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Use of Background Particles for Calibration of the GEM Muon System

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Procedures for calibration of the GEM muon system with prompt muons are proposed. Required amounts of statistics are estimated.

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Contents

P i
1 Introduction 1
2 Rates of background particles 2
2.1 Single-muon rates 2
2.2 $Z^0 \to \mu^+\mu^-$ rate 2
3 Local alignment with background particles 3
4 Global alignment with background particles 6
4.1 Single muons: alignment of muon towers with respect to IP, central tracker and calorimeter 6
4.2 $Z^0 \to \mu^+\mu^-$: alignment of muon towers with respect to each other 7
5 $Z^0 \to \mu^+\mu^-$: calibration of the magnetic field measurements 9

1 Introduction

Use of experimental data for calibration of detector is the important and complex problem of any HEP experiment. We will consider several issues, concerning, mainly, alignment of the GEM muon system with the background particles and, as well, calibration of the magnetic field with $Z^0 \to \mu^+\mu^-$ decays.

Alignment of the GEM muon system could be divided on the local alignment, i.e. alignment of muon superlayers with respect to each other inside one projective tower, and the global one, i.e. alignment of muon towers as wholes with respect to the interaction point (IP), with respect to each other, with respect to other GEM subdetectors (calorimeter, central tracker) and, finally, with respect to the magnet.

The requirements for the GEM muon system alignment performance were estimated in [1].

The most challenging problem of high p_t-momentum muons measurement, belonging mainly to the local alignment business, is supposed to be resolved by the method of sagitta correction with the interpolation of straightness monitor readings [2]. For the local alignment purposes the background particles could play important, but supplementary role.

Global alignment requirements are not very severe [1], and they could be fulfilled during muon system construction and installation. But there is one exception. For p_t measurement when one of SL is lost and for more accurate measurement of transverse momentum in the several TeV region, vertex constraint could be implemented [3]. The role of the background muons for the alignment of muon towers with respect to IP will be decisive in this case.

Sources of background particles are:

- cosmic fluxes;
- muons from the SSC tunnel;
- prompt muons from IP, including $Z^0 \to \mu^+\mu^-$ decays;
- secondary particles,penetrating to the muon system: punchthrough and decay muons.

Cosmic muons could be used for calibration of the GEM muon system before the SSC running. Their flux has the maximal value of order few Hz per square meter for horizontal surface, and, probably, they will be useful for alignment of the large part of the GEM muon barrel.

Muons from the beam halo could be used for alignment of the muon system endcaps before the collider will reach considerable luminosity.

The subject of this note is the background, produced due to pp-interactions at IP: prompt muons and secondary particles. It will be shown, that fluxes of this kind background particles are sufficient for certain alignment purposes even for luminosity $L \sim 10^{31} cm^{-2} s^{-1}$. For the nominal SSC luminosity $L \sim 10^{33} cm^{-2} s^{-1}$ background flux will provide us sufficient information for the global alignment of the GEM muon system.

2 Rates of background particles

2.1 Single-muon rates

We will consider one of 48 muon system sectors (see GEM Baseline II [4]). It consists of five projective towers, shown in Fig.1. We will estimate rates of background particles in dependence on the transverse momentum threshold p_t^{min} for each tower separately. It was shown in [5], for $p_t^{min} \geq 15GeV/c$ flux of background particles consists exclusively from prompt muons, originated at IP. For $p_t^{min} \simeq 5GeV/c$ background particles, penetrating into muon system, are mainly panchthrough particles and muons from π and K-meson decays. They could be used for the purposes of local alignment. Estimated rates of background particles for the nominal SSC luminosity $L \sim 10^{33}cm^{-2}s^{-1}$ are given in Table.1.

Table 1: **The rates of background particles: number of particles per hour**

	Tower 1	Tower 2	Tower 3	Tower 4	Tower 5
$p_t > 5GeV/c$	80,000	70,000	60,000	50,000	240,000
$p_t > 15GeV/c$	5,500	4,800	4,000	3,300	16,000
$p_t > 25GeV/c$	1,100	950	800	660	3,200
$p_t > 50GeV/c$	55	48	40	33	160

2.2 $Z^0 \rightarrow \mu^+\mu^-$ rate

Decay $Z^0 \rightarrow \mu^+\mu^-$ is the unique for calibration purposes:

- well measured values of Z-boson mass and width:

$$m_Z = 91.173 \pm 0.020GeV$$

and

$$\Gamma_Z = 2.487 \pm 0.010GeV;$$

- large branching ratio for two muons mode:

$$Br(\mu^+\mu^-) = (3.34 \pm 0.04)\%$$

- high production cross section at SSC energy:

$$\sigma(pp \rightarrow Z^0X \rightarrow \mu^+\mu^-X) \geq 10^3pb; (p_t^\mu \geq 25GeV/c)$$

So, the rate of $Z^0 \rightarrow \mu^+\mu^-$ events for the luminosity $L \sim 10^{33}cm^{-2}s^{-1}$ will be 1-2 Hz, and in 10^7s (the usual one year run) more than 10 millions muon pairs coming from Z particles can be produced and used for GEM calibration, but we will see that one-month ($\sim 10^6$) may be sufficient for certain calibration purposes.

3 Local alignment with background particles

Adopted for GEM Baseline II scheme of local alignment, using interpolation of monitor readings for correction of particle sagittas, doesn't provide us information about absolute position of muon superlayers with respect to one of them (base superlayer). This information is surplus for the sagitta measurement, because all we need to know is the value of false sagitta.

But if we wish to apply vertex constraint for P_t measurement when one of superlayers is lost (necessary vertex resolution is $500 - 1000\mu m$) or for more accurate measurement of P_t in TeV region (required vertex resolution is $200\mu m$) [3], we need to know each chamber position with respect to the base, and we need to know the base chamber position with respect to IP. For the resolution of both these problems background particles play the decisive role. In this section we will consider the first one: definition of chamber positions with respect the base chamber inside one tower.

Let choose inner superlayer of the given tower as a base for local coordinate frame.

Parameters, characterizing misalignment of middle and outer superlayers with respect to the base are (i= mid,out):

- D_x^i - displacement in x-direction;
- D_y^i - displacement in y-direction;
- R_x^i - rotation around x-axis;
- R_y^i - rotation around y-axis;
- R_z^i - rotation around z-axis.

First it's necessary to determine the required accuracy of alignment parameters.

There are two estimations for these requirements: maximal and minimal.

Maximal requirements arise when we pose the aim to know the relative chamber position with accuracy sufficient for sagitta resolution of 25μ, i.e. for p_t-measurement without corrections by straightness monitor readings interpolation.

The maximal reqirements are:

- $\sigma(D_x^{mid}) \leq 10\mu$;
- $\sigma(D_y^{mid}) \leq 100\mu$;
- $\sigma(R_x^{mid}) \leq 0.2mrad$;
- $\sigma(R_y^{mid}) \leq 0.02mrad$;
- $\sigma(R_z^{mid}) \leq 0.4mrad$.

The maximal requirements for outer superlayer are twice less restrictive.

Minimal requirements are defined by the vertex constraint value. If the accuracy of IP position with respect to the tower is 500μ, it is not necessary to know relative position of

superlayers with ten microns accuracy, because p_t-measurement resolution will be defined by the accuracy of vertex constraint only.

Minimal requirements for the value of vertex constraint 500μ are ten times less restrictive than maximal ones:

- $\sigma(D_x^{mid}) \leq 100\mu$;
- $\sigma(D_y^{mid}) \leq 1000\mu$;
- $\sigma(R_x^{mid}) \leq 1.5mrad$;
- $\sigma(R_y^{mid}) \leq 0.15mrad$;
- $\sigma(R_z^{mid}) \leq 3mrad$.

We propose the following procedure for definition of chamber positions with respect to the base chamber inside one tower using background particles.

The transverse momentum of any particle, detected by all three superlayers of the tower, will be determined by sagitta measurement, corrected with the interpolation of straightness monitor readings.

Inner superlayer measures x-coordinates of the particle trajectory in six layers with accuracy of order 75μ. It means, that we know x-coorinate of particle on the plane $y = Y^{inn}$ with the accuracy

$$\delta(x^{inn}) \simeq 75\mu/\sqrt{6} \approx 30\mu, \tag{1}$$

and we know the value $A_x^{inn} \equiv (\frac{dx}{dy})_{y=Y^{inn}}$ with the accuracy

$$\delta(A_x^{inn}) \simeq 75\mu/15cm = 0.5mrad. \tag{2}$$

The resolution of $A_z \equiv dz/dy$ is determined by z-measurement resolution ($\sigma_z \simeq 2cm$) and by the distance between Outer and Inner superlayers ($\sim 4.5m$). So,

$$\delta A_z \simeq 4mrad. \tag{3}$$

Using this information: p_t, x, A_x, we can propagate the particle trajectory through magnetic field, predict values of x and A_x at the planes $y = Y^{mid}$ and $y = Y^{out}$, and compare predicted values with measured ones. Differences between predicted and measured values provide us information about relative displacements and rotations of superlayers.

We will consider the middle superlayer for definiteness.

The dispersion of the x-coordinate predicted value

$$\delta x^{pr} \simeq (Y^{mid} - Y^{inn})\delta(A_x^{inn}) \simeq 2m * 0.5 * 10^{-3} = 1mm. \tag{4}$$

The accuracy of alignment parameters definition is determined by N_{st}, the number of particles, detected by the given tower.

With statistics N_{st} we can determine mean value of the x-distribution with the accuracy $\sim 1mm/\sqrt{N_{st}}$. So, to know the relative position of chambers with the accuracy, say, 100μ, statistics of $(1mm/100\mu)^2 = 10^2$ particles is needed.

The MonteCarlo calculations, accounting for all five parameters D_x, D_y, R_x, R_y, R_z, show that this rough estimation is valid in the order of magnitude.

Difference between measured and predicted values of x is equal to

$$\Delta x \equiv x^{mes} - x^{pr} = -D_x + A_x D_y - zA_x R_x + zR_y - xA_x R_z, \tag{5}$$

where we assumed, that $D_x, D_y << Y^{mid} - Y^{inn}$ and $R_x, R_y, R_z << 1rad$.

For the same assumptions difference between measured and predicted values of A_x is equal to

$$\Delta A_x \equiv A_x^{mes} - A_x^{pr} = A_x A_z R_x - A_z R_y + (1 + A_x^2) R_z. \tag{6}$$

We will minimize two functionals:

$$\Phi_x = \sum_{i=1}^{N_{st}} (\Delta x)^2 \tag{7}$$

and

$$\Phi_A = \sum_{i=1}^{N_{st}} (\Delta A_x)^2. \tag{8}$$

Both functionals are quadratic functions of D_x, D_y, R_x, R_y, R_z. So, the problem of minimization is reduced to two independent systems of linear equations:

$$\partial\Phi_x/\partial D_x = 0,$$

$$\partial\Phi_x/\partial D_y = 0,$$

$$\partial\Phi_x/\partial R_x = 0,$$

$$\partial\Phi_x/\partial R_y = 0,$$

$$\partial\Phi_x/\partial R_z = 0,$$

and

$$\partial\Phi_A/\partial R_x = 0,$$

$$\partial\Phi_A/\partial R_y = 0,$$

$$\partial\Phi_A/\partial R_z = 0.$$

MonteCarlo program, simulating coordinate measurement of particle trajectory by distorted tower of muon chambers and minimizing Φ_x and Φ_A, was written.

MonteCarlo calculations show that with statistic $N_{st} = 10^3$ it is possible to reach the following accuracy of alignment parameters knowing:

- $\sigma(D_x^{mid}) \leq 60\mu$;
- $\sigma(D_y^{mid}) \leq 400\mu$;
- $\sigma(R_x^{mid}) \leq 1mrad$;
- $\sigma(R_y^{mid}) \leq 0.05mrad$;

- $\sigma(R_z^{mid}) \leq 0.02mrad.$

It means that statistics of several hundred particles is enough for minimal requirements, and 10^5 particles give information sufficient for maximal requirements fulfilment, if the error $\delta(A_z^{inn})$ has pure statistical nature.

The problem of systematic error due to uncertainties in the knowldge of BL^2 are relaxed very much by the presence of particles of both signs (systematic errors for particles of different signs tend to cancel each other) [6].

Systematic error of inclination measurement, caused by layer-to-layer unhomogeneity, has to be studied.

4 Global alignment with background particles

4.1 Single muons: alignment of muon towers with respect to IP, central tracker and calorimeter

Procedure for the alignment of the tower as a whole with respect to IP is rather obvious. Background muons, whose transvers momentum and direction are measured by the given tower, have to be propagated through magnetic field to IP. Trajectory impact parameter with respect to beam direction is defined mainly by the multiple scattering in the calorimeter and misalignment of the tower.

The first factor is stochastic and symmetrical, so systematic deviation of particle trajectory from IP is due to tower misalignment only. So, sufficient statistics of background particles provides us the relative position of the muon tower and IP, and so allows to apply vertex constraint for p_t-measurement.

The numbers of background particles, necessary for the vertex resolution of 200μ, in dependance on p_t-threshold, were estimated by L.Rosenson [6].

Tower 1 and Tower 2 have the common base inner superlayer. So, alignment of this chamber is common for both towers and we can use statistics of both towers. The same arguments are valid for towers 3 and 4.

The results of his estimations are shown in Table 2.

Table 2: **Number of particles required for vertex location to 200μ**

	Tower 1 and Tower 2	Tower 3 and Tower 4	Tower 5
$p_t = 15GeV/c$	25,000	35,000	11,000
$p_t = 25GeV/c$	8,000	14,000	4,000
$p_t = 50GeV/c$	2,000	3,500	1,000

Comparison of the required number of statistics (Table 2) and rates of background particles (Table 1) leads to the following conclusions (all estimations for $L \sim 10^{33}cm^{-2}s^{-1}$):

- for the threshold $p_t = 15GeV/c$ (total event rate is $\sim$ 1000Hz) alignment of the worst towers 3 and 4, requires 5 hours run (total statistic for all towers is $7 * 10^6$);

- for the threshold $p_t = 25GeV/c$ (total event rate is $\sim$ 200Hz) alignment of the worst towers 3 and 4, requires 10 hours run (total statistic for all towers is $2.5 * 10^6$);
- for the threshold $p_t = 50GeV/c$ (total event rate is $\sim$ 10Hz) alignment of the worst towers 3 and 4, requires 50 hours run (total statistic for all towers is $6 * 10^5$).

Amount of statistics (and correspondingly run time), required for vertex location to 500 – 1000μ is approximately ten times less.

Alignment of muon towers with respect to IP is necessary procedure for each run, because interaction point is very stable only during the same run.

IP position determination with respect to the GEM central tracker is much more simple problem, because there are no significant multiple scattering between beam crossing and CT chambers.

We can hope that the position of muon towers with respect to central tracker is rather stable in the range of a hundred microns.

So, the problem of muon towers alignment with respect to IP can be decided by two-step procedure:

- position of IP with respect to CT is determined in every run, this problem does not require large statistics and hence dedicated trigger, and could be solved with background particles instantly;
- alignment of the muon towers with respect to CT with the necessary accuracy 200μ requires the same, or even less (if we will use angle measurement in CT) statistics, as for alignment of towers with IP , and it could be repeated once in the period of mutual muon system and central tracker stability.

4.2 $Z^0 \rightarrow \mu^+\mu^-$: alignment of muon towers with respect to each other

Requirements for relative alignment of muon towers with respect to each other are not very restrictive. It is necessary to know relative angles of towers with the accuracy (see [1]):

$$\sigma_\phi \leq 3mrad, \tag{9}$$

$$\sigma_\theta \leq 3mrad. \tag{10}$$

This requirements could be fulfilled during muon system construction and installation, and events $Z^0 \rightarrow \mu^+\mu^-$ can play an important role in alignment testing and calibration.

We propose to use Z^0-mass constraint for these purposes.

GEM muon system measures the following parameters of a particle:

- p_t - transverse momentum of particle;
- ϕ - polar angle;
- θ - azimuthal angle;

We can express the value of di-muon mass in terms of these parameters:

$$m^2_{\mu_1\mu_2} = 4p_{t_1}p_{t_2}(sin^2\Delta\phi + \frac{sin^2\Delta\theta}{sin^2\Theta - sin^2\Delta\theta}), \tag{11}$$

where

$$\Delta\phi = \frac{\phi_1 - \phi_2}{2},$$

$$\Delta\theta = \frac{\theta_1 - \theta_2}{2},$$

and

$$\Theta = \frac{\theta_1 + \theta_2}{2}.$$

Polar and azimuthal angles enter in this expression by different ways,because total momentum depends only on azimuthal angle:

$$p_{tot} = \frac{p_t}{sin\theta}. \tag{12}$$

Factors affecting di-muon mass resolution are:

- Transverse momentum resolution;
- Multiple scattering in the calorimeter;
- Intrinsic ϕ and θ resolution of the muon system;
- Global misalignment of the muon system.

Monte-Carlo simulation confirms L_3 observation that transverse momentum resolution dominates over multiple scattering and intrinsic angle resolution of the muon system.

$Z^0 \rightarrow \mu^+\mu^-(p_t^\mu \geq 25GeV/c)$ events, produced in $pp-$ collisions at the SSC energy, have following characteristics:

- Z^0's are approximately uniformly distributed over rapidity interval (-3,3);
- Characteristic transverse momentum of Z^0 is of order $100GeV/c$;
- Open angle between muons has rather wide distribution;
- Muons are detected mainly by the barrel part of GEM muon system.

The features of this decay allows to develop procedures for GEM muon system calibration.

GEM muon system consists of 480 muon chamber towers (48 sectors in ϕ by 10 subsections in θ). These towers could be misaligned from the "right" directions in global GEM coordinate system. We assume the stochastic distributions of deviation magnitudes are gaussian with dispersions σ_ϕ and σ_θ.

For correction of these deviations with $Z^0 \rightarrow \mu^+\mu^-$ events we propose following procedure.

For each tower four values are calculated:

- M_r^ϕ - average di-muon mass for events, when one of muons was detected by this tower, and the other has ϕ-direction to the **right** from the first;
- M_l^ϕ - the same, but the second muon has ϕ-direction to the **left** from the first;
- M_b^θ - average di-muon mass for events, when one of muons was detected by this tower, and θ-angle of the other is **bigger** than θ-angle of the first;
- M_s^θ - the same, but θ-angle of the second is **smaller** than θ-angle of the first.

The expression of di-muon mass in terms of measurable parameters 11 gives a supposition, that difference between M_r^ϕ and M_l^ϕ is proportional to ϕ - deviation of the tower, and difference between M_b^θ and M_s^θ is proportional to θ - deviation.

MonteCarlo calculations confirm this simple assumption completely.

One-month statistics of $Z^0 \to \mu^+\mu^-$ events ($\sim 10^6$) makes it possible to correct

- θ - deviations of muon towers with the accuracy of 3 mrad;
- ϕ - deviations of muon towers with the accuracy of 3 mrad;

It is important, that for correction of angle deviations we don't use difference between measured value of di-muon mass and absolute (table) value of Z^0-mass, but only relative values. This feature of the method makes it possible after correction of angle deviations to correct p_T - measurement errors due to lack of B-field knowing.

5 $Z^0 \to \mu^+\mu^-$: calibration of the magnetic field measurements

B-field inside GEM magnet has axial symmetry. If we devide all θ-range from 9.43^0 till 170.57^0 on, for example, 1000 intervals, and for each interval calculate the value

- M_i^θ - average di-muon mass for events, when one of muons had θ-direction inside i-th interval.

MonteCarlo calculations show that the difference between the value of M_i^θ and right value of Z^0-mass is proportional to relative error of the value BL^2 for i-th interval.

One-month statistics of $Z^0 \to \mu^+\mu^-$ events ($\sim 10^6$) makes it possible to correct value of BL^2 for 1000 θ-intervals with the accuracy of 0.5%.

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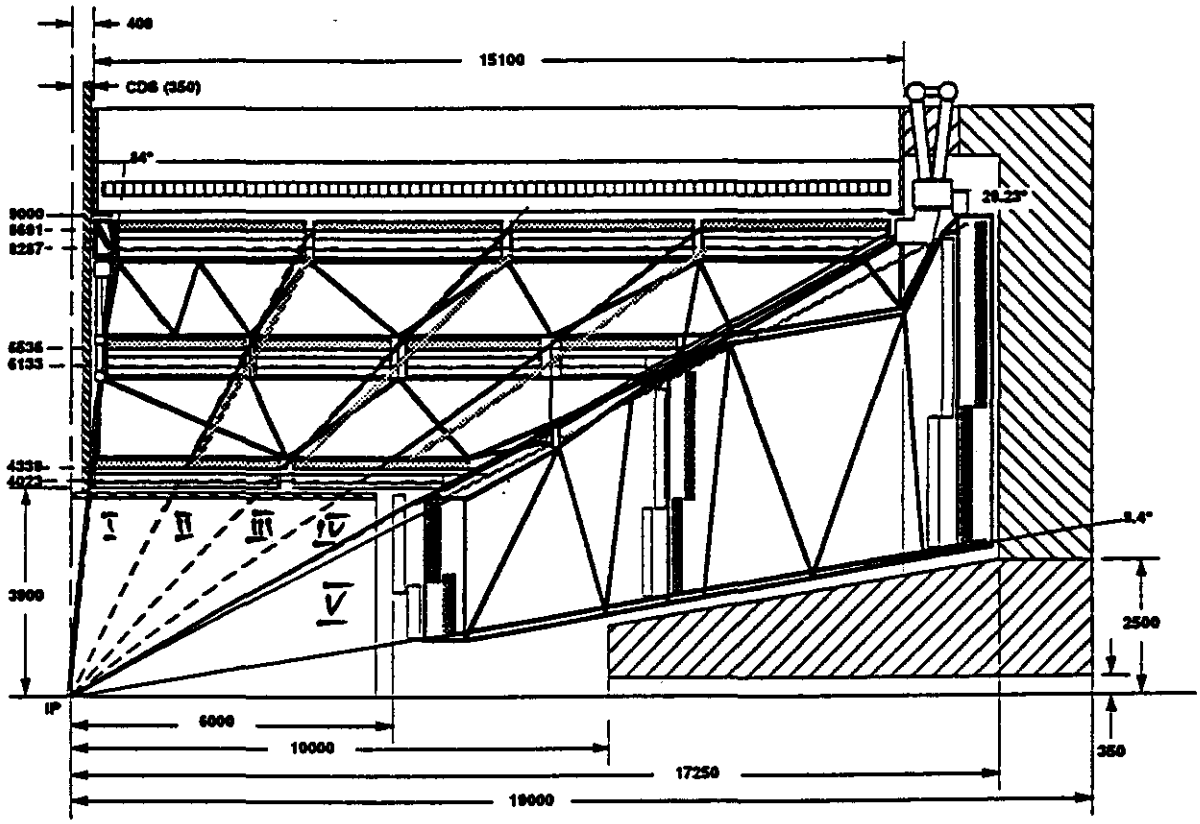

Fig.1 Geometrical Layout of the GEM muon system