Identification of slow charged particles in PANDA experiment with barrel TOF

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As known, every modern experiment begins with computing simulation of the experimental setup and response of it. For example, the existing computing framework of the future PANDA experiment at FAIR allows one to perform a fast simulation of detector responses, a fast reconstruction of tracks. It was foreseen to implement a simulation of Time of Flight (TOF) sub-detector for the identification of charged particles. We have included barrel TOF in the process of the fast simulation and reconstruction.

The used physical model is quite simple (see Fig. 1).

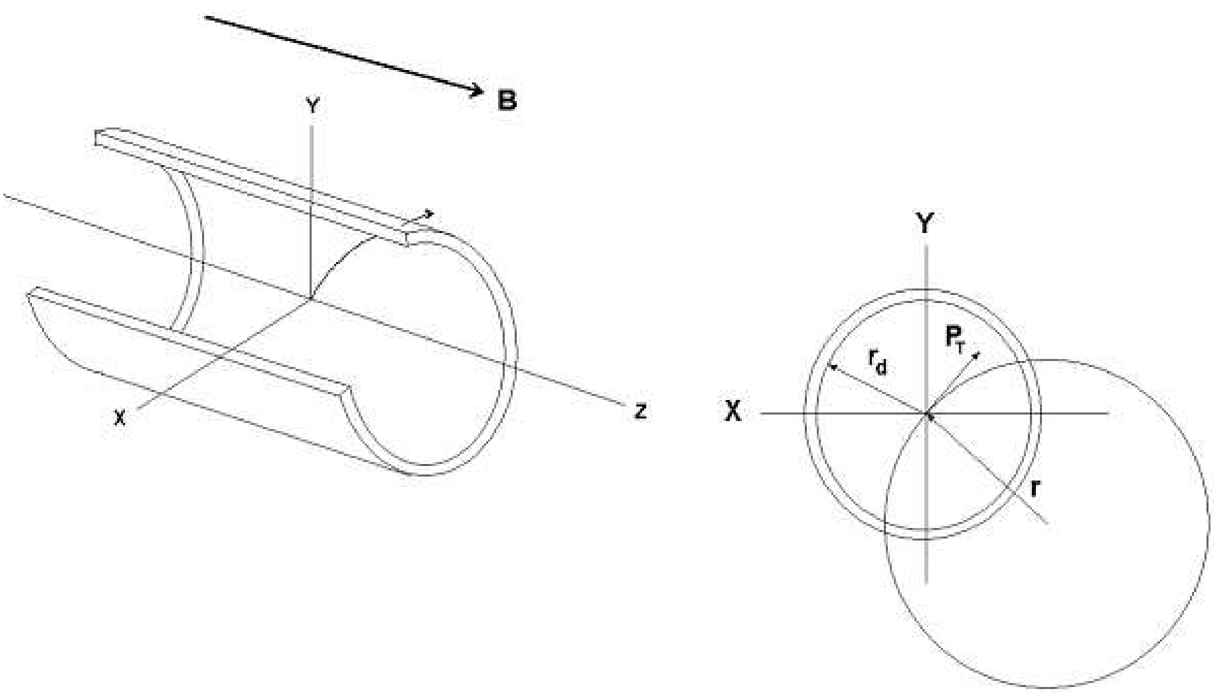

Figure 1: Schematic view of TOF.

We present TOF device as a sensitive tube with main axis paralleled to a magnetic field, B. Z-axis of a coordinate system is directed along the field too. It is assumed that the detector covers angles between 22° and 140° around the STT/TPC and has the inner radius of $r_d = 48\ cm$ [1]. If the field is a homogeneous one, a charged particle produced in the center of the barrel will move along surface of cylinder with radius r, as it is shown in the right side of Fig. 1. The time, when the particle penetrates the surface of sensitive tube, is determined as the time-of-flight.

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The equations of the motion of the particle according to the book by L.D.Landau and E.M.Lifshitz [2] are:

$$\begin{aligned} z &= z_0 + v_{0z}t & v_z &= v_{0z} \\ x &= x_0 + r\ sin(\omega t + \alpha) & v_x &= v_{0T}\ cos(\omega t + \alpha) \\ y &= y_0 + r\ cos(\omega t + \alpha) & v_y &= v_{0T}\ sin(\omega t + \alpha) \end{aligned} \quad (1)$$

It is following from the equations that the particle moves on a spiral with constant velocity along Z-axes. The radius of the spiral is given by the well known formulae: $r = cP_T/eH$, where P_T is transverse momentum, and H is induction of the magnetic field. The angular velocity of the particle $\omega = ecH/E$.

Assuming that the particle is produced in the origin of the coordinate system at $t = 0$ ($x = y = z = 0$) with components of the velocity $v_{0x},\ v_{0y},\ v_{0z}$, one can re-write the equations of the motion as:

$$\begin{aligned} z &= v_{0z}t, \\ x &= r\ [sin(\omega t + \alpha) - sin(\alpha)], \\ y &= r\ [cos(\omega t + \alpha) - cos(\alpha)], \\ tg(\alpha) &= -v_{0y}/v_{0x}. \end{aligned} \quad (2)$$

When the track crosses the detector surface, we have a condition for determination of the time-of-flight, t_0.

$$\sqrt{x^2 + y^2} = r_d \quad \rightarrow \quad 2sin\frac{\omega t_0}{2} = r_d/r \quad \rightarrow \quad t_0 = \frac{2}{|\omega|} arcsin(r_d/2r)$$

For simulation of the process, we assume that the time-of-flight is distorted on Δt, $t_{0f} = t_0 + \Delta t$. The value of Δt is distributed according to the Gauss law with dispersion of $100 * \sqrt{2}$ (ps). For distortion of the momentum we accepted the value about $1 - 3\%$ of one. It is typical value of tracking devices like Micro vertex detector (MVD) or Straw Tube Tracker (STT).

Knowing time-of-flight, momentum and emission angle, we calculate the particle energy and squared mass.

$$E = t_{of}\ ecH/2/arcsin\left(\frac{r_d eH}{2cp_T}\right), \quad m^2 = E^2 - p^2 \quad (3)$$

The algorithm of the particle squared mass determination using barrel TOF sub-detector is included in the FastSimApp package of the PANDA framework.

Let us consider the possibilities of identification of charged particles with help of TOF response.

In Fig 2 we presented the simulation results for squared mass of π-, K-mesons and anti-protons at various momenta. We generated production of 10000 of π-mesons, kaons and anti-protons using "Single generator" of the framework. As seen, at lower momenta we have a good separation of all particles. At intermediate momenta π-mesons and K-mesons start to overlap.

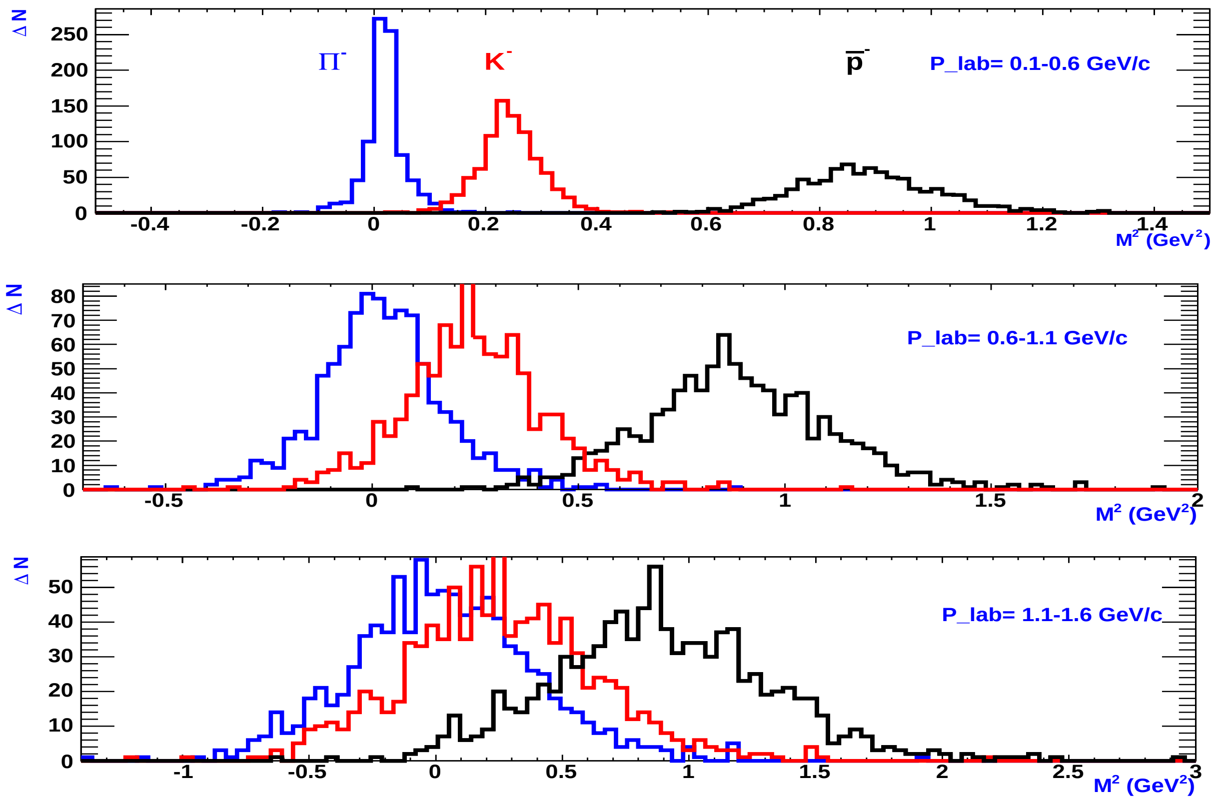

Figure 2: Distribution of the squared masses of π -mesons, K-mesons and anti-protons at the various momenta.

Anti-protons can be separated quite well. At higher momenta π-mesons and K-mesons almost overlap. The obtained results are quite satisfied because TOF sub-detector is aimed to identify the slow charged secondary particles. At lower momenta, the squred mass distributions can be parameterized in gaussian forms. These can be useful for determination of probabilities of various hypothesis: that a particle is π-meson, or K-meson, or proton/anti-proton. This information will be needed when global particle identification (PID) is implemented.

In experiment, the inclusive cross-sections of produced particles of various species are different. Momenta of the particles are distributed in a wide interval. All of these can complicate the identification of secondary particles. To analyze the problem, we have studied a response of the implemented TOF sub-detector for $\bar{p}p$-events simulated by Dual Parton Model (DPM) generator implemented in the Panda framework. We considered 10000 $\bar{p}p$-interactions calculated at antiproton momentum of 1.5 GeV/c.

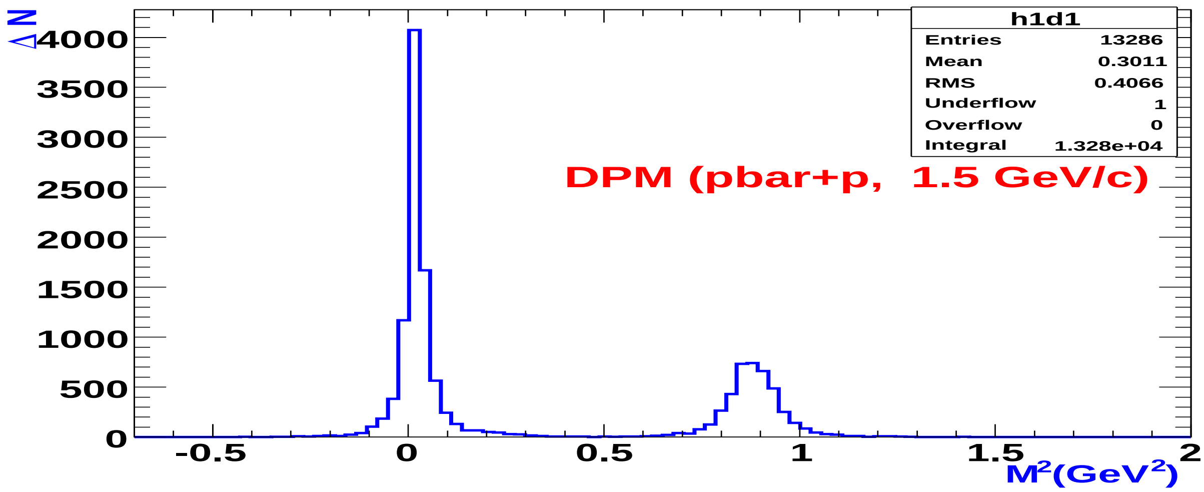

Figure 3: Distribution of the squared masses of particles produced in $\bar{p}p$-interactions at 1.5 GeV/c.

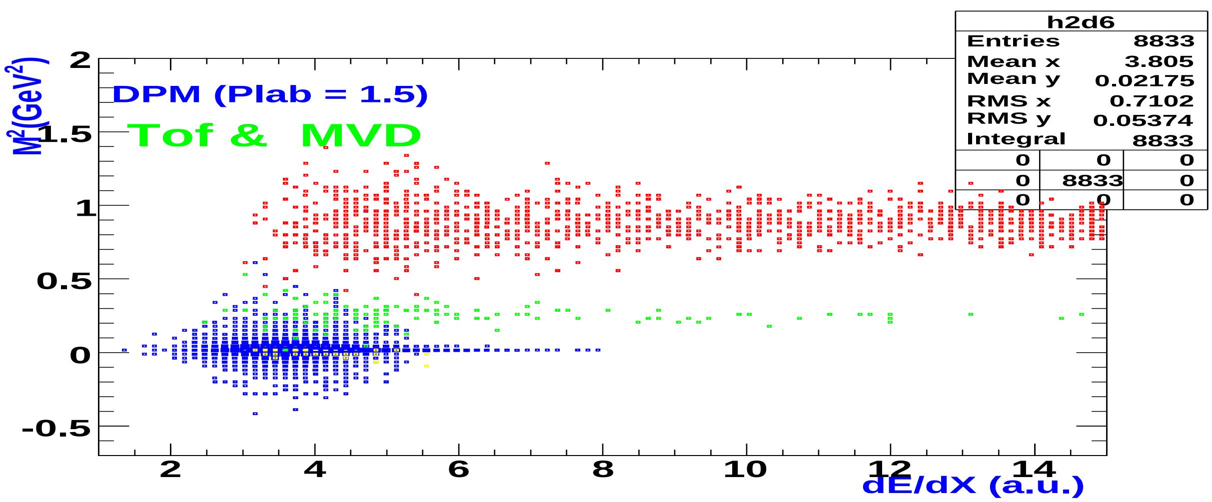

Figure 4: Two dimension distributions of π -mesons (blue points), K-mesons (green points), protons (red points) and electrons (yellow points) on squared masses m^2 and dE/dx from MVD.

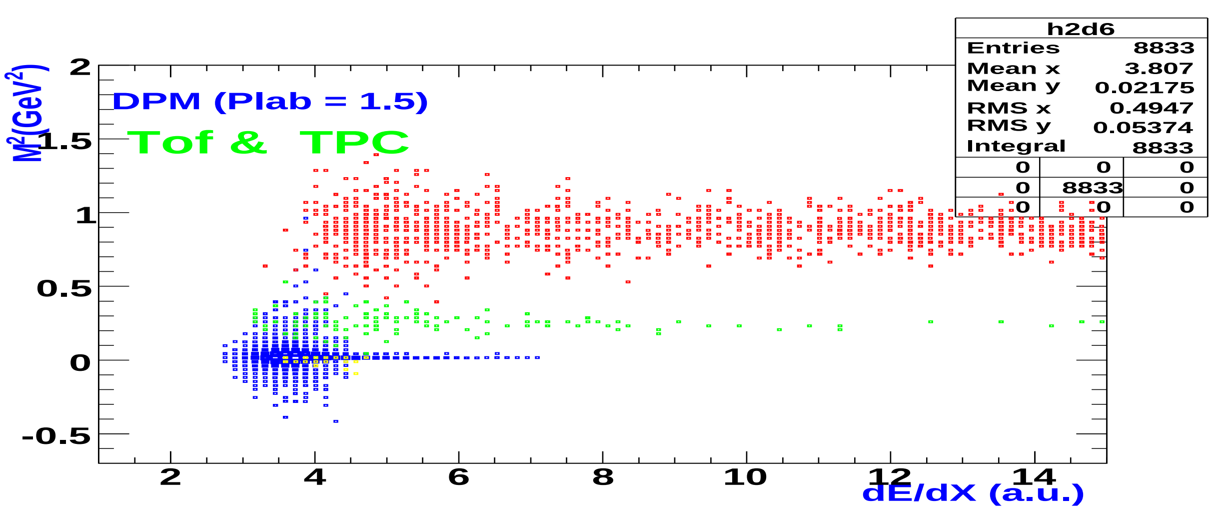

Figure 5: Two dimension distributions of π -mesons (blue points), K-mesons (green points), protons (red points) and electrons (yellow points) on squared masses m^2 and dE/dx from TPC.

Fig. 3 presents the particle squared mass derived from the TOF information. As seen, there are two peaks in the distribution. One of them corresponds to π-mesons, the second one is connected with protons. Because of the large number of pions, the peak of K-mesons can not be allocated obviously.

Analogous situation took place in many experiments [3], where a particle identification was achieved by TOF, by measurements of the specific energy loss dE/dx, or by combined TOF and dE/dx.

To check the capability of PANDA detector, we show in Fig.4 combined distributions on m^2 calculated using response of TOF sub-detector and energy losses dE/dx from Micro Vertex sub-detector (MVD) for π -mesons, K-mesons and protons produced in $\bar{p}p$-interactions. In Fig.5, the analogous distributions are given for energy losses dE/dx from Time Projection Chamber (TPC) sub-detector. As seen from Figs. 4, 5, protons are rather well identified. The separation of K-mesons and π-mesons can be achieved at special restrictions on m^2 and dE/dx.

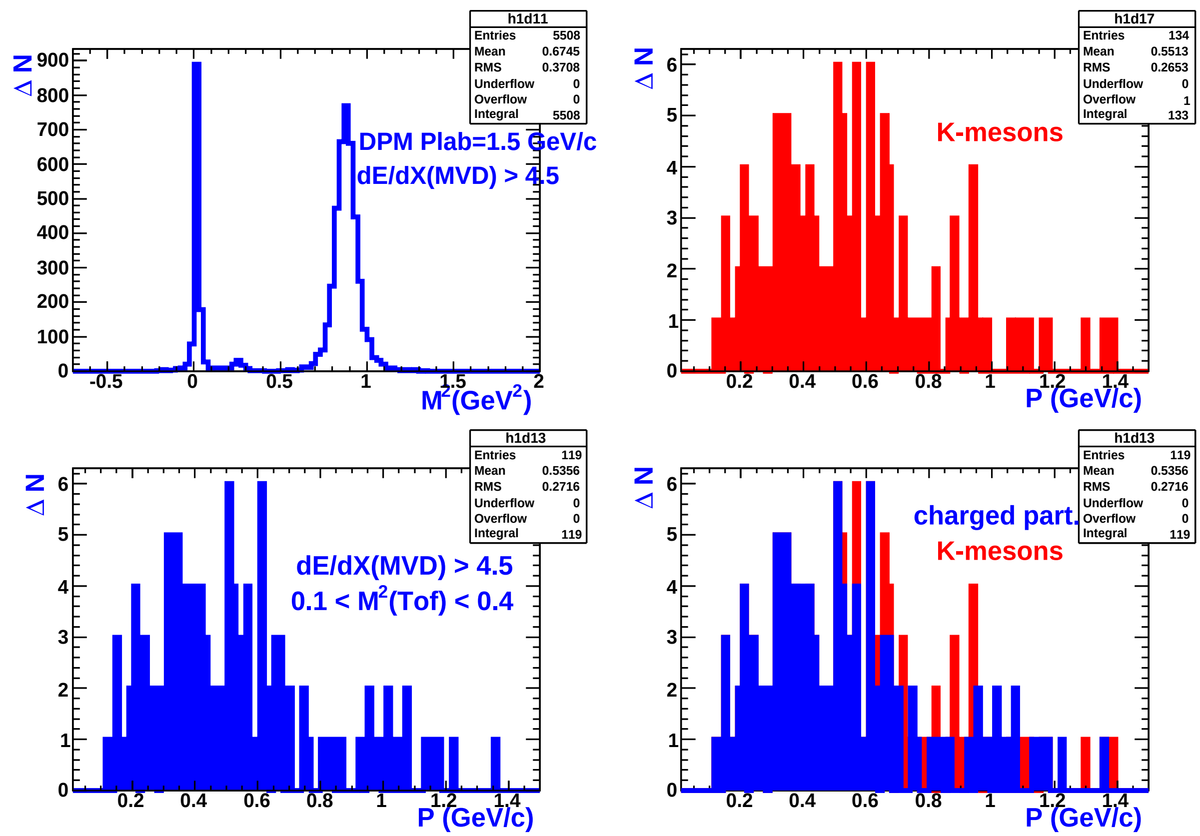

Figure 6: Different characteristics of charged particles and K-mesons in $\bar{p}p$-interactions at 1.5 GeV/c calculated by DPM model.

As an example, we show in Fig. 6 properties of produced particles in $\bar{p}p$-interactions at $dE/dx > 4.5$ a.u. from MVD. In left upper figure, where the mass squared distribution of charged particles is plotted, a signal of

K-mesons can be seen. The right upper figure presents the momentum distributions of charged kaons. According to it, the number of kaons is 134. To select them, we considered two conditions together: $dE/dx > 4.5$ a.u. and $0.1 < m^2 < 0.4$ GeV^2. The momentum distribution of all charged particles obtained using these restrictions is given in the left bottom corner of Fig. 6. Here, the multiplicity of the particles is equal to 119. In right bottom figure the momentum distribution (blue histogram) of these charged particles is lied on one of K-mesons (red histogram). As seen, some energetic kaons aren't included in the charged particles under the conditions: $0.1 < m^2 < 0.4$ GeV^2 and $dE/dx > 4.5$ a.u. from MVD.

Fig.7 illustrates the momentum distributions of the charged particles of various species with mass squared from TOF in the interval $0.1 < m^2 < 0.4$ GeV^2. Upper left figure shows the distribution at $dE/dx > 4.5$ a.u. from MVD, upper right figure - at $dE/dx > 5.0$ a.u. from MVD, down left figure - at $dE/dx > 4.2$ a.u. from TPC, down right figure - at $dE/dx > 4.5$ a.u. from TPC.

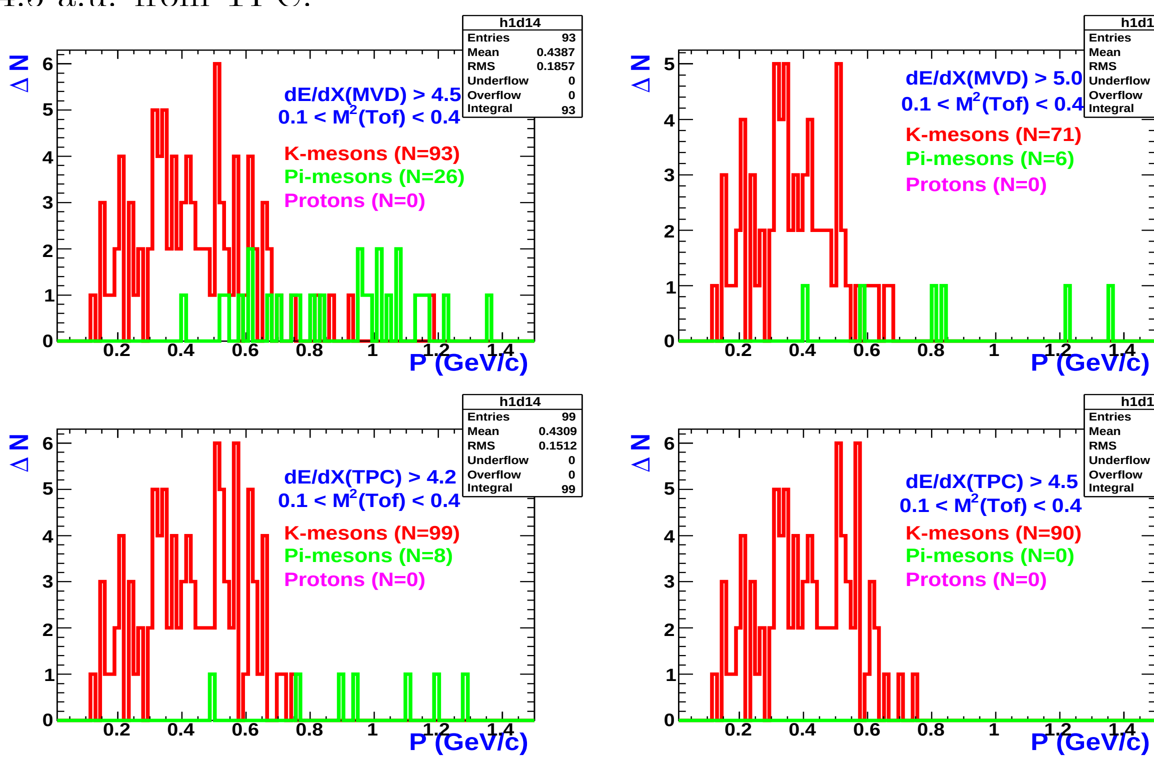

Figure 7: Momentum distributions of π-, K - mesons produced in $\bar{p}p$-interactions at 1.5 GeV/c momentum of antiprotons calculated by DPM model. Particles are chosen at the conditions: $0.1 < m^2 < 0.4$ GeV^2 and various restrictions on dE/dx.

As seen from Fig.7, the separation of K-mesons is not sufficient at the condition $dE/dx(MVD) > 4.5$. In this case, the number of kaons is 93, the number of pions is 26, protons are absent in the selected 119 charged particles. Using $dE/dx(MVD) > 5.0$ the selection of K-mesons becomes better. The multiplicity of K-mesons is about 96-97% of the charged particles at momentum of produced particles less than 0.75(GeV/c). When we are separating K-mesons and pions choosing restriction on TPC energy losses and particle squared mass, the identification of kaons becomes more accurate. At $dE/dx(TPC) > 4.2$ and $0.1 < m^2 < 0.4$ GeV^2, K-mesons are identified with 98% probability at momenta till 0.8 GeV/c (left bottom figure). At $dE/dx(TPC) > 4.5$ and $0.1 < m^2 < 0.4$ GeV^2, probability of K-mesons separation is equaled to 100% (see right down figure).

Summing up, we conclude that a good identification of slow charged particles – π-mesons, K-mesons and protons can be reached at PANDA experiment with help of combined information: m^2 from barrel TOF and dE/dx from tracker sub-detector (TPC or STT).

References

[1] PANDA Collaboration, *Technical Progress Report for: PANDA Strong Interaction Studies with Antiprotons*, FAIR-ESAC/Pbar 2005.

[2] L.D.Landau and E.M.Lifshitz, *"Field theory"*, Moskow, 1962.

[3] V. Friese et al. (NA49 Collab.), J. Phys. **G30** (2004) S119.