters.

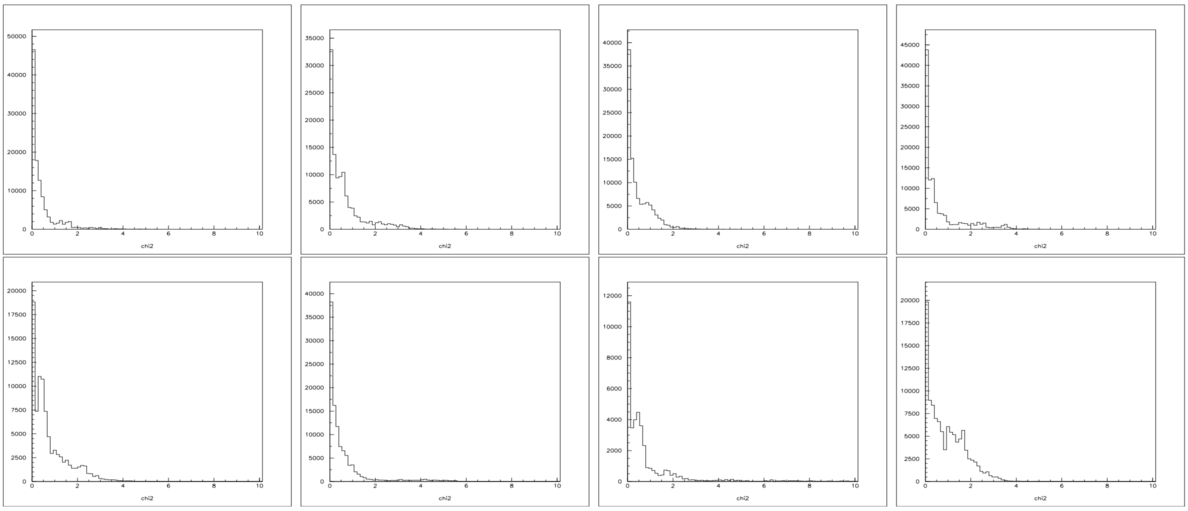

FIG. 9. Quality check of each detector by χ^2 ($1^{st}\div8^{th}$). This is evident bad resolution for 5^{th} and 8^{th} detectors.

A preliminary alignment procedure was worked out through a simple generator of the accidental tracks with including misalignment and also tracks obtained from GEANT. After that the produced for alignment packets based on **MILLEPEDE** was tested for the misalignment determination of 18 proportional cameras of a magnetic spectrometer. For these purposes 114769 tracks from the data of 2002 run (pA - events) were used. Misalignment parameters for every camera of spectrometer (except 2 first and 2 final) were estimated. The precision of shifts determination was about $\leq 4\ \mu m$, angle - $1 \div 2\ \mu rad$, out-of-plane translation - $1 \mu m$.

Histogram of χ^2/n_{df} for local fits are done automatically by **MILLEPEDE** and in our program package additionally. In Figure 8 distributions of these values are shown before alignment (left) and after one (right). The significant improvement is remarkable after taking into account of alignment. We can also make analysis of every detector quality through χ^2 on it (Figure 9) and residual distributions (Figure 10). At 2005 test run we had obtained data on hydrogen target. We had picked out some events with good identification of 449 space tracks for vertex detector and carried out alignment. Histograms of χ^2/n_{df} for local fits before and after alignment are in Figure 11.

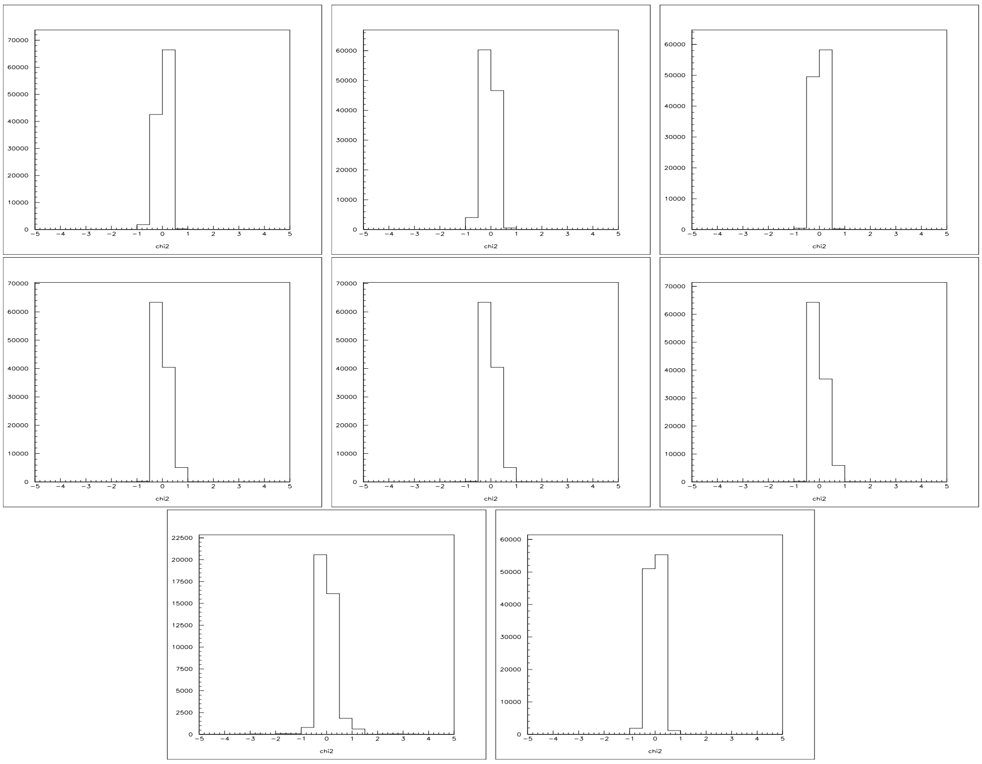

FIG. 10: Residuals in mm ($1^{st} \div 8^{th}$ detectors). Bad resolution for 7^{th} detector.

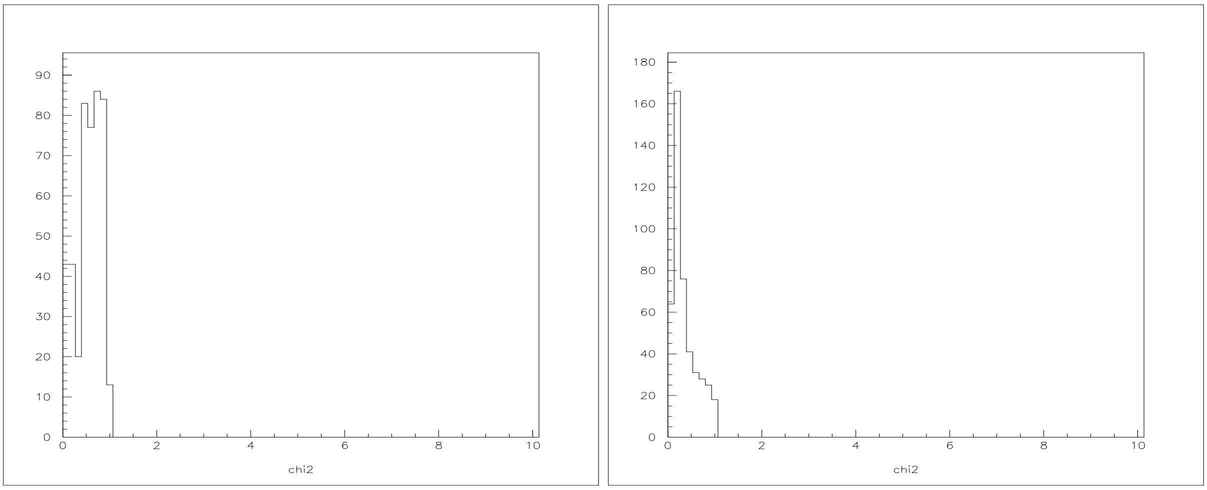

FIG. 11: χ^2/n_{df} for VD alignment: (left) before and (right) after alignment.

4. Pentaquark θ^+

Our collaboration SVD-2 had analyzed experimental data which were obtained at 70 GeV/c on IHEP accelerator U-70 in 2002 run on the nucleus targets (Si, C and Pb). The reaction $pA \to pK_s^0 + X$ with a limited multiplicity was used in the analysis to search for an exotic baryon state, the θ^+ baryon, in a pK_s^0 decay mode in the analysis. The pK_s^0 invariant mass spectrum shows a resonant structure with $M = 1526 \pm 3(stat.) \pm 3(syst.)$ MeV/c^2 and $\Gamma < 24$ MeV/c^2 [8]. The statistical significance of this peak was estimated to be of 5.6 σ. The mass and width of the resonance is compatible with the recently reported θ^+-baryon with positive strangeness which was predicted as an exotic pentaquark ($uudd\bar{s}$) baryon state. The total cross section for θ^+ production in $pN-$ interactions for $x_F > 0$ was estimated to be $30 \div 120$ μb and no essential deviation from A-dependence for inelastic events ($A^{0.7}$) was found.

The further study of narrow baryon resonance decaying into pK_s^0 in pA interactions at 70 GeV/c with SVD-2 setup were continued [9]. It was used two independent data samples, selected by the point of K_s^0 decay: inside or outside the vertex detector (decay length $0-35$ or $35-600$ mm, respectively). A narrow baryon resonance with the mass $M = 1523 \pm 2(stat.) \pm 3(syst.)$ MeV/c^2 was observed in both samples of the data (Figure 12). The main contribution to the systematic error is connected with the setup alignment uncertainties. We observed the total of 392 signal events over 1990 background ones. Using additional track quality cuts we obtained $\Gamma < 14$ MeV/c^2 on 95 % C.L. The statistical significance of the peak can be estimated to be $s/\sqrt{b} = 8.7\sigma$. This new analysis and larger statistics confirm that our previous results [8] and the resonance observed is nor a statistical fluctuation neither induced by background processes. We plan to continue our investigations to understand the creation mechanisms of K_s^0p resonance, momentum and angular dependencies and cross sections. It is more careful studies and detailed Monte-Carlo simulations. We agree with [10]: the conclusion that the existence of pentaquarks in general , and the θ^+, in particular, demands further researches with better statistics and particle identification.

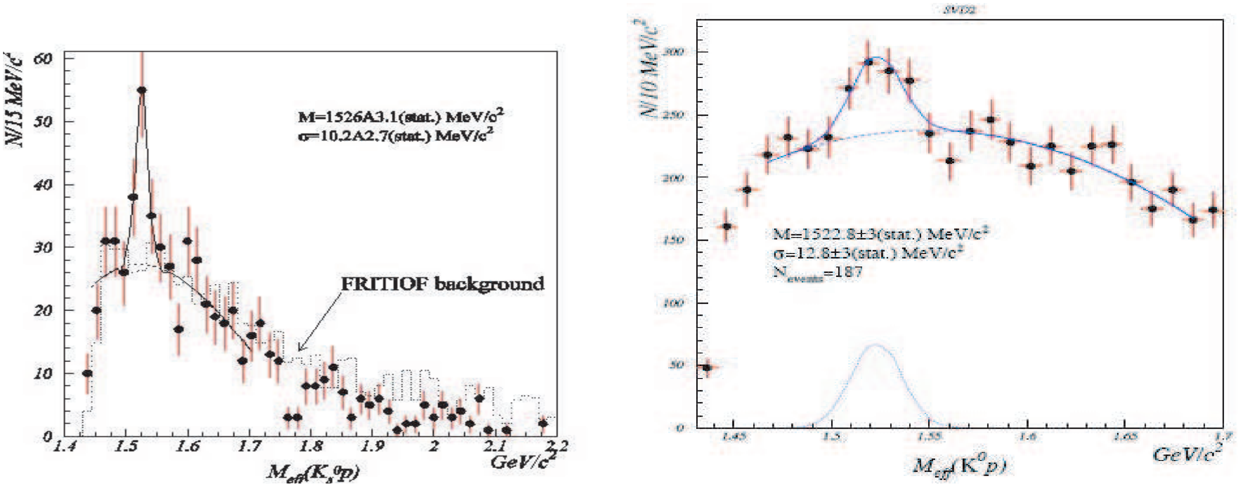

FIG. 12. K^0p effective mass. Left: analysis I, $0.5 \div 35$ mm region. Right: analysis II, after the tracking detector, $35 \div 600$ mm.

5. Summary

We are planing continue our work to making of program packets for tracking tasks and implementation of researches of new phenomena in the region of high multiplicity.

6. Acknowledges

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