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Alignment of the MEG II cylindrical drift chamber

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ABSTRACT

We present the ongoing development of an algorithm for the software alignment of the MEG II drift chamber based on the MillePede global approach. This method uses cosmic rays data collected during the 2022 data taking period to perform wire-by-wire alignment. We discuss first results obtained on data.

1. Introduction

The MEG II experiment at Paul Scherrer Institut started in 2021 its physics program to search for the charge lepton flavor violating process $\mu \rightarrow e\gamma$ [1,2]. The tracking detector of the experiment is a single volume, highly segmented Cylindrical Drift CHamber (CDCH), composed of 1728 sense wires arranged in 9 concentric stereo-layers. Detector performances and characteristics are described in [3].

2. CDCH alignment with MillePede

The software alignment of the detector modules (wires) is central to attain optimal performances. Currently, the CDCH geometrical parameters of each wire are determined with an iterative procedure to minimize spatial residuals $x_{i,meas} - x_{i,fit}$ between measured coordinates $x_{i,meas}$ of the hit and fitted coordinates $x_{i,fit}$ in $\mu \rightarrow e\nu\bar{\nu}$ events [3].

We illustrate the results of an attempt to align the CDCH using the MillePede strategy [4] on cosmic rays data (a strategy successful in MEG experiment [5]). The MillePede algorithm is faster than the iterative one since optimal track and wire parameters are determined in a single step (few hours instead of one month in MEG II analysis framework). In addition, cosmic rays tracks collected with the magnetic field turned off allow to disentangle wire and magnetic field misalignment. An independent estimate of geometrical correction with a different dataset is also important to cross check results and identify possible *weak modes* of the system.

2.1. Alignment parameters

The free parameters for each wire are 6: $\vec{q} = \{x_0, y_0, \theta, \phi, s_0, \gamma\}$. The wire position and orientation in the MEG II reference system is

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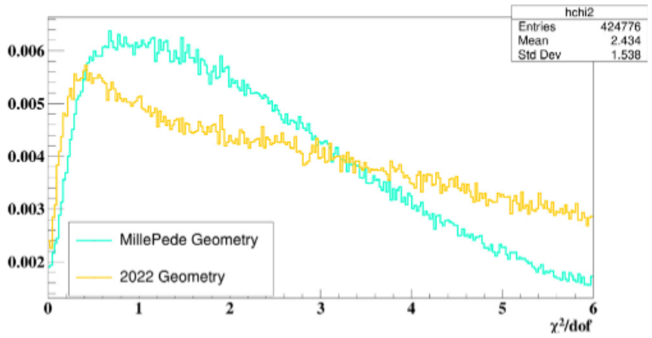

Fig. 1. χ^2/dof distribution of fitted tracks. Yellow: initial distribution with nominal geometry for 2022 reconstruction. Light blue: after one iteration of MillePede.

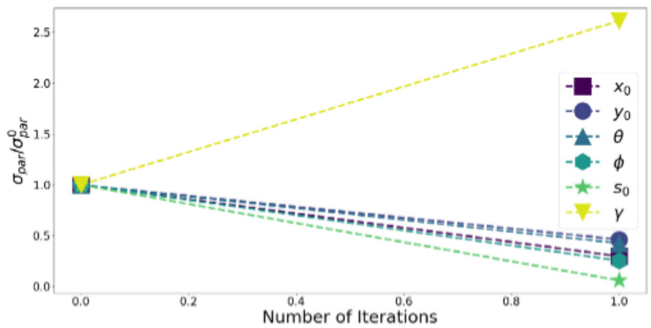

Fig. 2. Width of the misalignment distribution for all geometrical parameters after one iteration. σ_{par}/σ_0 is 1 at the beginning, < 1 (> 1) if there has been a convergence (divergence) of the alignment algorithm.

described by six parameters: $(x_0,\ y_0,\ z_0)$ is the position of the wire center; θ and ϕ are the polar and azimuthal angles defining the orientation of the wire vector (in case of straight wires). Wires are approximated by parabolic functions [3] where s_0 is the wire "sagitta" and γ is the angle defining the orientation of the plane in which the sagitta lies with respect to the radial direction. These additional degrees of freedom describe the deformation on the wire acted by the gravitational and electric forces. With a total of 954 sense wires (excluding noisy or non-working channels), the number of degrees of freedom of the CDCH geometry are 5724 in total (no constraints applied, 2 central wires per sector fixed for reference).

3. Results on data

This study used a set of ~300k events of cosmic rays collected in 2022 with magnetic field off. The analysis procedure for cosmic rays tracks is described in [3]. We use the MillePede II[1] software tool to build and solve the linearized global χ^2 function and obtain alignment parameters corrections. The starting point for the alignment of the CDCH with MillePede is the geometry determined after an iterative alignment procedure on 2022 data. In Fig. 1 the χ^2/dof distribution of cosmic tracks is shown. The average χ^2/dof value drops from 3.0 to 2.4. In general, correction parameters are correctly centered at zero and the width of the distribution of correction parameters is compatible with that from the derived from the iterative alignment procedure. Correlation between parameters is negligible.

When the corrected geometry was used to reprocess a set of $\mu \to e\nu\bar{\nu}$ data we observed a worsening of residual widths and detector resolutions: this is hint of a bad convergence of the MillePede algorithm.

4. Results on Monte Carlo

Monte Carlo (MC) simulations provided insight on the poor convergence observed on real cosmics data. MC events are reconstructed with a misaligned geometry and fed into the alignment algorithm; MillePede output is then compared with the true misalignment parameters. We observe that:

1. In just one iteration, all misaligned parameters converge to the correct solution except for γ (Fig. 2);
2. A global deformation of the CDCH (*stretching*) is observed (Fig. 3). This deformation tends to enlarge outer layers and restrict the inner ones, while it does not affect intermediate layers.

[1] https://gitlab.desy.de/claus.kleinwort/millepede-ii

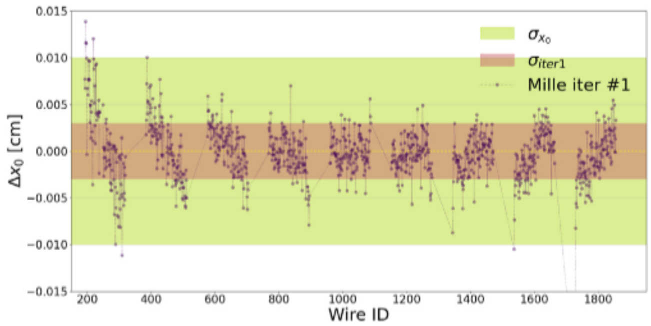

Fig. 3. Residual misalignment of x_0 after one iteration of MillePede on Monte Carlo. Red dots are the wire-by-wire residual misalignment and the pink band is the RMS of the distribution; the green band is the initial applied misalignment to the x_0 parameter.

We interpret both of these problems to be caused by the topology of cosmic tracks: vertical tracks have an up-down ambiguity in the hit position which does not allow a precise determination of the orientation of the wire bending in space (i.e. γ). Similarly, vertical tracks do not allow to correlate inner and outer layers nor the left and right side of the CDCH. Since many sections of the CDCH are independent for tracking, faulty local minima emerge (weak modes).

5. Conclusions

Studies are ongoing to find ways to mitigate these systematic effects that spoiled the alignment with MillePede, such as the application of external constraints from the CDCH survey measurements (e.g. fixed layer radii). Another possible solution that will be investigated is to apply the MillePede technique also to $\mu \to e\nu\bar{\nu}$ data (see [6]): complementary datasets are indeed known to be helpful in avoiding weak modes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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