Geometry optimization of the B0 tracking system

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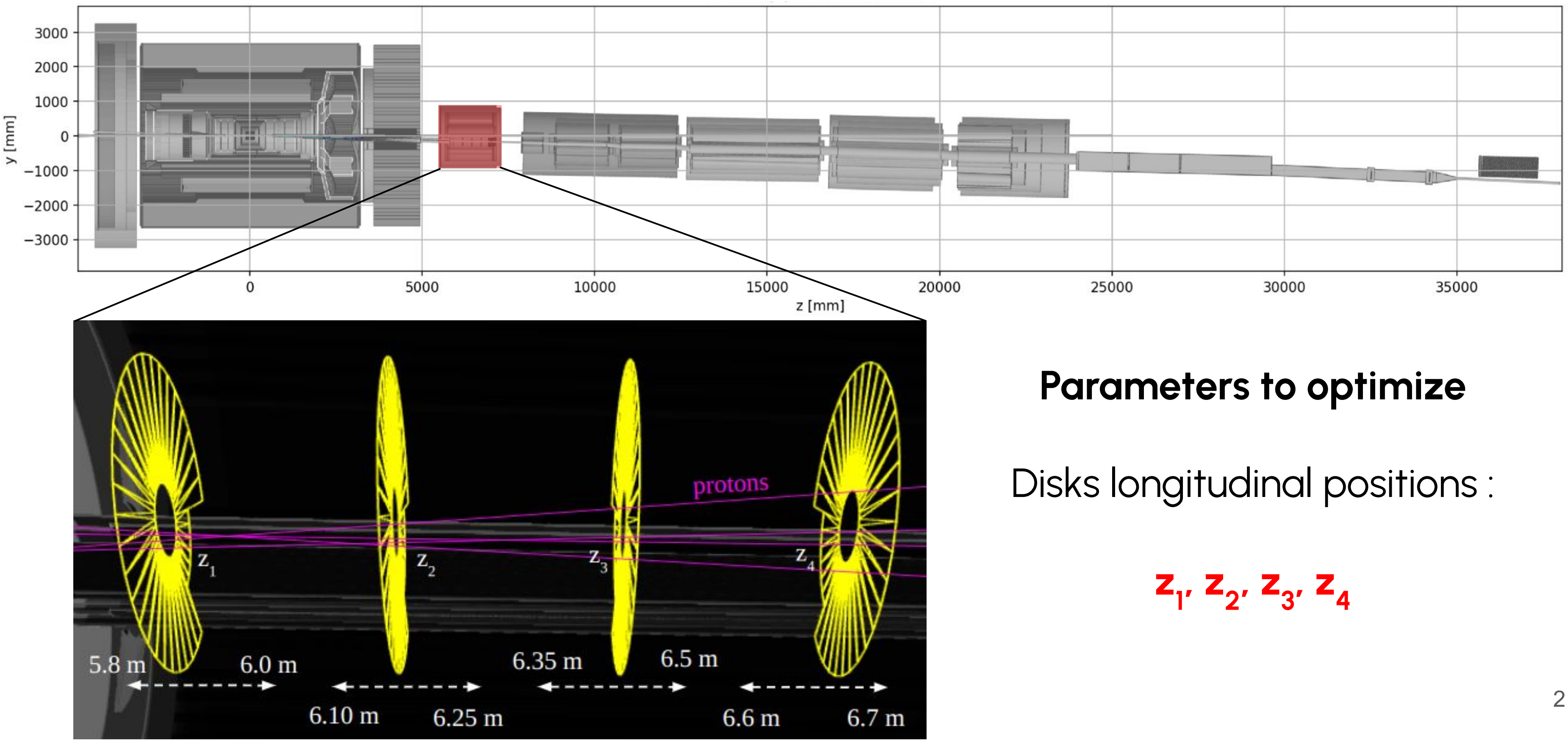
7/15/2026

B0 detector : tracking disks position

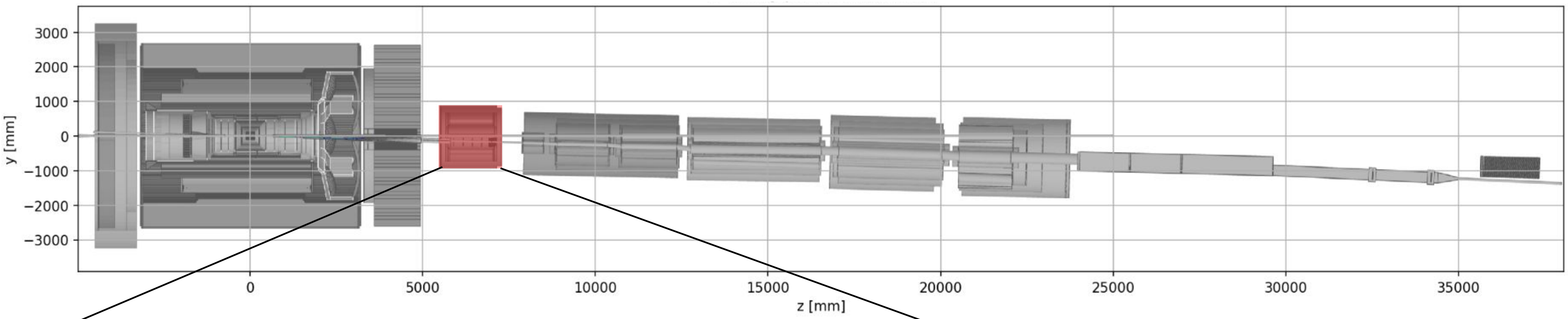


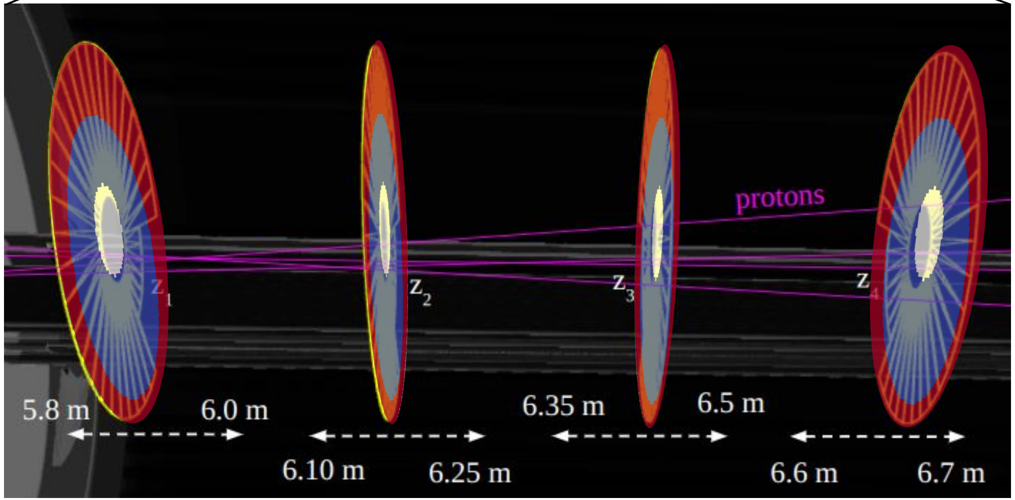
Parameters to optimize

Disks longitudinal positions :

z_1, z_2, z_3, z_4

B0 detector : tracking disks active area





Parameters to optimize

Superficial distribution of silicon cells as a decomposition of Zernike polynomials (2D)

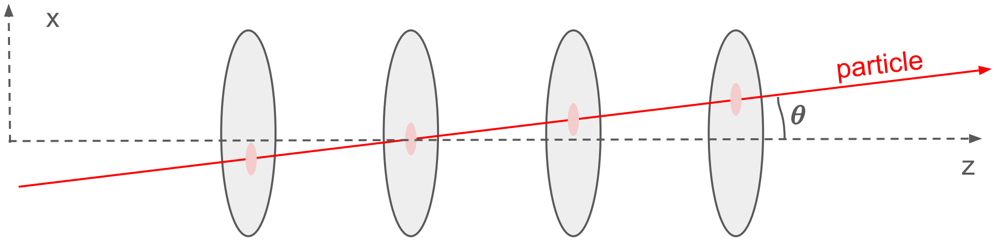
Decomposition coefficients a_{ij}

Bayesian optimization method and objective

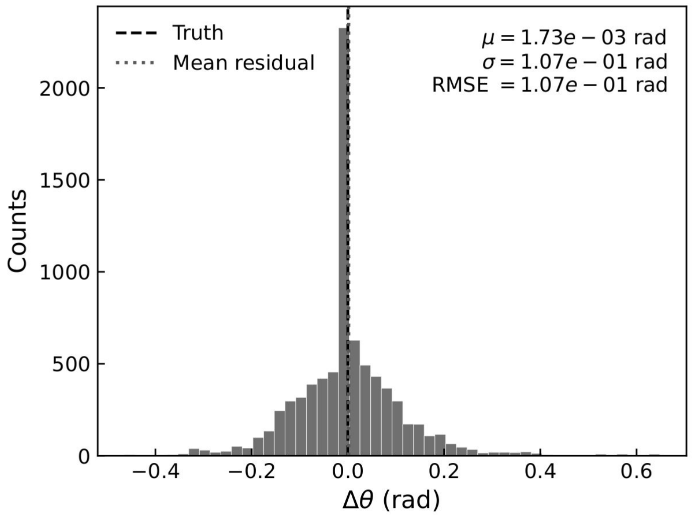
Objective

Reconstructed angle precision and resolution

$$OF^2 = \mu_{\Delta\theta} + \sigma_{\Delta\theta}$$



Reconstructed angle (fit) : $x_{hits} = \theta_{fit}\, z_{hits}$



Motivation

- *Detector-intrinsic observable*
- *Geometry driven (lever arm)*
- *Independent of reconstruction chain*
- *Direct impact on forward kinematics (t, pT)*

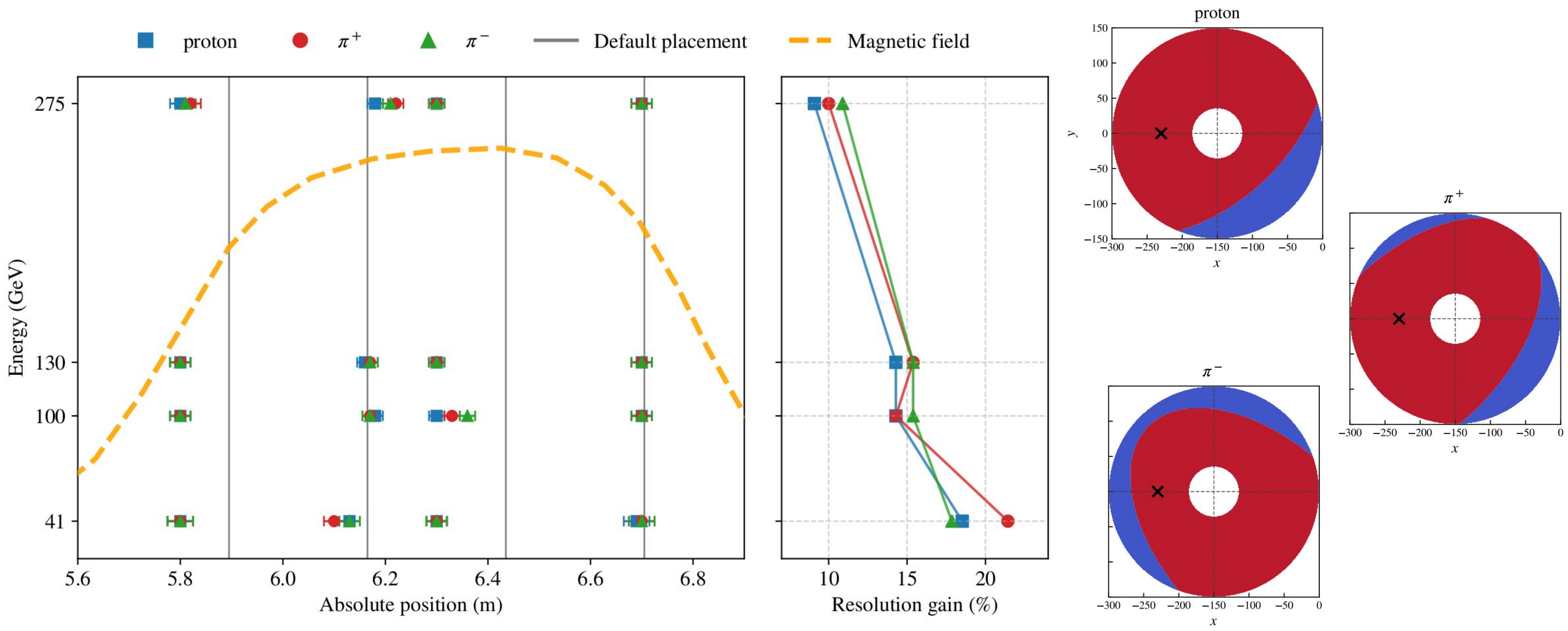
Method : Bayesian optimization

Surrogate function : Gaussian process

Acquisition function : logNEI

Parameters space : z_1, z_2, z_3, z_4, a_{ij}

Results : best longitudinal positions and cell distributions



Physical interpretation

Geometrical drivers

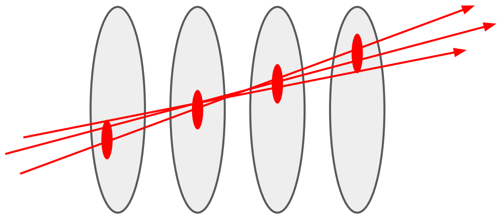
Angle fit : $x_{hits} = \theta_{fit}\, z_{hits}$

Resolution : $\sigma_\theta = \sigma_x / S_{zz}$

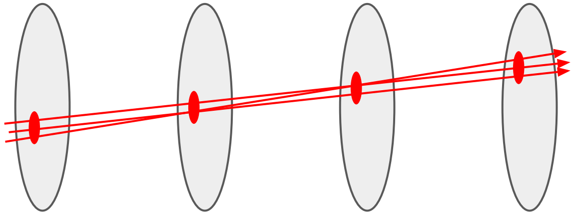
Where $S_{zz} = \sqrt{\Sigma(z_i - \bar{z})^2}$
is the "spread" of B0 disks
(lever arm)

At the leading order, for a given intrinsic spatial resolution σ_x, the Bayesian optimization will minimize σ_θ by maximizing S_{zz}

Intuition



Smaller S_{zz}, poorer resolution



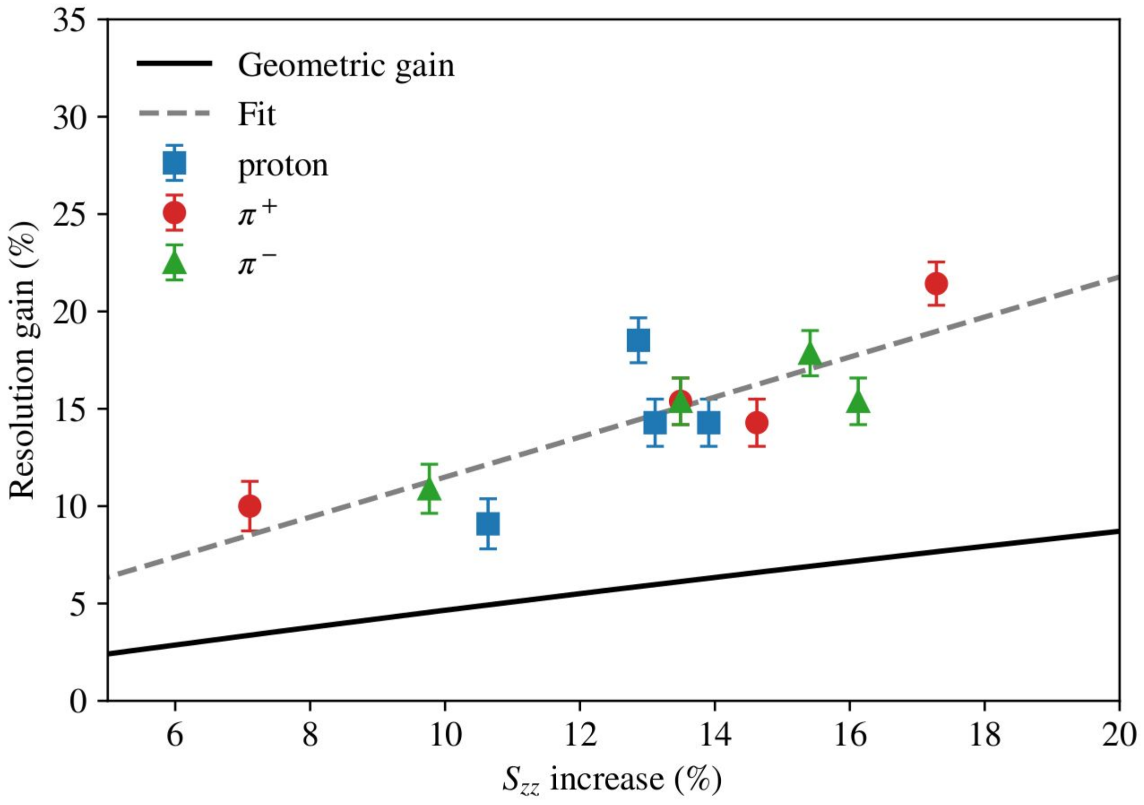
Larger S_{zz}, better resolution

Additional effects (simulation only)

- *Magnetic field trajectories*
- *Multiple scattering*
- *Finite detector acceptance*
- *Disk geometry*
- *Active/inactive regions*
- *Hit inefficiencies / clustering*

Conclusion
Optimization balances geometrical lever arm with realistic detector effects

Physical interpretation



Bayesian optimization **increases the effective lever arm (S_{zz})** and systematically do better by **accounting for non-ideal effects** such as magnetic field distortions, multiple scattering, detector acceptance, and geometric constraints.

Conclusion and outlooks

Results

- Best B0 disk positions
- 10-30 % resolution gain
- Robust and stable (energy, particle, acquisition function, Monte Carlo seed)

Interpretation

- Not a black box
- Maximize S_{zz}+ other effects
- Higher order effects managed by transport simulation Geant4

Resources

- Technical report : zenodo.org/records/21224455
- Code (iFarm, PanDA) : github.com/baptistefraisse/bob0

Ongoing works

- "Grid" model for the pavement of Silicon detectors on both sides of tracking disks
- AID2E project : multi-objective holistic optimization of ePIC (aid2e.github.io/aid2e)
- Optimization for calibration of calorimeters using π^0 verified with NPS/Hall-D data

Backup : validation tests

Number of particles

Tested fo 10, 100, 1000, 10000 particles : rapid convergence from 100 particles

Acquisition function

Tested logNEI and UCB acquisition functions : under-centimeter differences

Species and energy

Tested protons, pi+, pi- from 41 to 275 GeV : under-centimeter differences

Incident particles angle

Tested 10, 15 and 20 mrad (inside B0 acceptance) : under-centimeter differences

Correlation studies

Elongated correlation structures : under-centimeter tolerance of performances