Alignment of the MEG II Cylindrical Drift Chamber
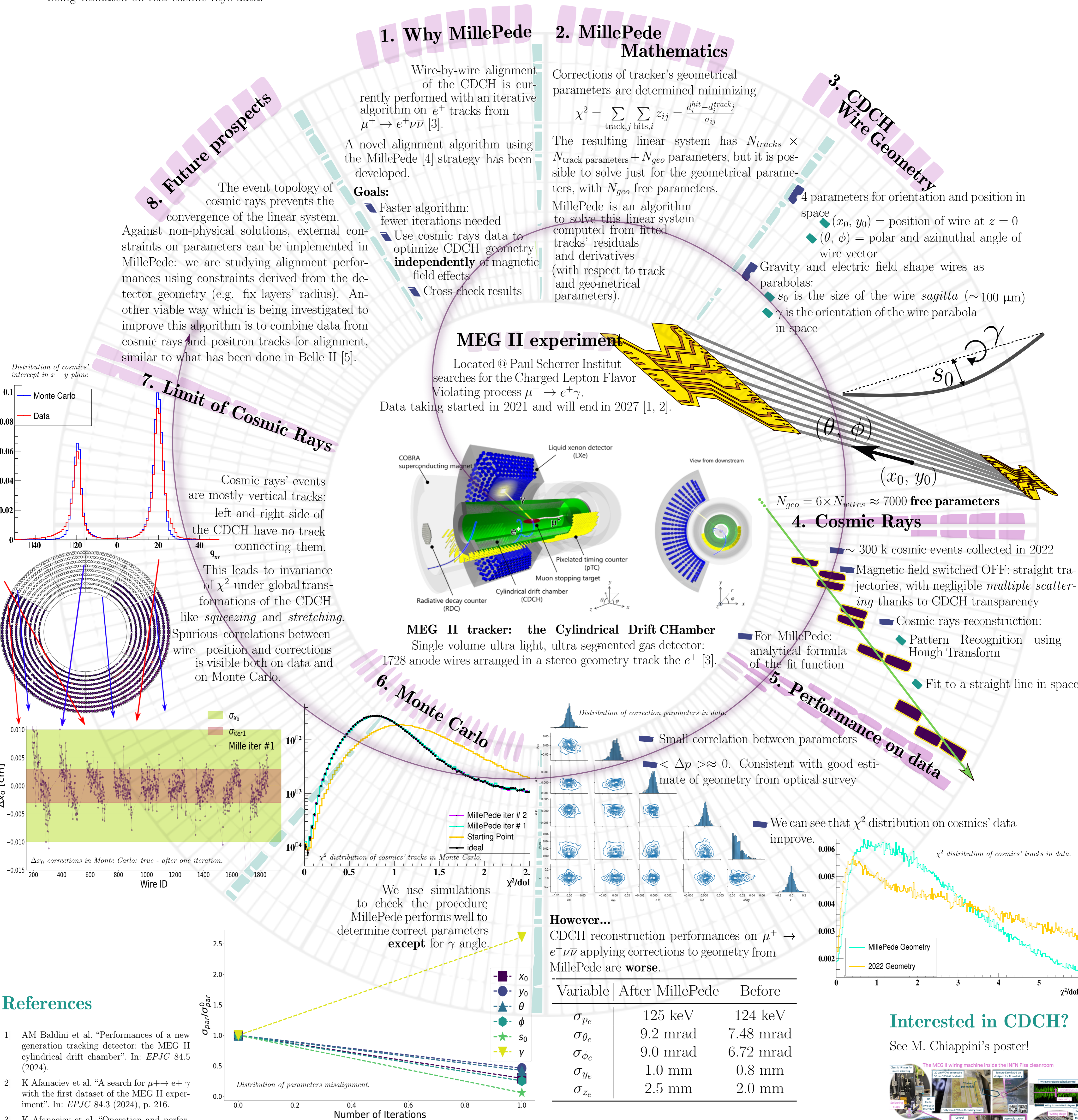
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Abstract

The MEG II experiment has been searching for the charged lepton flavor-violating decay $\mu^+ \to e^+\gamma$ since 2021. An integral component of the detector apparatus is the an ultra-light and highly segmented drift chamber. The tracker optimization relies on the **software alignment** of the geometry on data. 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 and 2023 data taking period to disentangle the tracker wire-by-wire alignment and the relative alignment of the drift chamber with the magnetic field. The algorithm has been successfully tested on Monte Carlo simulations and is being validated on real cosmic rays data.

1. Why MillePede

Wire-by-wire alignment of the CDCH is currently performed with an iterative algorithm on e^+ tracks from $\mu^+ \to e^+ \nu\bar{\nu}$ [3].

A novel alignment algorithm using the MillePede [4] strategy has been developed.

Goals:
- Faster algorithm: fewer iterations needed
- Use cosmic rays data to optimize CDCH geometry **independently** of magnetic field effects
- Cross-check results

2. MillePede Mathematics

Corrections of tracker's geometrical parameters are determined minimizing

$$\chi^2 = \sum_{\text{track},j} \sum_{\text{hits},i} z_{ij} = \frac{d_i^{hit} - d_j^{track_j}}{\sigma_{ij}}$$

The resulting linear system has $N_{tracks} \times N_{\text{track parameters}} + N_{geo}$ parameters, but it is possible to solve just for the geometrical parameters, with N_{geo} free parameters.

MillePede is an algorithm to solve this linear system computed from fitted tracks' residuals and derivatives (with respect to track and geometrical parameters).

3. CDCH Wire Geometry

4 parameters for orientation and position in space
- (x_0, y_0) = position of wire at $z = 0$
- (θ, ϕ) = polar and azimuthal angle of wire vector

Gravity and electric field shape wires as parabolas:
- s_0 is the size of the wire *sagitta* ($\sim 100 \ \mu$m)
- γ is the orientation of the wire parabola in space

$N_{geo} = 6 \times N_{wtkes} \approx 7000$ **free parameters**

4. Cosmic Rays

- ~ 300 k cosmic events collected in 2022
- Magnetic field switched OFF: straight trajectories, with negligible *multiple scattering* thanks to CDCH transparency
- Cosmic rays reconstruction:
  - Pattern Recognition using Hough Transform
  - Fit to a straight line in space
- For MillePede: analytical formula of the fit function

MEG II experiment

Located @ Paul Scherrer Institut searches for the Charged Lepton Flavor Violating process $\mu^+ \to e^+\gamma$. Data taking started in 2021 and will end in 2027 [1, 2].

COBRA superconducting magnet
Liquid xenon detector (LXe)
Pixelated timing counter (pTC)
Muon stopping target
Cylindrical drift chamber (CDCH)
Radiative decay counter (RDC)
View from downstream

MEG II tracker: the Cylindrical Drift CHamber
Single volume ultra light, ultra segmented gas detector: 1728 anode wires arranged in a stereo geometry track the e^+ [3].

5. Performance on data

Distribution of correction parameters in data:

- Small correlation between parameters
- $< \Delta p > \approx 0$. Consistent with good estimate of geometry from optical survey
- We can see that χ^2 distribution on cosmics' data improve.

χ^2 distribution of cosmics' tracks in data.

MillePede Geometry
2022 Geometry

6. Monte Carlo

MillePede iter # 2
MillePede iter # 1
Starting Point
ideal

χ^2 distribution of cosmics' tracks in Monte Carlo.

We use simulations to check the procedure. MillePede performs well to determine correct parameters **except** for γ angle.

However...
CDCH reconstruction performances on $\mu^+ \to e^+ \nu\bar{\nu}$ applying corrections to geometry from MillePede are **worse**.

Variable	After MillePede	Before
σ_{p_e}	125 keV	124 keV
σ_{θ_e}	9.2 mrad	7.48 mrad
σ_{ϕ_e}	9.0 mrad	6.72 mrad
σ_{y_e}	1.0 mm	0.8 mm
σ_{z_e}	2.5 mm	2.0 mm

Distribution of parameters misalignment.

x_0
y_0
θ
ϕ
s_0
γ

7. Limit of Cosmic Rays

Cosmic rays' events are mostly vertical tracks: left and right side of the CDCH have no track connecting them.

This leads to invariance of χ^2 under global transformations of the CDCH like *squeezing* and *stretching*. Spurious correlations between wire position and corrections is visible both on data and on Monte Carlo.

Distribution of cosmics' intercept in x y plane

Monte Carlo
Data

σ_{x_0}
σ_{iter1}
Mille iter #1

Δx_0 corrections in Monte Carlo: true - after one iteration.

8. Future prospects

The event topology of cosmic rays prevents the convergence of the linear system. Against non-physical solutions, external constraints on parameters can be implemented in MillePede: we are studying alignment performances using constraints derived from the detector geometry (e.g. fix layers' radius). Another viable way which is being investigated to improve this algorithm is to combine data from cosmic rays and positron tracks for alignment, similar to what has been done in Belle II [5].

References

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Interested in CDCH?

See M. Chiappini's poster!

The MEG II wiring machine inside the INFN Pisa cleanroom