



Realistic CAD-Based Geometries for Arbitrary Magnets With Beam Delivery Simulation (BDSIM)

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Monte Carlo simulations are required to accurately evaluate beam losses and secondary radiation in particle accelerators and beamlines. Detailed Computer-Aided-Design (CAD) geometries are critical to provide the most realistic distribution of material masses but increase the model complexity and often lead to code duplication. Beam Delivery Simulation (BDSIM) and the Python package `PYG4OMETRY` enable handling such accelerator models within a single, simplified workflow to run complete simulations of primary and secondary particle tracking and interactions with matter using Geant4. Replacing geometries of straight magnets is trivial in BDSIM. However, for curved magnets, the procedure is significantly more complicated and time-consuming for the user. Additional capabilities have therefore been developed to facilitate the design of arbitrary bent magnets by associating externally modelled geometries to the magnet poles, yoke, and beampipe. Individual field descriptions can be associated with the yoke and vacuum pipe separately to provide fine-grained control of the magnet model. The implementation of these new features is described in detail and applied to the modelling of the CERN Proton Synchrotron (PS) combined function magnets.

1. BDSIM effortless beamline design

Beam Delivery SIMulation (BDSIM) [1] provides tunable default geometries for any accelerator-based elements allowing effortless beamline design. Once the components of a system are defined, BDSIM builds the model based on a sequence of elements provided by the user.

To improve the magnet realism, a user can import Computer-Aided-Design (CAD) files for the external geometry of the magnets. **Unfortunately, in the current version of BDSIM,**

- CAD-based external geometry cannot be directly applied to a sector dipole magnet (Sbend).
- The magnets vacuum pipe design can only be chosen among some predefined default apertures.

➔ **A new feature has been developed to provide extra degrees of freedom to the user.**

2. External geometry customisation

User-defined external geometries are imported into a BDSIM model using Geometry Description Markup Language (GDML) files [2]. Users can create these GDML files using the Python library `PYG4OMETRY` [3] by converting CAD files inputs or constructing them from scratch.

If an outer geometry is defined for a simple element using a GDML file, BDSIM creates a default beampipe corresponding to the magnet dimension and adds the outer geometry to complete the magnet.

BDSIM builds hard-edged components in a sequence. Therefore, **to achieve a curved magnet with a complex cross-section, BDSIM splits up the curved element into many small straight sections.** Each component contains an "outer" yoke geometry and a beam pipe. Then, **if an outer geometry is externally supplied, this conflicts with the splitting into many smaller sections that BDSIM does.**

3. Vacuum pipe customisation

So far, BDSIM only provided the option to use default apertures for the pipe of common shapes leading to difficulties in efficiently simulating specific processes.

The only solution for these situations was the implementation of the complete geometry of an element in BDSIM using a GDML file and associating a field map to it. This method can be time-consuming and complex for the user.

➔ **The new feature allows to use one or several volumes of the external geometry GDML as beampipe for the magnet.** The magnetic field is then placed inside these chosen volume.

4. Illustration with the CERN PS extraction

Both new developments have been applied to the CERN Proton Synchrotron (PS) extraction magnet, called MU16, which consists of two combined dipole magnets, one focusing and one defocusing, encapsulated around a complex vacuum pipe composed of the extraction and the circulating parts.

The MU16 magnet GDML file has been created using PYG4OMETRY discarding the minor details of the CAD files:

- The external geometry of each combined magnet is composed of 5 blocks of two possible types, "open" or "closed". The external magnet geometry is realised by combining the model of each block several times with different orientation.
- The vacuum extraction pipe different inner parts have been modelled separately.

A GDML file is written for each of the two combined dipoles of MU16. **The MU16 extraction magnet is therefore implemented in BDSIM by a sequence of two Sbends using the new developments [4].**

The other Sbends of the PS have also been modelled using the new feature capabilities to build the CERN PS complete BDSIM model.

Conclusion and outlook

A new feature has been implemented in BDSIM to allow a GDML-provided external geometry to be used for the entire modelling of an Sbend magnet with the possibility to define specific volumes of the magnet geometry to be considered the vacuum pipe and encapsulate the correspondent magnetic field.

The use of more realistic external geometries in combination with the primary and secondary particle tracking allows BDSIM to become a powerful tool to reach new levels of accuracy in energy deposition, activation and shielding design studies [5, 6]. Different machine regimes and critical failure cases can be directly studied with one model, from the optics to the energy deposition in the magnets and walls for machine protection and radioprotection purposes.

Acknowledgments

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BDSIM default geometry for the Sbend

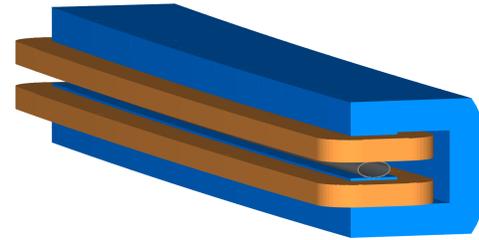


Figure 1: BDSIM model of an Sbend using the default geometry. The coils are represented in brown while, the yoke is represented in blue. An elliptical generic beampipe is represented in grey.

CAD-Based external geometry option before and after new feature

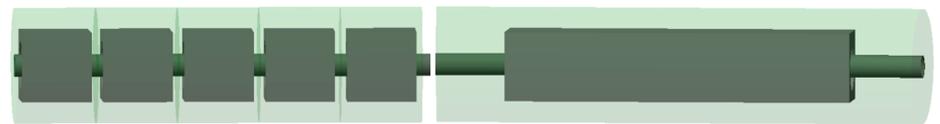


Figure 2: Sbend construction in BDSIM with and without the new feature. When the new feature is not activated, the outer geometry provided by the user (intentionally shorter than the straight sections for illustrating purposes) is implemented for all the straight segments composing it while the outer geometry provided by the user as one continuous piece is implemented for the Sbend assembly with the new feature. The magnet container logical volume is represented in light green.

CERN PS MU16 extraction magnet

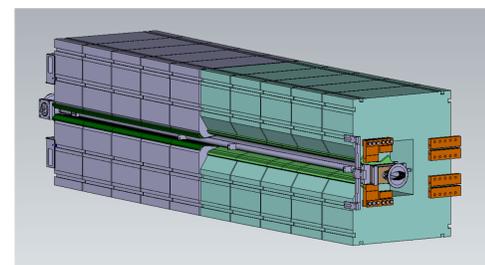


Figure 3: CAD representation of the MU16 extraction magnet showing the two half-units, the beampipe and the coils.

GDML Modelling of the MU16 with PYG4OMETRY

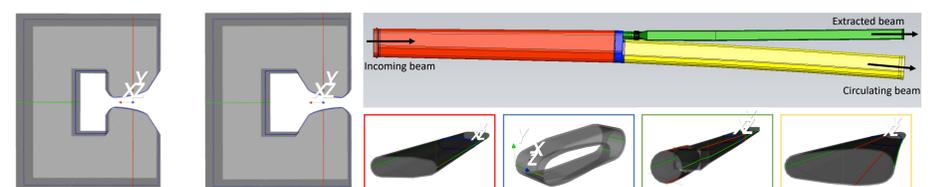


Figure 4: CAD representation of the vacuum extraction chamber. Each color corresponds to a different part of the chamber that has been separately modelled in `PYG4OMETRY` before being combined.

BDSIM model of the MU16 extraction magnet

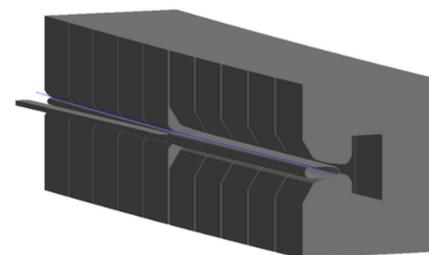


Figure 5: BDSIM model of MU16 composed of two combined dipoles each with a different GDML for their external part. The circulating primary beam can be observed in blue.

BDSIM CERN PS complete model

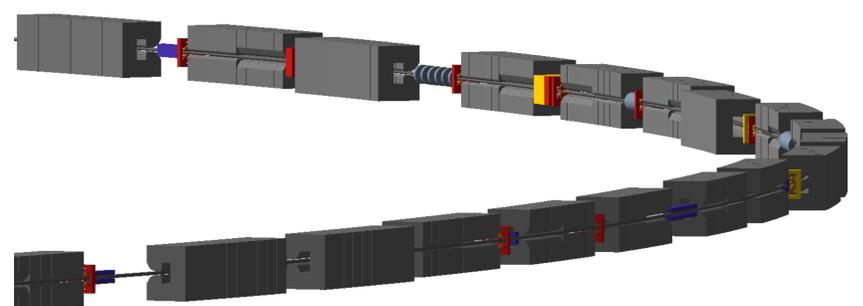


Figure 6: Close-up of the PS BDSIM model whose Sbends have been modelled using the new feature capabilities.