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DT67 PATTERN RECOGNITION IN **PHOENIX**

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Пешехонов Д.В., Медведь К.С., Позе Д. E1-95-391
Процедура восстановления треков в детекторе ДТ67 программой PHOENIX

В эксперименте НА-47 проводится измерение спин-зависимой структурной функции нуклона в ГНР поляризованных мюонов на поляризованной мишени. Важным этапом процедуры обработки экспериментальных данных является восстановление треков рассеянных мюонов. В данной работе описана процедура восстановления мюонных треков в детекторе Плоскости Дрейфовых Труб (ДТ67) программой PHOENIX.

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Peshekhonov D.V., Medved K.S., Pose D. E1-95-391
DT67 Pattern Recognition in PHOENIX

The spin dependent structure function of the nucleon is being studied in the NA-47 experiment by the measurement of the deep inelastic polarized muon — polarized targed scattering. The reconstruction of the scattered muon tracks is one of the most important steps of the data analysis procedure. The pattern recognition of the muon tracks in Drift Tubes plane detector (DT67) implemented in PHOENIX is described.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

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1 Introduction

The Spin Muon Collaboration (SMC) [1] experiment is located on the muon beam line of the CERN SPS [2] and measuring the deep inelastic polarised scattering (Figure 1).
The pattern recognition program PHOENIX [3] is the first stage in the off-line track reconstruction process. This program performs separate track reconstruction in the various parts of the SMC detector to obtain the scattered muon track. In this paper we describe this procedure for the Drift Tube planes detector (DT67) created and supported by JINR.

2 DT67 Geometry

DT67 consists of 12 large planes of drift tubes located behind the iron absorber (see figure 1).

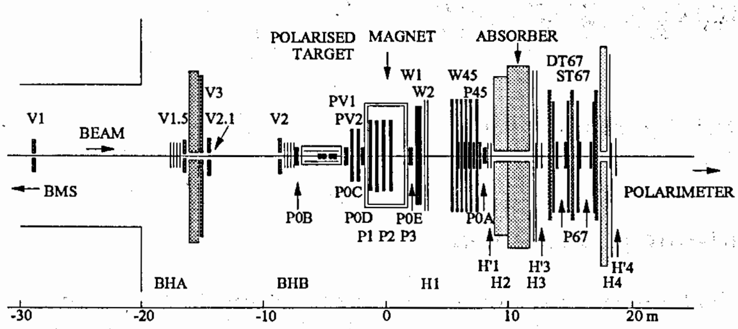

Fig.1 *The Spin Muon collaboration spectrometer.*

DT67 planes are used, together with ST67 planes, for detection of scattered muons. Each four drift tube planes (two orthogonal pairs) are mounted in one block. The sequence of DT67 planes is : (Y1 Y2 , Z1 Z2) (Y3 Y4 , Z3 Z4) (Y5 Y6 , Z5 Z6). The distance between Y1 and Z6 planes is about 4 meters. In each pair (e.g. Y1,Y2) two adjacent parallel planes are shifted relative to each other to one half of the tube diameter. Each **Y** plane is composed of 96 tubes, **Z** plane – of 80 tubes.
Each DT67 plane has a hole in the center (beam region) of 85x85 cm^2 in size; therefore, DT67 is not sensitive to small-angle scattered muons. The structure of the planes is shown in figure 2.

· The aluminium tubes of 52 mm outer diameter, 4.2 or 5 m length are the registering elements of the detector. The thickness of tube walls is 0.75 mm. In the center of the tube, a tungsten wire with gold-covered surface is stretched. All the tubes (wires) are equally spaced. The tube itself is a cathod, and the wire is anode of the drift volume. The wires are stretched with calibrated tension of 250g. No special wire supporters inside the tube are used.

The gas (70% Argon, 30% Ethan mixture) flows in series, from one tube to another. with the gas rack No EP 151. There 6 gas channels are used for DT67. With this mixture, the tube drift time turns out to be about **450 ns.**

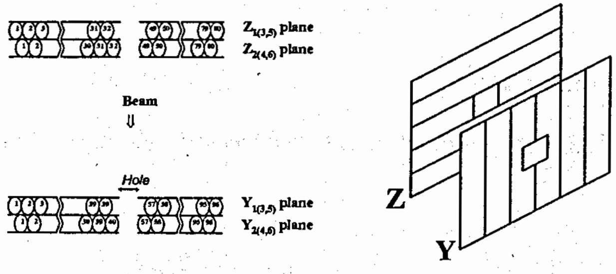

Fig. 2. *DT67 geometry of planes.*

3 Read-out electronics.

The coordinates of charged muons are being determined by measuring the drift times. The tubes are read out at one end. The amplifier cards are mounted on the DT67 module and contain 8 wire amplifiers each. Each wire amplifier has an input circuit built with μA733, and a discriminator-shaper built with K597CA1.
The characteristics of the amplifier are shown in Table 1.

Table 1.

Input impedance	1.5 KOhm
Input sensitivity	1-10 mkA
Output signal propagation (ECL)	550 +/- 50 ns
Power dissipation of one amplifier card	- 6V : 0.750 A
	+ 6V : 0.375 A

The output signal propagation was chosen according to the maximum drift time in tube. Paraphase ECL signals are transmitted from the amplifier card via twisted pairs cable of 40m length to the inputs of the Time-to-Digit Converter TDC–16 [4]. One CAMAC module of TDC–16 serves to read out 16 drift tubes. One cable is used for 32 tubes.
The Converter reads input signals with a clock cycle rate of 100 MHz. The cycles are produced by one Time-Generator for the whole detector. TDC stores the drift time and corresponding drift tube number. The Timer-generator is started after the readout processor is ready to accept the data. At the start of the time series, all TDC-16 modules are ready to store the signals in their inner memory. The Timer-Generator stops on the trigger signal. At this moment, all TDCs also keep the Stop Time, in addition to the information from the tubes. The incoming data are being cleared out to store the meaningful data only. The TDC-16 LIFO memory provides the storage of up to 16 last coming drift times and corresponding drift tube numbers. One unit of a Time counter is 5 ns. Any standard CAMAC crate controller may be used to read the data out of TDC-16. In SMC experiment ROMULUS system is used to read and control the TDCs. The readout electronics check is performed by a Test Block in between the accelerator cycles. It generates the signals (known in advance) to all the channels and they may be read out in between the spills.
The total number of electronic channels in DT67 is 1056. The basic characteristics of TDC–16 are shown in Table 2.

Table 2.

Time precision	+/- 2.5 ns
Measuring range	0 - 5.12 mks
Channel dead time	40 ns
LIFO memory depth	16 16-bit words
Power dissipation	- 6V / 3 A ,
	+6V / 0.5 A
Modes of work	"Common Start",
	"Common Stop"

4 DT67 in Phoenix.

Reference system and plane definition of DT67 are the same as for ST67 :
Y–axis : horisontal, positive pointing left.
Z–axis : vertical, positive pointing up.
Y–PLANE : Tubes parallel to Z–axis (vertical wires). Measures Y–coordinate of the hit from the muon track.

Z–PLANE : Tubes parallel to Y-axis (horizontal wires). Measures Z-coordinate of the hit.
DT67 *has no θ planes*, and the way the detector implemented in Phenix is not assuming the independent reconstruction of muon track using *only* DT67 hits. The tracks reconstructed in ST67 are used for tagging the DT67 hits. Then, these DT67 hits are being used together with the ST67 hits to fit (correct) the parameters of muon track. The standard routine STFIT1 is used for fitting the track (combined ST+DT hits).
ST67 has 32 planes, the position of a hit in one plane can be determined with the accuracy $\geq$0.35 cm. The average number of planes used for track reconstruction is 24.

The position of hit in any DT67 plane can be determined with the accuracy $\sim$0.1 cm. The average number of planes used for track reconstruction is 9.

The common fit of the muon track using both ST67 and DT67 hits noticeably improves the accuracy of final fit parameters of muon track.

4.1 DT67 Pattern recognition routines

PHOENIX uses the following routines related with DT67 detector:

```
P=D67REC  D=
          D= D67AHT
          D= D67DEF
          D= D67CNS
          D= D67GEV
          D= FWPOS
          D= D67EXT
          D= SGNFUN
          D= DEVFUN
          D= D67HIS
          D= DTEND
P=TRNSLT  D= DCDT67
```

4.1.1 D67HIS

This subroutine is used for definition of DT67-related histograms. The histograms, being filled in routine D67DEF mostly related to the alignment / calibration procedure. Histograms, filled in D67EXT include also the

information about ST67+DT67 common fit procedure. If the **CMZ key IF=DT67SYST** is set, more special histograms are defined for methodical studies of DT67. All the histograms have numbers 19XXX, as DT67 detector number in Phenix is 19.

4.1.2 D67CNS

In this subroutine, most of the constants for DT67 recognition routines are stored / defined.

- Dead plane flags.
- Alignment/production flag INCLT.
- DT67 planes RMS.
- 3 pairs of V_{dr} and T_0 , defined from multi-linear fit of T_{hit}–D_{hit} distributions. (D_{hit} is the distance between hit wire and muon track passed through the drift tube). The typical distribution of the value T_{hit}–D_{hit} is shown in figure 3 (the one-line fit, presented in the figure 3, can be used as a first approximation).

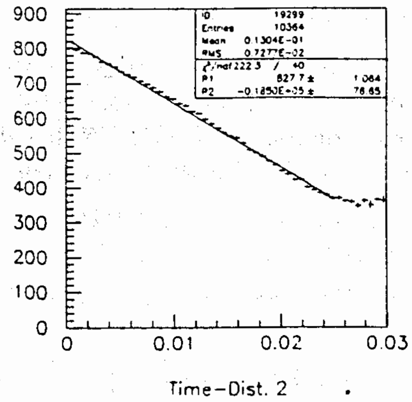

Fig.3 *One line fit of* $1/V_{drift}$

- V_{dr} and T_0 , defined from the rough fit of T_{hit}–D_{hit} distribution, using one–line approximation.
- Relative uncertainties of V_{dr} and T_0 . In alignment file, these values are multiplied by 1000.

- Limits for T_{hit} values, used to cut the noise hits duting the reconstruction.
- Half-sizes of DT67 beam hole.
- Also, some preparation for (ST67+DT67) combined fit is done. The positions and geometrical parameters of both ST67 and DT67 planes from COMMON/WIRES1/XWIRE1(NTPLAN) are stored in local arrays.

4.1.3 D67AHT

This is a main control routine for pattern recognition with DT67. This subroutine organizes : the cycle on DT67 hits; (possible) re-fitting of ST67 lines using additional DT67 info; rearranging ST67 banks adding DT67 info.

- Calls D67GEV to get coordinates and drift times of DT67 hits.
- Loops over all ST67 lines, preparing arrays for (possible) common fit of ST67 and DT67 hits. (ST67 lines are used for tagging the DT67 hits).
- Checks if ST67 track has enough hits outside DT67 hole. If most of the intersections of ST67 line with the DT67 planes are inside the hole, no attempts are being done to use the DT67 information. Loop is organized separately for Y–planes, then for Z–DT67–planes.
- In the alignment/calibration run, calls routine D67DEF, that stores the information for calculation of V_{dr} and T_0. The ST67 line fit parameters are transmitted through internal array STDTIN. In calibration run, ST67 track is not refitted, and DT67 information is not added to LIN67 bank.
- In data–processing run, it calls routine D67EXT. This routine calculates the real coordinates of DT67 (tagged) hits. The ST67 line fit parameters and fit uncertainties are transmitted through internal arrays STDTIN and STDERR.
- If the number of found DT67 hits (tagged by ST67 line) is enough (at least 3 for each Y– and Z– projections), the ST67 fit parameters are stored at the end of LIN67 bank. Then **STFIT1** is called to perform the common fit of ST67 and DT67 hits. STFIT1 is a General Least Squares fit routine; it allows to get slopes and intercepts in 2 projections plus their variances. You may find it in //PHENIX/UTILITY. This procedure repeats in details the fitting algorithm used for ST67 line in STRK67; the same ST67 hits coordinates, errors and χ^2–cuts are used.

- Checks for "bad hits" during the fit. Worst hit is rejected; track is refitted once the bad hit is removed.
- If combined (ST67+DT67) track was accepted, it is stored in LIN67 Zebra bank (old ST67 track is also saved). Description of modified ST+DT67 LIN67 bank could be found in SMC/91/7 or SMC/92/35 [5].
- Compares the characteristics of muon track fitted using only ST67 hits with the result of common fit; stores statistics on number of tagged and used hits, and on number of processed ST67 and ST67+DT67 lines.

Subroutines called : D67GEV, D67EXT and D67DEF.

4.1.4 D67DEF

In alignment/calibration run, this subroutine stores the information for calculation of T_0 and V_{dr} for drift tubes. To tag the DT67 hits, ST67 lines are used. This subroutine :

- Checks the characteristics of DT67 event : if there are too many hits from muon showers, this event is not used for calibration.
- For each ST67 line calculates the coordinates of intersections with all 12 DT67 planes. Each ST67 track is represented as Y(x) = (dY/dx) + Y_0 and Z(x) = (dZ/dx) + Z_0 . Slopes (dY/dx) and (dZ/dx) are given at some point (X_0,Y_0,Z_0 — "gravity center").
- Loops over all DT67 hits, tagging all the hits close enough to ST67 line. Gives the rough coordinates of tagged hits. Calculates the distance between position of hit wire and position of ST67 line–DT67 plane intercept.
- Corrects the T_{hit} taking into account muon flight time between DT67 planes, and the delay in signal wires.
- Fills the T_{hit}–D_{hit} profile histograms. V_{dr} and T_0 will be obtained from these histograms in routine D67ALI. The soft cuts on T_{hit} are applied to decrease the influence of noise hits.
- Calculates the left/right (up/down) deviation of DT67 relative to the hit wire, computes DT67 residuals and fills the special alignment histograms.

Subroutine called : FWPOS.

4.1.5 D67EXT

This routine defines the exact DT67 hit coordinates during the data processing (not calibration run). Most of the things are treated in the same way as in D67DEF.

- ST67 line is projected onto each DT67 Y–plane, then each Z–plane. Coordinates of intersections are calculated. Dead planes are excluded.
- Loops over all DT67 hits, tagging all the hits close enough to ST67 line. Gives the rough coordinates of tagged hits, number of plane and wire (FWPOS). Calculates the distance between position of hit wire and position of ST67 line–DT67 plane intercept.
- Checks if we have enough tagged hits for this projection.
- Corrects the T_{hit} taking into account muon flight time between DT67 planes, and signal wires delay.
- Calculates the exact Y– or Z– coordinate of DT67 hit using T_{hit} (function DEVFU3). For each hit, calculates its error. The error has three components : inaccuracy due to drift time uncertainty; inaccuracy due to resolution of read-out electronics; inaccuracy due to uncertainty of drift velocity..
- books and fills histograms for T_{hit}–D_{hit} and DT67 residuals. These distributions may be used to control of DT67 performance and alignment during the data taking and processing.

Subroutines called : FWPOS, DEVFU1 and DEVFU3.

4.1.6 D67GEV

- Calls DT67_data_decoding routine DCDT67.
- Transforms and stores the decoded data into internal array IEVV.
  IEVV(i) = N_{YZ}*1000 + N_{plane}*100 + N_{wire} ; where N_{YZ}=1 for Y–plane, =2 for Z–plane.
  IEVV(i+1) = T_{hit}.
- Returns LENE = number of pairs N_{wire}–T_{hit}.

4.1.7 DTEND

This routine is called at the very end of Phenix run, after the required number of events has been processed. It is called by the Phenix routine OUTPUT, and prints a summary, statistics, and values of some DT67 constants.

Also, during the alignment/calibration run, it calls routines D67ALI and D67NAL. These routines prepare the calibration data for next iteration step and write out the temporary alignment file.

4.1.8 D67ALI

- Calculates the corrections to the y– and z–positions of planes using the data (residuals) stored in D67DEF.
- Performs the calibration of DT67 tubes, using T_{hit}–D_{hit} distribution. (profile histogram 19299 with the noise cuts applied). The line fit in three regions is performed by routine D67FIT.
- Checks the boundary conditions for multi-line fit to be sure that the obtained function is continuous.

4.1.9 D67NAL

This subroutine prints out the temporary file newalign.dat (logical unit 66).

This file is just the DT67–relevant part of the general alignment file, with the updated calibration constants and plane positions.

Newalign.dat is used for updating the current alignment file before the next iteration.

4.1.10 D67FIT, DEVFU1, DEVFU3, FWPOS

D67FIT is a small subroutine that performs linear fit of T_{hit}–D_{hit} distribution in the given D_{hit} region.

DEVFU1 and DEVFU3 are the functions that for given T_{hit} return the value of the distance between muon hit and sensitive wire. 1– or 3–lines approximation of V_{dr} is used.

For any given hit number (from D67GEV), function **FWPOS** returns the projection number, plane number, wire number, and Y–(Z–) coordinate of the hit wire.

5 DT67 resolution

To perform the common fit of the combined ST67 + DT67 data, the correct value for drift tubes resolution should be set in the procedure. To obtain this value, the muon line fit using *only* DT67 hits was performed. The standard fitting procedure STFIT1 was used, with the same χ^2 cuts for bad hits done for ST67. The ST67 muon line from LIN67 bank was used to tag the DT67 hits around this line.

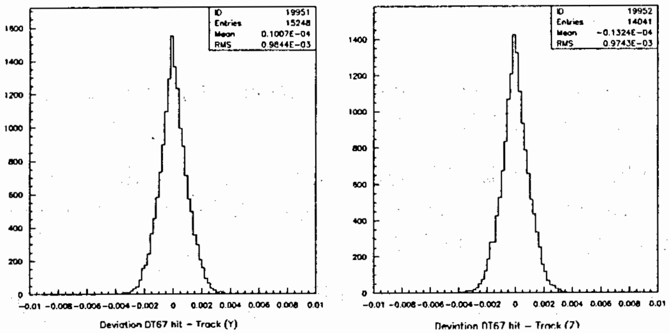

Fig. 4. *Residuals between the DT67 muon line and the hits used for the fit.*

The residuals between the obtained DT67 muon line and the position of DT67 hits are shown in figure 4, for Y– and Z–planes, respectively. The obtained values of RMS are 0.9–1.0 mm. These values are almost independent of plane number and position of hit at the plane. So these values were taken as RMS for the whole plane.

We were performing DT67 fit using several RMS values; The best one, being set in alignment file and used in Phenix, is **0.95 mm.** It is used in calculation of hit coordinate error. The χ^2 , as well as P(χ^2) distributions for this RMS value, are shown in figure 5. With this RMS value, the procedure of common (ST67+DT67) fit doesn't distort the P(χ^2) distribution obtained from ST67 fit.

The RMS value for the DT67 drift tubes is the combined product of read–out electronics accuracy, calibration uncertainties, variations of V_{dr} for given gas mixture, etc. Obviously, it has to be recalculated if any serious changes of gas mixture, hardware, or fitting procedure have been done.

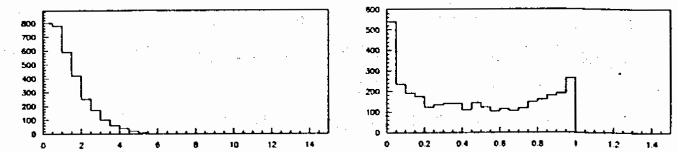

Fig. 5. *χ^2 and $P(\chi^2)$ distributions for DT67 muon line fit. RMS(DT67 plane) = 0.95 mm.*

Previous data taking periods demonstrate the stability of the DT67 characteristics. The detector covering the scattered muon at the azimutal angle range $\theta \geq 40mrad$ with the efficiency about 97% by the track. An information from DT67 allows to decrease in a few times the error of the muon line parameters, what is demonstrated in the figure 6.

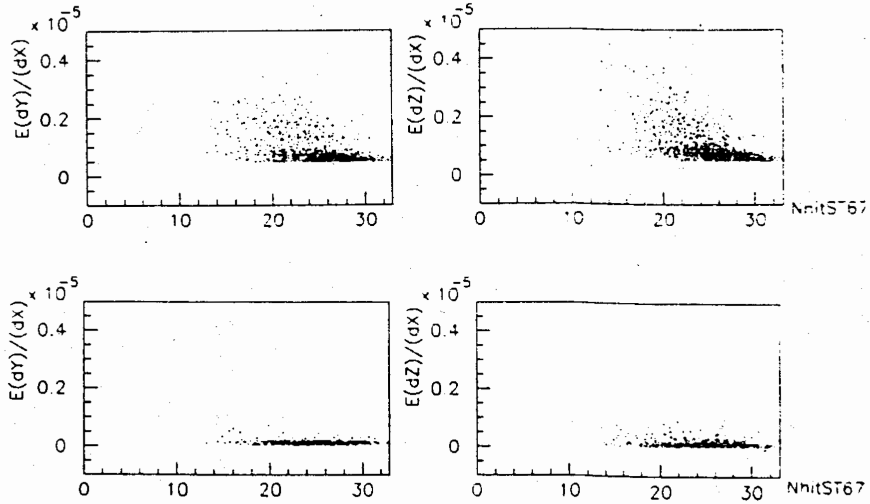

Fig. 6 *Dependence of the muon line parameters errors on the number of ST67 hits (upper plots). Dependence of the muon line parameters errors on the number of both ST67 and DT67 hits (down plots).*

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