Simulation of the MICE Lattice

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Simulation models for MICE

- Magnet models
  - Tracking accuracy
  - Effect of PRY
- RF models
  - Tracking accuracy
  - Handling of cavity shape and Beryllium windows

MAUS and Geant4

- Simulation in MICE is principally done using MAUS
  - ICOOL and G4Beamline codes also used
- MAUS tracking is performed by Geant4
  - 4^{th} order Runge Kutta integrating Lorentz force law
  - Time is independent variable
  - Other tracking routines are available
- MAUS geometry model uses hybrid G4 gdml parser and custom MICE geometry parser
  - Generated from CAD model (Step IV) or theoretical model (Demonstration of ionisation cooling)
- Integrated into the MAUS framework via a Simulation mapper

MAUS and Geant4

- Geant4 stores geometry internally
- On each step Geant4
  - Checks for geometry boundary crossings
  - Applies physics processes
    - Energy loss
    - Multiple Coulomb scattering
    - Particle decays
  - Performs field lookups for tracking
- MAUS provides field maps to Geant4

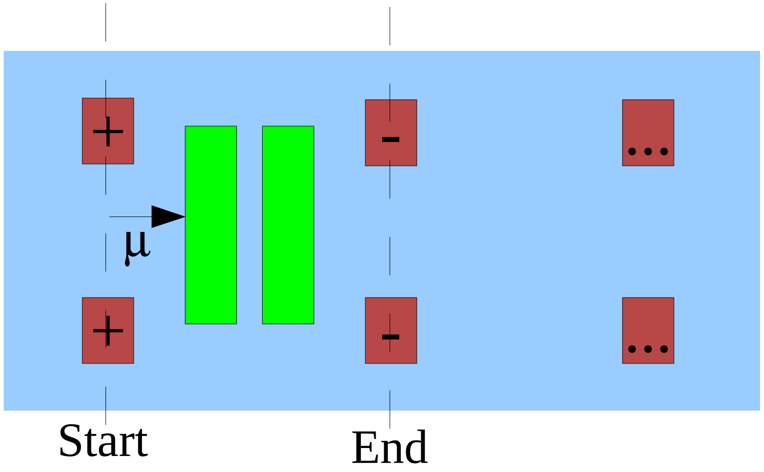
Field Map Routines

- Each field map has a rectangular bounding box
- MAUS divides the world into a rectilinear grid of voxels
  - Stores the list of fields whose bb impinges on a voxel
- Geant4 asks MAUS for the fields at a given position
  - MAUS iterates over the list of field maps in a voxel
  - Translates into local coordinate system
  - Accesses the local field map
  - Translates the field map to global coordinate system
  - Sums the field maps in global coordinate system
- Enables fully 3D field maps with overlapping fringe fields
  - Voxelisation is an optimisation
- Field map routines were validated in 2007 and 2009
  - Essentially stable since 2009

Solenoid Routines

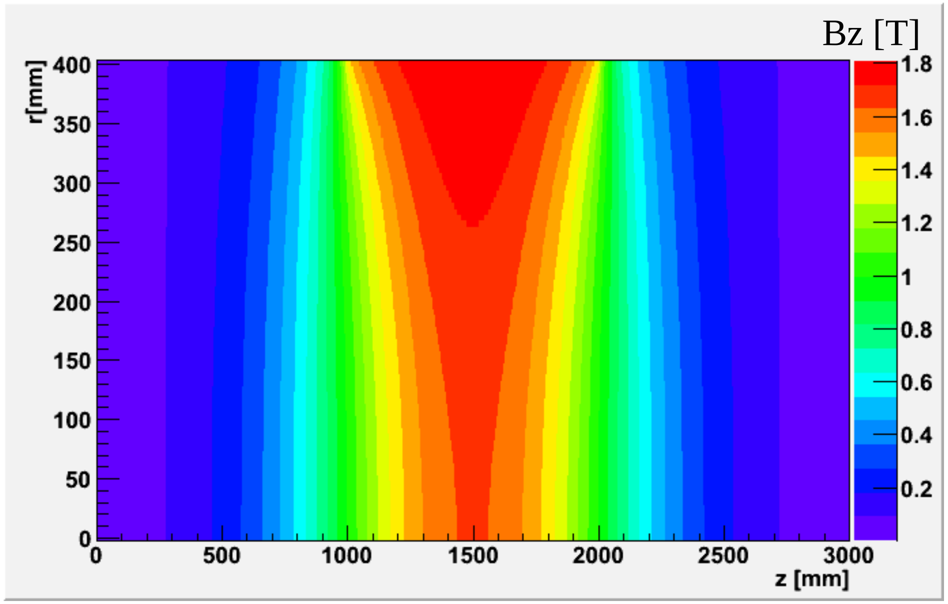
- MAUS has four solenoid routines
  - Load solenoid field from a 2D field map
    - Linear-cubic interpolation from the grid points
  - Load field (not necessarily solenoid) from a 3D field map
    - Trilinear interpolation from the grid points
  - Generate analytical field map based on a longitudinal field model
    - Maxwell's laws used to calculate off-axis field
    - Arbitrary order analytical derivatives available
  - Generate semi-analytical field map based on a sum of infinitely thin current carrying sheets
    - Each current sheet generates fields according to an elliptical integral
    - Can cache on disk in 2D for fast lookups
    - This is the “standard” field map model

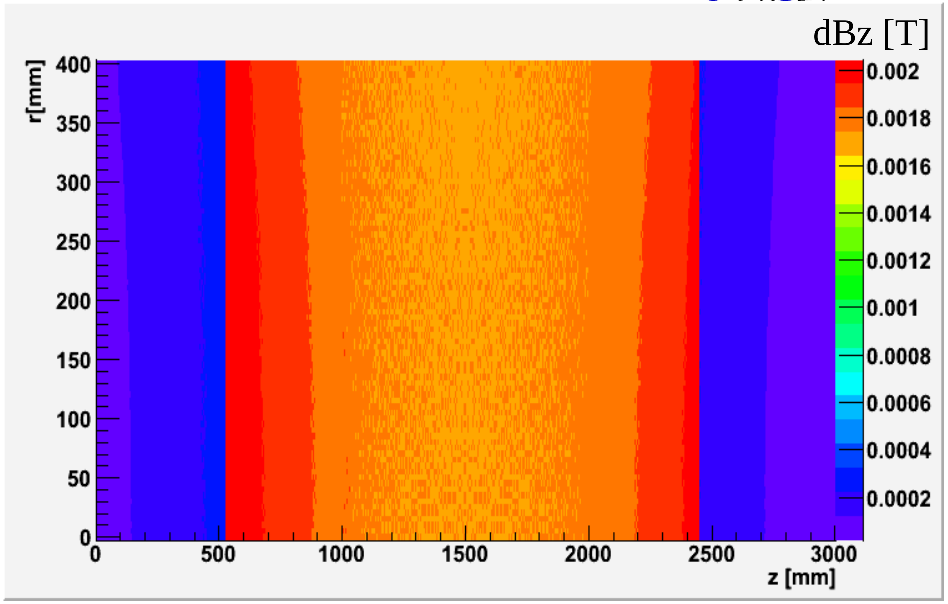
Comparison with ICOOL



- Toy cooling cell used for comparison with ICOOL
  - Coils separated by 3 m, arranged with opposite polarity
  - Two 500 mm long RF cavities
- Insert beam at “Start” and extract at “End”
- Look at residual distributions varying conditions

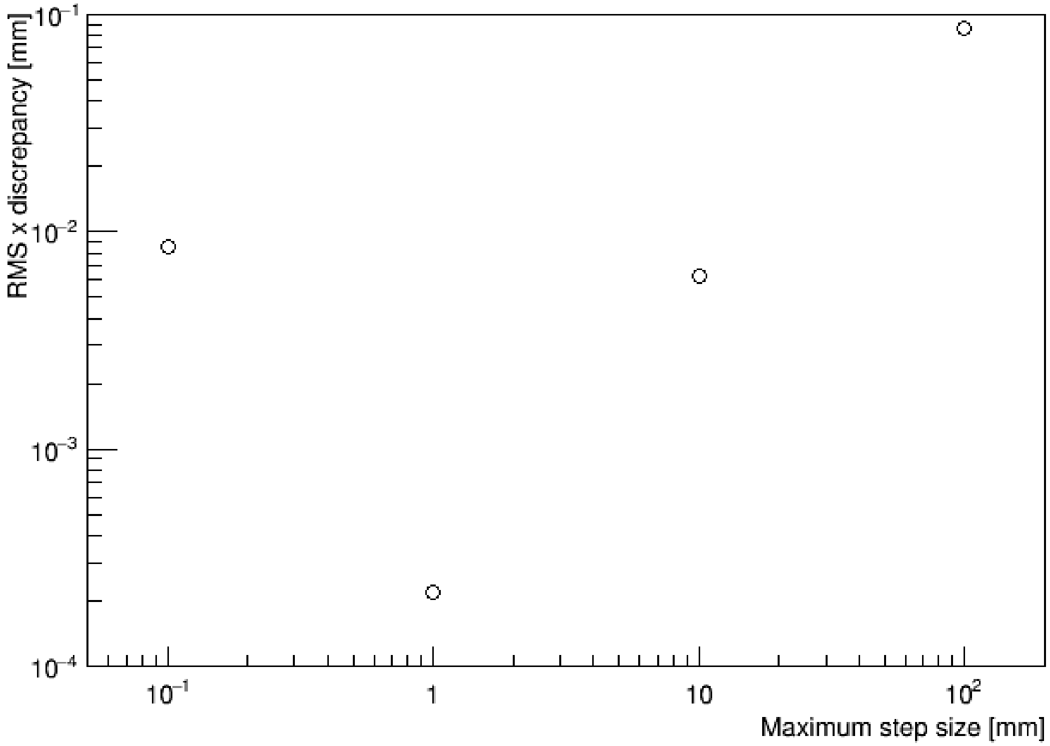
Comparison with ICOOL





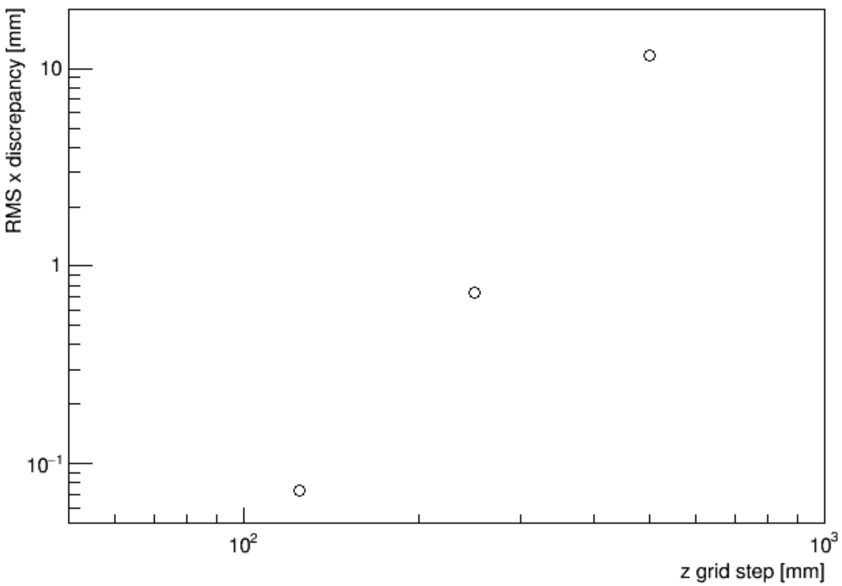
- Compare field generated in ICOOL with MAUS
- Discrepancy at 1e-3 level

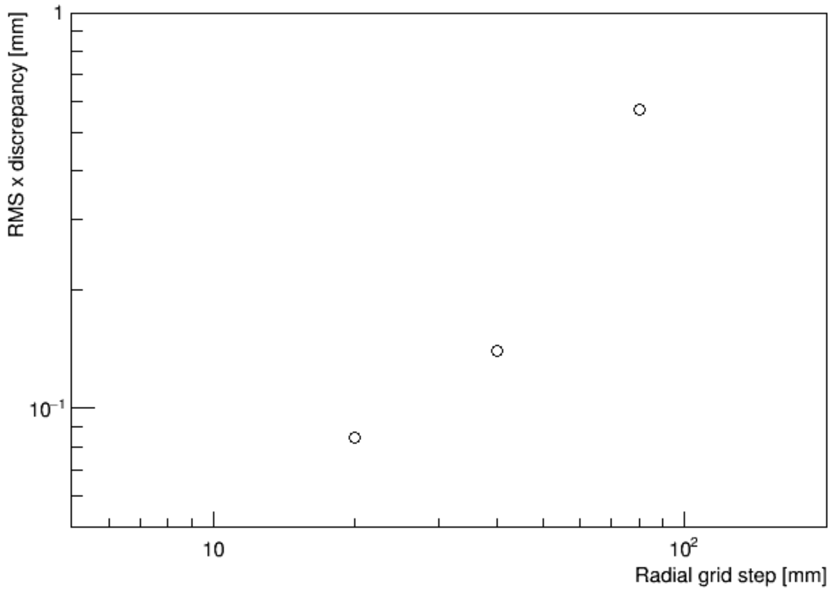
Comparison with ICOOL



- Compare tracking in ICOOL with MAUS
  - Tracking shows pretty good convergence
  - Some tracking noise at sub-mm step size

Grid size of field map



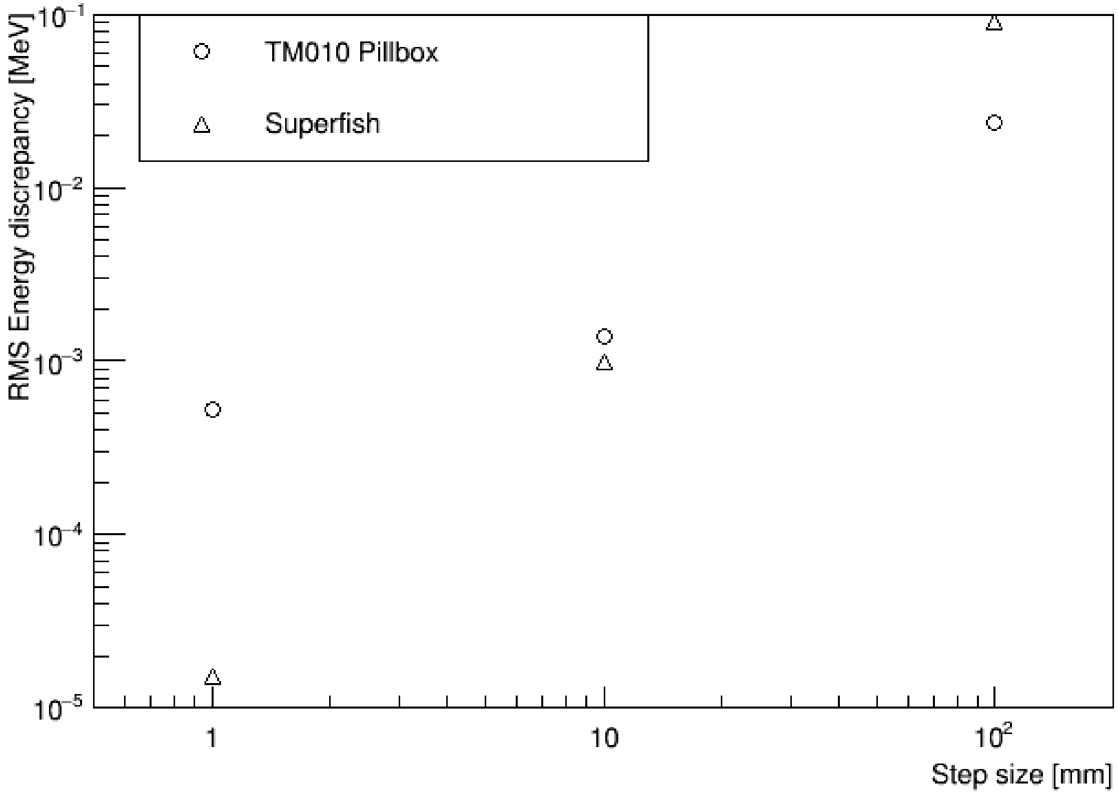


- By default MAUS caches solenoid field map to disk
  - Speed optimisation
  - Performs interpolation off of the grid to get field
  - Grid size?

RF Cavity Models

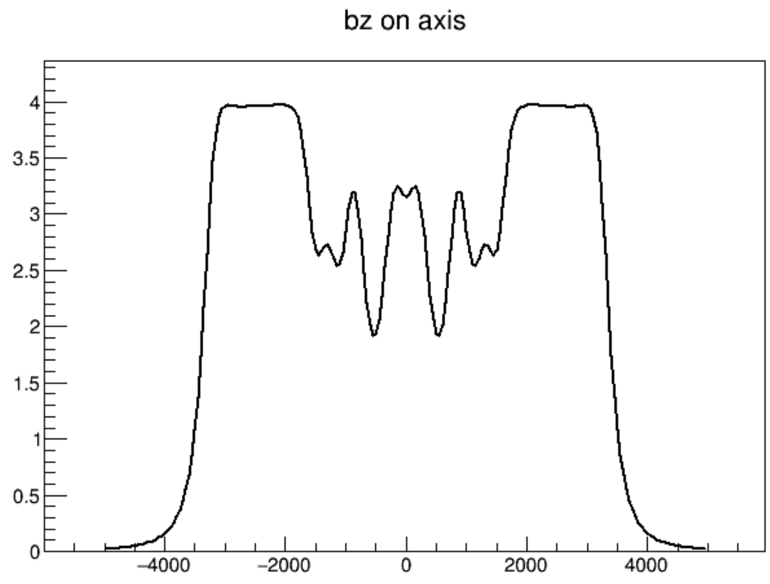
- MAUS has two RF cavity models
- TM010 Pillbox cavity
  - Electric and magnetic fields given by a Bessel function
- Poisson Superfish model
  - Read in a 2D cylindrically symmetric field map file from superfish

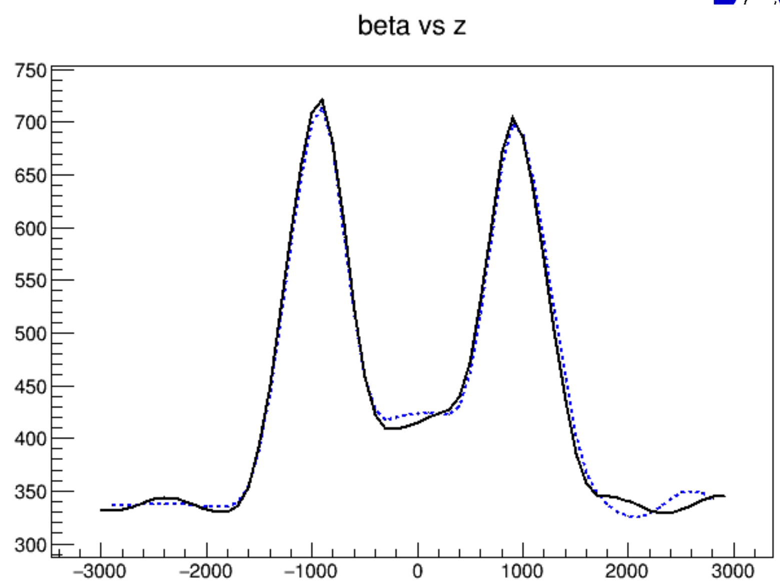
RF Simulation



- Stability of tracking through RF cavity
  - Tracking is convergent

Step IV Lattice



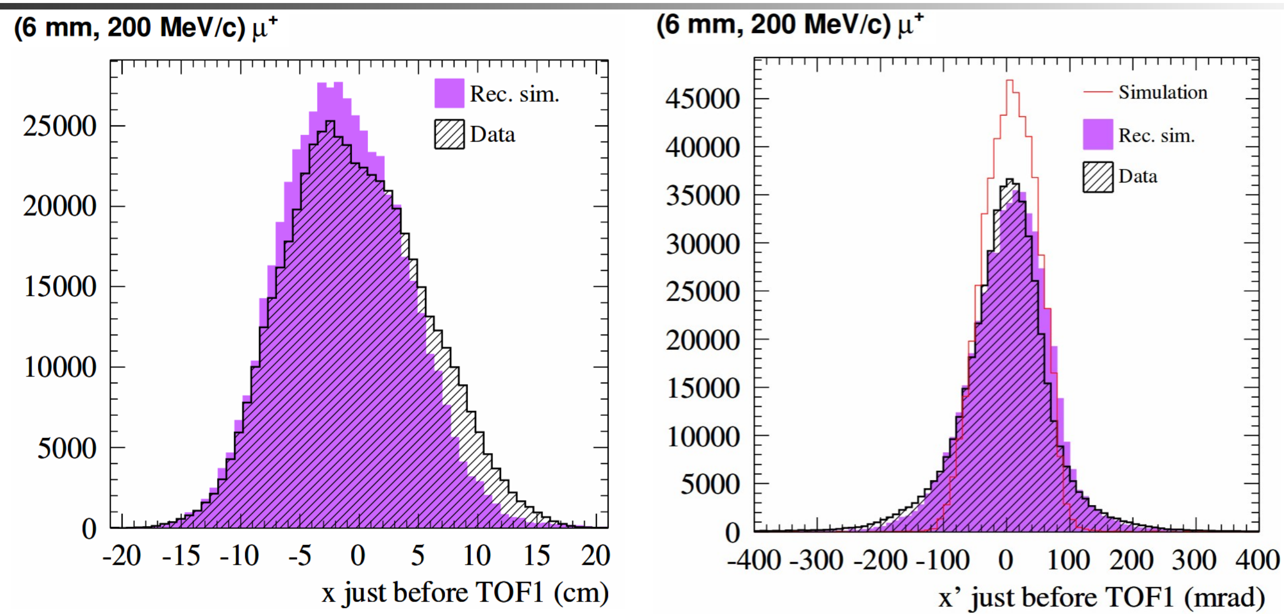


- Example: Step IV lattice (with M1 in SSD)
  - Only magnets were simulated
  - Tracking agrees reasonably well with linear optics model
  - Some deviations due to sampling accuracy in initial beam

Particle Generation

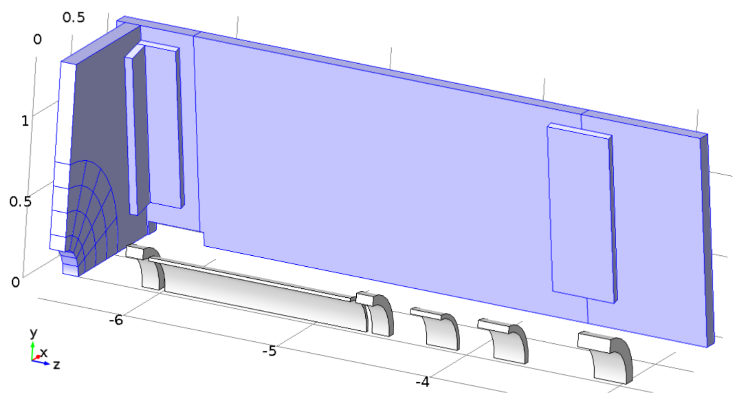
- Several different input particle generation algorithms have been implemented
- Gaussian multivariate in transverse
  - Use 2D or 4D Twiss-like parameters
  - Use general 4D covariance matrix
- Gaussian in pz, p or energy
- Uniform or sawtooth in t
- Input particle files from ICOOL or G4Beamline codes
  - This is the default

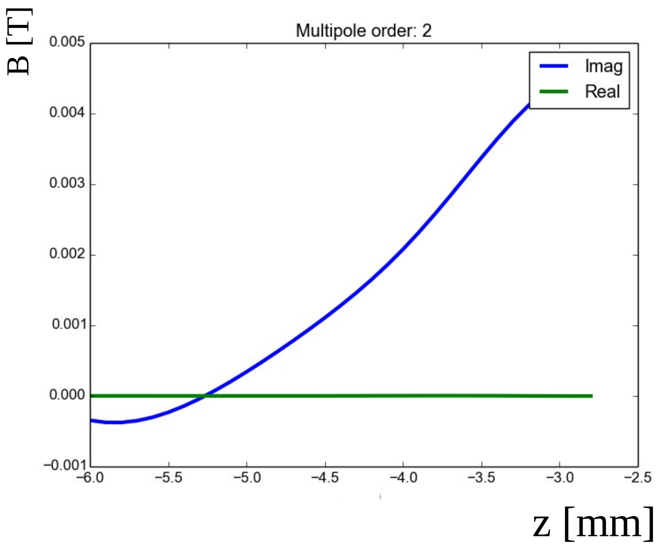
G4BL Simulation of Beamline



- Accurate simulation of the MICE Muon Beam has been developed in G4Beamline
  - Given precision requirements, accurate model of the input distribution is essential
  - Including non-muon impurities
- This is very CPU intensive due to inefficiency of transport line
  - 480,000 CPU hours to produce sample of 1e6 “good” muons
  - Cf. 1e5 good muons in a standard dataset
- Limited practically to simulating ~ 100 datasets

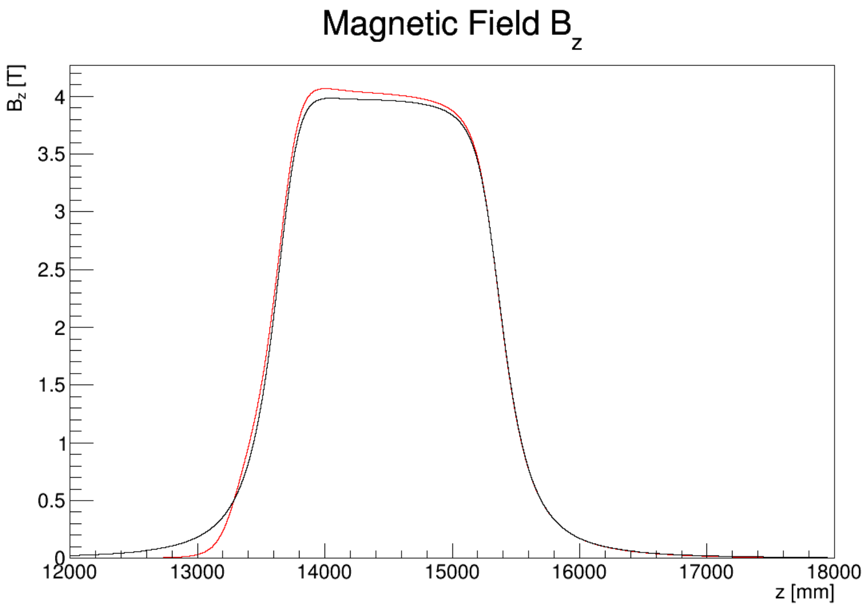
OPERA Model

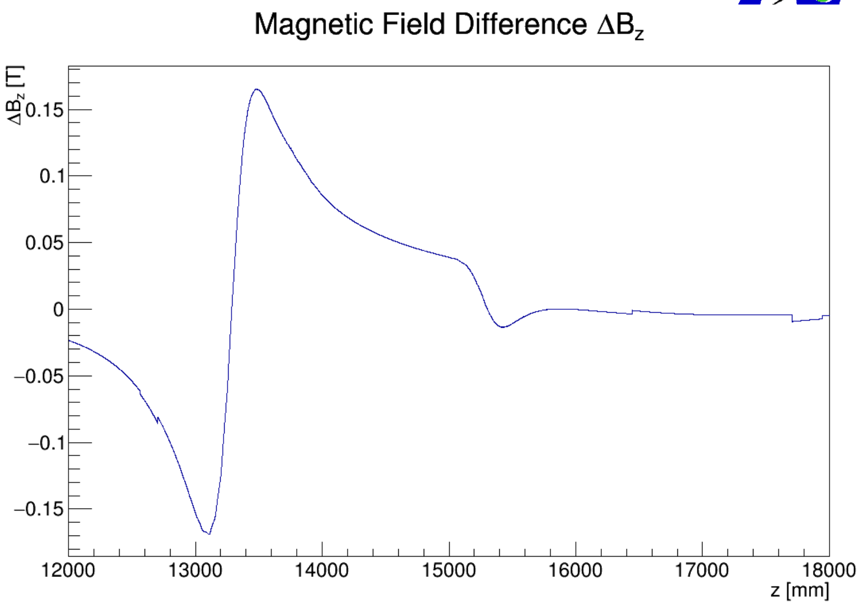




- OPERA model of Step IV
  - PRY induces a weak multipole component into the field maps
  - PRY pulls more field onto the axis of the cooling cell
    - Induces few percent non-linearity in field on-axis
  - End plate induces significant deviation in solenoid end field

OPERA Model Run 7469





- Increase of field by ~ few percent
- Field near the end plate is pulled towards aperture

Field model - plan

- Plan to
  - Use OPERA for field near end plate
  - Scale for coils elsewhere
- Verify models using beam-based alignment techniques
  - Minimise residuals between upstream and downstream trackers
  - Use measured transfer matrix to determine transverse kicks
  - Tilted helix fit (in solenoid region)
- Verify models using field map
  - Check field axis
  - Find best coil geometry for the field map; modify OPERA/MAUS model accordingly

Conclusion

- MICE has a comprehensive simulation tool in MAUS
- MAUS has been shown to compare well with other codes used for accelerator simulation
- Further comparison is now in progress against data
  - The final arbiter