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Alignment, Based on the Measurements of Particle Non-Bend Coordinate

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Alternative scheme of the GEM muon system local alignment is proposed. Correction of sagitta measurement is fulfilled with the help of particle non-bend coordinate measurements.

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1 Introduction

The local alignment of the GEM muon system uses readings of optical straightness monitors for correction of sagitta systematic error, caused by deviations of muon chambers from their ideal positions [1],[2].

It will be shown in this note, there is another, alternative or additional, approach, based on the measurement of particle coordinate in non-bend plane, z-coordinate in the GEM coordinate system.

Correlations between two orthogonal measurements of straightness monitors were demonstraited in [2], and they make the system of straightness monitor readings highly redudant.

The new approach is a development of this principle.

2 Description of the method

Let introduce function $F(\phi,\theta)$ - false sagitta dependence on the direction of trajectory [2]. The value of this function is defined by the magnitude of chamber deviation from their right positions.

Misalignment of each chamber as a plane rigid body with respect to global coordinate system is characterized by six parameters: three displacements D_x,D_y,D_z and three rotations R_x,R_y,R_z (see fig. 1).

If the values of D_x,D_y are much smaller than distances between chambers and IP, and R_x,R_y,R_z are much smaller than 1rad, we can neglect second order of magnitude terms, and the function $F(\theta,\phi)$ has the following simple polinomial in $tg(\phi)$ and $tg(\theta)$ form:

$$F(\phi,\theta) \approx a_{00} + a_{10} * tg(\phi) + a_{01} * tg(\theta) + a_{11} * tg(\phi) * tg(\theta) + a_{20} * tg^2(\phi), \tag{1}$$

where

$$a_{00} = c * D_x^{out} + (1-c) * D_x^{inn} - D_x^{mid}, \tag{2}$$

$$a_{10} = -c * D_y^{out} - (1-c) * D_y^{inn} + D_y^{mid}, \tag{3}$$

$$a_{01} = -c * R_y^{out} * Y^{out} - (1-c) * R_y^{inn} * Y^{inn} + R_y^{mid} * Y^{mid}, \tag{4}$$

$$a_{11} = c * R_x^{out} * Y^{out} + (1-c) * R_x^{inn} * Y^{inn} - R_x^{mid} * Y^{mid}, \tag{5}$$

$$a_{20} = c * R_z^{out} * Y^{out} + (1-c) * R_z^{inn} * Y^{inn} - R_z^{mid} * Y^{mid}, \tag{6}$$

and

$$c = \frac{Y^{mid} - Y^{inn}}{Y^{out} - Y^{inn}}. \tag{7}$$

The coefficients a_{ij} of this polynomial are independent.

In analogy with the function of false sagitta $F(\phi,\theta)$, related to the bending direction measurements, we can introduce another function (say, non-straightness) $N(\phi,\theta)$, which equals to the measured value of sagitta in non-bending direction.

For the same assumption about magnitudes of chamber movements, the function $N(\phi,\theta)$ has the polynomial form (compare with /1/):

$$N(\phi,\theta) \approx b_{00} + b_{10} * tg(\phi) + b_{01} * tg(\theta) + b_{11} * tg(\phi) * tg(\theta) + b_{02} * tg^2(\theta), \tag{8}$$

where

$$b_{00} = c * D_z^{out} + (1-c) * D_z^{inn} - D_z^{mid}, \tag{9}$$

$$b_{01} = -c * D_y^{out} - (1-c) * D_y^{inn} + D_y^{mid}, \tag{10}$$

$$b_{10} = c * R_y^{out} * Y^{out} + (1-c) * R_y^{inn} * Y^{inn} - R_y^{mid} * Y^{mid}, \tag{11}$$

$$b_{11} = c * R_z^{out} * Y^{out} + (1-c) * R_z^{inn} * Y^{inn} - R_z^{mid} * Y^{mid}, \tag{12}$$

$$b_{02} = c * R_x^{out} * Y^{out} + (1-c) * R_x^{inn} * Y^{inn} - R_x^{mid} * Y^{mid}, \tag{13}$$

and

$$c = \frac{Y^{mid} - Y^{inn}}{Y^{out} - Y^{inn}}. \tag{14}$$

Comparing equations () and (), we see, that

$$a_{10} = b_{01}, \tag{15}$$

$$a_{01} = -b_{10}, \tag{16}$$

$$a_{11} = b_{02}, \tag{17}$$

and

$$a_{20} = b_{11}. \tag{18}$$

So, particle sagitta measurements in non-bend direction contain an information about all the constituent parts of the function $F(\phi, \theta)$, false sagitta in bending direction, except the constant term a_{00}.

The measured value of trajectory sagitta in non-bend direction is determined by the following factors:

- Misalignment of muon chamber tower;
- Multiple scattering of particle in the middle chamber;
- Deviation of trajectory from the straight line due to nonuniformity of magnetic field;
- Chamber deformations.

Impact of the last two factors will be discussed later. For the first step we will assume, that it is negligible.

In this case we propose the following procedure of the function $F(\phi, \theta)$, false sagitta in bend direction, determination.

Statistics of n_{st} particles with momentum greater than P_{min} is collected for every muon chamber tower.

Set of non-bend direction sagitta measurements $N^i, i = 1, n_{st}$ is fitted by polinomial

$$N^{fit}(\phi^{mes}, \theta^{mes}) = b_{00}^{fit} + b_{10}^{fit} * tg(\phi^{mes}) + b_{01}^{fit} * tg(\theta^{mes}) + b_{11}^{fit} * tg(\phi^{mes}) * tg(\theta^{mes}) + b_{02}^{fit} * tg^2(\theta^{mes}), \tag{19}$$

where ϕ^{mes} and θ^{mes} are the measured values of trajectory angles.

Coefficients b_{10}^{fit}, b_{01}^{fit}, b_{11}^{fit}, b_{02}^{fit} are used for determination of the corresponding coefficients a_{01}, a_{10}, a_{20}, a_{11} of the function $F(\phi, \theta)$ (see eqs./15/-/18/).

For the determination of the remaining coefficient a_{00} the reading of the straightness monitor F^{mon}, situated somewhere on the tower perimeter, is used:

$$a_{00} = F^{mon} - a_{10} * tg(\phi^{mon}) - a_{01} * tg(\theta^{mon}) - a_{11} * tg(\phi^{mon}) * tg(\theta^{mon}) - a_{20} * tg^2(\phi^{mon}), \tag{20}$$

where ϕ^{mon} and θ^{mon} are the angles of the straightness monitor array.

The proposed method was tested with the MonteCarlo program.

This program take into account various factors, affecting the correction of sagitta measured value:

- multiple scattering of particles;
- limited size of interaction region;
- limited coordinate resolution of chambers.
- possible non-orthogonality of cathode strips and anode wires.

3 Realization of the scheme. MonteCarlo simulations

The proposed scheme requires z-resolution of muon chambers, adequate to $25\mu m$ limit for the sagitta alignment error, and this value is higher, than the TDR specified value.

The required value of z-resolution depends on n_{st}, total number of particles, used for polinomial coefficients determination, and on momenta of these particles.

The assumptions of the MonteCarlo calculation were:

- the value of z-resolution for all the tower solid angle is constant, and every particle with momentum greater than p_{min}, detected in this tower, can be used for alignment purposes;
- $n_{st} = 4000$;
- $p_{min} = 15GeV/c$;
- tolerances for the middle and the outer chamber positions with respect to the inner one:

  $D_x^{mid} \leq \pm 3mm$;
  $D_y^{mid} \leq \pm 3mm$;
  $D_z^{mid} \leq \pm 3mm$;
  $R_x^{mid} \leq \pm 2mrad$;
  $R_y^{mid} \leq \pm 2mrad$;
  $R_z^{mid} \leq \pm 6mrad$;
  $D_x^{out} \leq \pm 5mm$;
  $D_y^{out} \leq \pm 5mm$;
  $D_z^{out} \leq \pm 5mm$;
  $R_x^{out} \leq \pm 3mrad$;
  $R_y^{out} \leq \pm 3mrad$;
  $R_z^{out} \leq \pm 8mrad$;
- range of the interaction region $\Delta Z = \pm 5cm$
- orthogonality (or knowing of the angle) between cathode strips and anode wires is better than 10mrad.

The dependence of the corrected sagitta error RMS_{fs} on the z-resolution of muon chambers σ_z is shown in Table 1.

Table 1: The accuracy of bend-direction sagitta correction versus z-coordinate resolution of muon chambers ($p_{min} = 15GeV/c, n_{st} = 4000$)

σ_z	0	$100\mu m$	$200\mu m$	$300\mu m$	$400\mu m$	$500\mu m$	
RMS_{fs}	$13\mu m$	$14\mu m$	$16\mu m$	$18\mu m$	$21\mu m$	$24\mu m$	

So, if z-resolution of muon chambers is $500\mu m$ or better, statistics of 4000 particles with momentum higher than 15GeV/c per tower (one-hour run for the nominal SSC luminosity $L = 10^{33}cm^{-2}s^{-1}$, see [3]) allows to correct sagitta measured value with required accuracy $25\mu m$.

For the luminosity $L = 10^{32}cm^{-2}s^{-1}$ the trigger rate is ten times lower and it is possible to decrease the momentum threshold down to 10GeV/c. In this case one-hour run gives statistics $n_{st} = 2000$ per tower and it allows to correct sagitta with accuracy $30\mu m$ ($\sigma_z = 500\mu m$).

The possible hardware implementation of this option is the 100% anode wire readout in several layers with a simple yes/no electronics.

Readout of each wire (wire spacing is 2.5mm) in one layer provides z-resolution

$$\sigma_z^{1l} = \frac{2.5mm}{\sqrt{12}} \approx 700\mu m. \tag{21}$$

For two layers:

$$\sigma_z^{2l} = \frac{\sigma_z^{1l}}{\sqrt{2}} \approx 500\mu m. \tag{22}$$

4 Effect of nonuniform magnetic field

It's necessary to stress here, that the deviation of particle trajectory in non-bend direction, if it is constant inside tower solid angle, affects on the value of the irrelevant coefficient b_{00}^{fit} only.

So, even if the magnetic field has nonvanishing components, caused trajectory deviation in non-bend direction, but these components don't change considerably inside tower solid angle, it doesn't affect perfomance of this method.

Uniformity of the GEM magnetic field was studied by S.Timofeev,see [4].

His calculations show, that magnetic field in the barrel region is symmetrical about the beam axis to 0.23%, and, cosequently, is highly uniform inside every barrel tower solid angle.

Magnetic field in the last superlayer of the endcap muon chambers is non-symmetric about z-axis to 10.5% in worse case. The main source of this nonuniformity is the ferromagnetic FFS support. So, the applicability of this method for the muon towers, close to the FFS support, needs more study.

5 Chamber deformations

The ability to correct sagitta errors, caused by different kinds of chamber deformations, is one of the most attractive features of this method.

MonteCarlo calculations demonstrate high correction accuracy of sagitta errors, caused by torsion deformations, thermal expansion/contraction, gravitational sag of muon chambers.

5.1 Torsion deformations

If tower chambers have torsion deformations, the function of false sagitta $F(\phi,\theta)$ has the following form:

$$F(\phi,\theta) \approx a_{00} + a_{10} * tg(\phi) + a_{01} * tg(\theta) + a_{11} * tg(\phi) * tg(\theta) + a_{20} * tg^2(\phi) + a_{21} * tg^2(\phi) * tg(\theta), \tag{23}$$

the function of non-straightness $N(\phi,\theta)$:

$$N(\phi,\theta) \approx b_{00} + b_{10} * tg(\phi) + b_{01} * tg(\theta) + b_{11} * tg(\phi) * tg(\theta) + b_{02} * tg^2(\theta) + b_{12} * tg(\phi) * tg^2(\theta), \tag{24}$$

and

$$a_{21} = b_{12}. \tag{25}$$

The last equation means that it is possible to correct sagitta error, caused torsion deformations of muon chambers, with the help of non-bend coordinate measurements.

MonteCarlo calculations confirm this statesment. Torsion deformations less than 3mrad are corrected so precisely, that it doesn't change the results, shown in Table 1.

5.2 Thermal expansion/contraction

MonteCarlo simulation demonstrates the ability of the proposed method to control this kind of chamber deformations in wide range of temperature difference. For $\Delta t^0 = \pm 10^0 C$ there are no impact on the previous results.

5.3 Gravitational sag

The major effect of gravitation on the form of muon chamber surface is a sag in z-direction. The minor effect is a sag in x-direction. This approach allows to correct systematic errors of bend-direction sagitta, caused by both these deformations as well.

If chambers have sags in z-direction, the function of false sagitta $F(\phi,\theta)$ has the following form:

$$F(\phi,\theta) \approx a_{00} + a_{10} * tg(\phi) + a_{01} * tg(\theta) + a_{11} * tg(\phi) * tg(\theta) + a_{20} * tg^2(\phi) + a_{12} * tg(\phi) * tg^2(\theta), \quad (26)$$

and the function of non-straightness $N(\phi,\theta)$:

$$N(\phi,\theta) \approx b_{00} + b_{10} * tg(\phi) + b_{01} * tg(\theta) + b_{11} * tg(\phi) * tg(\theta) + b_{02} * tg^2(\theta) + b_{03} * tg^3(\theta), \quad (27)$$

where

$$a_{12} = b_{03}. \quad (28)$$

For sag in x-direction:

$$F(\phi,\theta) \approx a_{00} + a_{10} * tg(\phi) + a_{01} * tg(\theta) + a_{11} * tg(\phi) * tg(\theta) + a_{20} * tg^2(\phi) + a_{30} * tg^3(\phi), \quad (29)$$

and

$$N(\phi,\theta) \approx b_{00} + b_{10} * tg(\phi) + b_{01} * tg(\theta) + b_{11} * tg(\phi) * tg(\theta) + b_{02} * tg^2(\theta) + b_{21} * tg^2(\phi) * tg(\theta), \quad (30)$$

and, again,

$$a_{30} = b_{21}. \quad (31)$$

MonteCarlo calculations show, that bend-direction sagitta errors could be precisely corrected right up to 1cm of chamber sag amplitudes.

5.4 Complex chamber deformations

The proposed method provides us the unique possibility to control complex chamber deformations, caused by production defects, support structure bends and so on.

This approach uses muons, continuously distributed over all tower solid angle, whereas straightness monitors can control only discrete set of points.

MonteCarlo simulation shows, that with sufficient statistics of particles, it is possible to correct bend-direction sagitta errors, caused by different deformations of chamber parts.

6 Conclusions

The proposed procedure of the GEM muon system alignment can be both an alternative, and an addition of the current alignment scheme.

As an alternative, this procedure has the following advantages:

- number of straightness monitors could be drastically reduced;
- gaps for light between the first and the second barrel towers and between the third and the fourth barrel towers could be eliminated,
- it allows to control large variety of chamber deformations, which can't be controled with six straightness monitors (the most important example is the gravitational sag),

and the disadvantage:

- this procedure requires at least one-hour run statistics, so it can't control fast change of chamber position (tower oscillations).

As an addition, this method complements the method, based on the straightness monitor measurements, and thereby it increases reliability of the muon system alignment.

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