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ASME METHOD FOR PARTICLE RECONSTRUCTION

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Метод ASME для восстановления параметров частиц

Метод приближенного решения уравнения движения в магнитном поле (ASME) используется для восстановления параметров заряженной частицы. Метод обеспечивает хорошую точность восстановления импульсных, угловых и пространственных параметров частиц, зарегистрированных в координатных детекторах. Обсуждается его применение для установок CBM, HADES и MPD/NICA.

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ASME Method for Particle Reconstruction

The method of approximate solution of motion equation (ASME) was used to reconstruct the parameters for charged particles. It provides a good precision for momentum, angular and space parameters of particles registered in coordinate detectors. The application of the method for CBM, HADES and MPD/NICA setups is discussed.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

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1. CHARGED PARTICLE RECONSTRUCTION

The coordinate (track) detectors are extensively used in high energy physics to determine parameters of the produced secondary particles. For that the track detectors are usually placed into the magnetic field. The trajectory of charged particle in magnetic field is complicated curve whose curvature depends on particle momentum and on the value of the magnetic field in the track points. The track detector records the spatial coordinates (or some other values depending on them) of the trajectory of charged particle. The task is to determine the parameters of the particle (momentum and angles) using the measured coordinates of the particle track.

The equation of motion of charged particle in magnetic field is written usually in the following form:

$$\frac{d\mathbf{P}}{dt} = \frac{e}{c}\mathbf{v} \cdot \mathbf{H} + \frac{\mathbf{P}}{P} \cdot \frac{dP}{dt}. \tag{1}$$

Very effective method of approximate solution of motion equation (ASME) was used in JINR for track reconstruction in big bubble chambers [1].

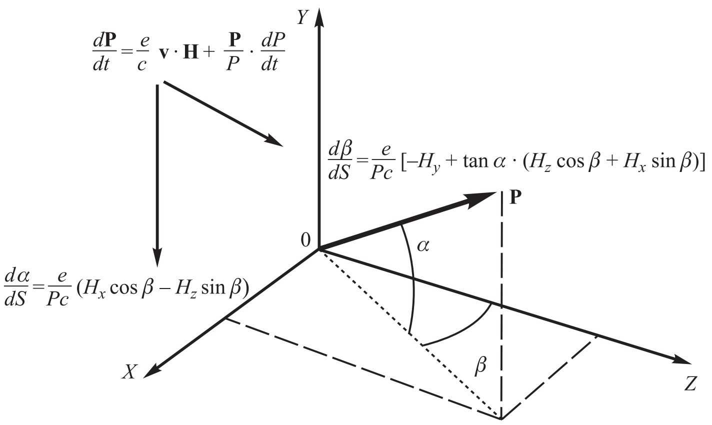

Fig. 1. Coordinate system for ASME method

The equation of motion can be split into two equations in Cartesian coordinate system (see Fig. 1):

$$\frac{d\alpha}{dS} = \frac{e}{Pc}\Big(H_x \cos\beta - H_z \sin\beta\Big) \tag{2}$$

and

$$\frac{d\beta}{dS} = \frac{e}{Pc}\Big[-H_y + \tan\alpha \cdot (H_z \cos\beta + H_x \sin\beta)\Big], \tag{3}$$

where

P — momentum of the particle,
β — azimuth angle,
α — deep angle,
S — length of track,
H — magnetic field.

To get the coordinates of the particle trajectory it is necessary to integrate Eqs. (2) and (3).

First integration procedure gives the equations about azimuth and deep angles:

$$\beta(S) = \beta_0 + \frac{e}{c}\int_0^S \frac{1}{P}\,\Big[-H_y + \tan\alpha \cdot (H_z \cos\beta + H_x \sin\beta)\Big] dS$$

and

$$\sin\alpha(s) = \sin\alpha_0 + \frac{e}{c}\int_0^s \frac{1}{P}\,\Big(H_x \cos\beta - H_z \sin\beta\Big) dS.$$

Second integration procedure gives the equations about x and y coordinates of the particle trajectory:

$$x(s) = x_0 + \int_0^s \sin\beta(s) ds$$

and

$$y(s) = y_0 + \int_0^s \tan\alpha(s) ds.$$

In that way the coordinates of track trajectory depend on track parameters P_0, β_0, $\tan\alpha_0$, x_0 and y_0 at initial point.

Then, it is necessary to minimize the following functionals to get the track parameters:

in $X0Z$ plane

$$\chi^2 = \sum_{i,j}^{n} (x_i^{\exp} - x_i)\,(G + D_x E)^{-1}_{ij}\,\left(x_j^{\exp} - x_j\right) \Rightarrow \min$$

and in $Y0Z$ plane

$$w^2 = \sum_{i,j}^{n} (y_i^{\exp} - y_i)\,(G + D_y E)^{-1}_{ij}\,\left(y_j^{\exp} - y_j\right) \Rightarrow \min,$$

where
G — matrix of multiple scattering,
D_x, D_y — matrices of errors,
E — unity matrix,
$x_i^{\exp}$, $y_i^{\exp}$ — measured points of the track at some fixed z_i coordinates.

How to minimize these functionals? The iterative variation procedure is suggested to use for this task. Let's take the following expansion of x and y coordinates for $k+1$ iteration:

$$x_i^{k+1} = x_i^k + \delta x_0 + \left.\frac{\partial x}{\partial \beta}\right|_i \delta\beta_0 + \left.\frac{\partial x}{\partial p}\right|_i \delta p_0$$

and

$$y_i^{k+1} = y_i^k + \delta y_0 + \left.\frac{\partial y}{\partial \tan\alpha}\right|_i \delta \tan\alpha_0,$$

where δpar_0 are increments of corresponding arguments (x_0, y_0, p_0, β_0 or $\tan\alpha_0$).

It is easy to show that the condition of minimum for these functionals

$$\frac{\partial \chi^2}{\partial \delta par_i} = 0 \quad \text{and} \quad \frac{\partial w^2}{\partial \delta par_i} = 0$$

comes to the system of linear equations:

$$\begin{cases} a_{11}\delta x_0 + a_{12}\delta\beta_0 + a_{13}\delta p_0 = b_1 \\ a_{21}\delta x_0 + a_{22}\delta\beta_0 + a_{23}\delta p_0 = b_2 \\ a_{31}\delta x_0 + a_{32}\delta\beta_0 + a_{33}\delta p_0 = b_3 \end{cases}$$

$$\begin{cases} a_{44}\delta y_0 + a_{45}\delta \tan\alpha_0 = b_4 \\ a_{54}\delta y_0 + a_{55}\delta \tan\alpha_0 = b_5 \end{cases}$$

and each $k+1$ iteration gives new values of parameters:

$$par_0^{k+1} = par_0^k + \delta par_0.$$

Minimization by variation procedure takes 2–3 iterations to get the minimum. Results are:

$x_0,\ y_0,\ \beta_0,\ \alpha_0,\ p_0$ — parameters of the track at the first point,

$\sigma_x^2,\ \sigma_y^2,\ \sigma_\beta^2,\ \sigma_\alpha^2,\ \sigma_P^2,\ \delta_{P\beta}$ — errors and correlations.

2. ASME FOR CBM

Method ASME was tested for CBM setup [2] (GSI, Germany) that is planned to build up for investigation of hot and dense matter. Silicon tracking station (STS) of CBM consists of some (7–10) Si planes (Fig. 2) of various thickness placed into essentially non-uniform magnetic field (Fig. 3). Si plane registers X and Y coordinates of track moving through the magnetic field. Z coordinate of the track is taken equal to Z position of corresponding Si plane.

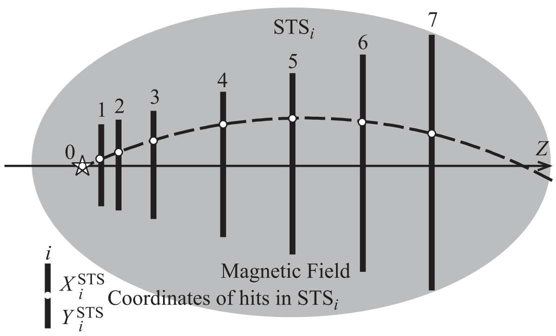

Fig. 2. Scheme of Silicon Tracking Station (STS) of CBM setup

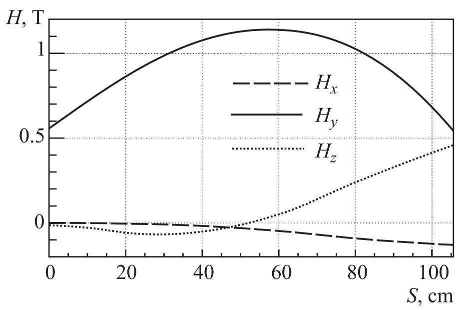

Fig. 3. Magnetic field along the track in CBM STS

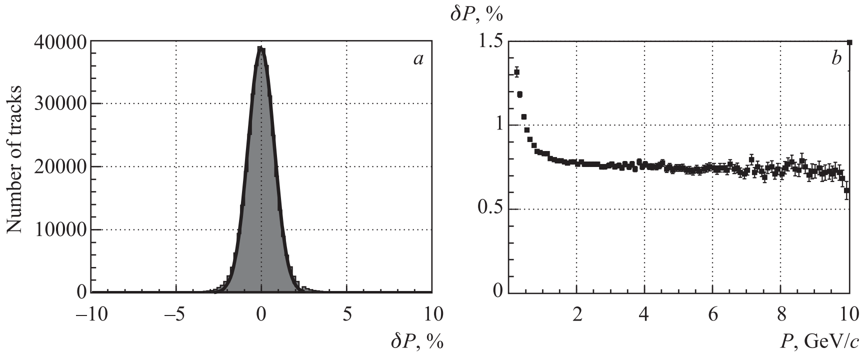

Fig. 4. Momentum resolution $\delta P \sim 0.79\%$ (*a*) and momentum resolution vs momentum (*b*) for CBM STS (7 Si planes)

There were used $4 \cdot 10^5$ tracks simulated by URQMD (central Au+Au collisions at $25A$ GeV) and processed by GEANT procedure. The X and Y coordinates of track points (so-called hits) were selected by special TrackFinder procedure [5]. Some results of track reconstruction using ASME algorithm are shown in Fig. 4 for 7 STS planes ($d\mathrm{Si}_{\mathrm{tot}} \sim 1200\ \mu$m).

Momentum resolution for 8 STS planes ($d\mathrm{Si}_{\mathrm{tot}} \sim 3500\ \mu$m) is $\delta P_0 \sim 1.40\%$.

3. ASME FOR HADES

HADES [3] (GSI, Germany) is functioning setup designed to study hadron–nucleon, hadron–nucleus and nucleus–nucleus interactions at intermediate energies. Main part of HADES consists of multilayer drift chambers (MDC) [4] and intends to register the tracks of charged particles. 2 sets of MDC (Fig. 5) are placed before extremely non-uniform magnetic field (Fig. 6) and another 2 sets

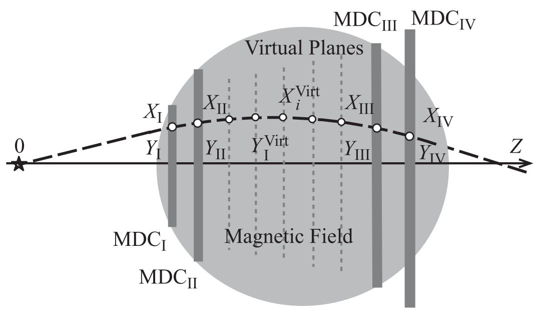

Fig. 5. MDC system of HADES setup

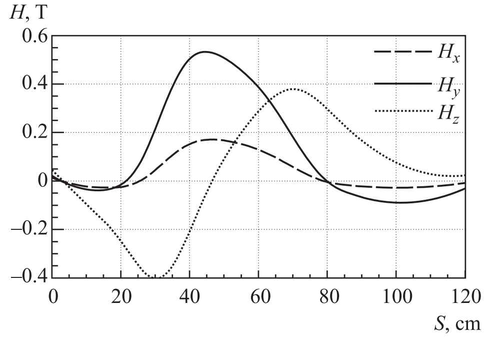

Fig. 6. Magnetic field along the track in MDCs at HADES

after it. It is necessary to note that MDC do not register the coordinates of track points but drift times t_i for corresponding sense wires of layers.

Therefore, track reconstruction in HADES is now double-step procedure:
1st — determination of inner and outer track segments parameters (x_i, y_i, z_i, i = 1–4) that implies fit by straight line [6] (input data — drift times t_i, track model — straight line),
2nd — determination of momentum by Spline [7] or RK (Runge–Kutta) procedure using coordinates of track segments (x_i, y_i, z_i, i = 1–4) as input data.

ASME was tested for the 2nd step of the track reconstruction procedure. The following results were obtained for reconstructed parameters of protons (Fig. 7)

ASME ensures better resolution than Spline at the same count rate. As far as RK procedure is concerned, ASME ensures practically the same resolution at 4–5 less count rate.

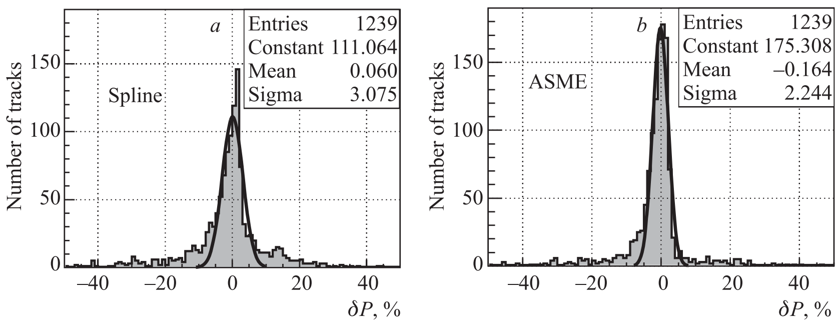

Fig. 7. Momentum resolution for protons: *a*) spline procedure ($\delta P \sim 3.08\%$); *b*) ASME ($\delta P \sim 2.24\%$)

4. ASME FOR HADES — FULLFIT PROCEDURE

Weakness of the present double-step track reconstruction procedure in HADES:

— does not take into account energy loss and multiple scattering,
— hard to propagate errors (momentum and angles) for track,
— global min sometimes was not found,
— not quite sufficient fakes rejection (hits filtering),
— problem of close tracks.

The solution is to combine the 1st (segments fit) [6] and the 2nd step (momentum fit) [7] into single-step FullFit procedure. In this case, the functional to be minimized is written in the following form:

$$w^2 = \sum_{i,j}^{n} (t_i^{\exp} + t_{\text{off}} - T_i)(G_t + D_t E)^{-1}_{ij} (t_j^{\exp} + t_{\text{off}} - T_j) w_{ij}, \qquad (4)$$

where

$T_i = T(d_i)$ — drift time (calculated),
$d_i = d(x_0,\, y_0,\, \beta_0,\, \alpha_0,\, P_0)_{i-\text{layer}}$ — distance between track and sense wires,
w_{ij} — Tukey weights,
G_t — matrix of multiple scattering in time representation,
D_t — matrix of drift times errors.

Expected results:

— sufficient accuracy of determination of track parameters, taking into account energy loss and multiple scattering,
— calculation of errors of parameters (important for kinematic fit),
— better hits filtering during track reconstruction.

CONCLUSION

ASME method was successfully implemented for particle reconstruction on HADES and CBM setup. ASME method takes into account energy loss and multiple scattering, provides a good momentum resolution, permits one to calculate both track parameters and errors and has a sufficient count rate. FullFit (single-step procedure, proposed further development of ASME for HADES) seems to be more effective for track reconstruction, especially at large multiplicities.

ASME method can be successfully realized for MPD detector (NICA project, JINR). Since TPC of the MPD detector is very close to MDC system of HADES setup in mode of functioning, then FullFit version of ASME is the most optimal to reconstruct parameters of charged particles in MPD.

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