Purging magnet - Particle transport in a magnetic field

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Geant4 can handle transport of charged particles travelling through a magnetic field. This test was made to compare a Geant4 simulation of the deviation of electrons passing through a magnetic field with calculated values of the deviation. The design of the field and the calculation of the deviation were made with an electromagnetic finite element and finite difference analysis software, developed and manufactured by VECTOR FIELDS Ltd. The deflection capacity of the magnet depends crucially on its design. The goal in this work is to bend the electron beam in the y-direction, as the electron collector will be located downstream the purging magnet transferred in the y-direction. This is a description of the implementation and test of a 3D field grid in Geant4.

1. Geometry and simulation

The setup in this example is simply the 50 MeV electrons passing through a purging magnet in negative z-direction, (Figure 1). The electron beam was simulated as a point beam with no intrinsic and angular scattering, i.e., all electrons originating from the same point. In Geant4 the purging magnet was implemented as a 3-D grid of field values and geometrically as an iron gap. The dimensions of the opening of the pole gap were implemented according to CAD-drawings on the treatment head.

The design of the magnetic field was made with the OPERA-3d package. The 3-D grid and the deviation were calculated with the OPERA-3d module TOSCA. The 3-D field grid was then imported to be used in the simulation of particle transport. This means that the same field was used both in Geant4 simulation and in the TOSCA calculation of the deviation. However, one distinct difference between Geant4 and the OPERA-3d module TOSCA is that the latter only uses electromagnetic field equations without any particle interactions with matter. Therefore minimal particle interaction was simulated in Geant4 by using a vacuum as medium in the setup. The vacuum was simulated in Geant4 with standard temperature and pressure conditions composed of three elements; nitrogen, oxygen and argon. The composition was a mass fraction 0.7557 of nitrogen, 0.2315 of oxygen and 0.0128 of argon.

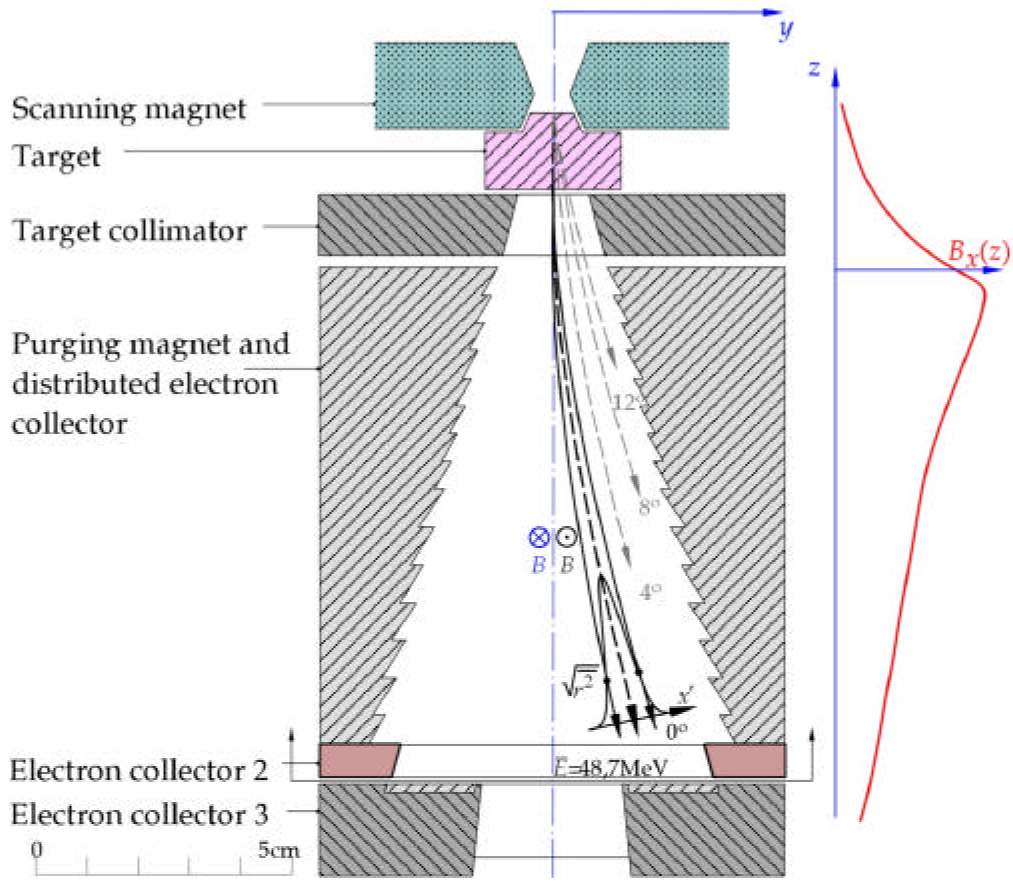

Figure 1 *Schematic drawing of the components along the beam from the last scanning magnet, target collimator, purging magnet and integrated electron collector. A cross section of the magnetic field, $B_x(z)$, is shown to the right in the picture. Four analytically calculated trajectories [5] for electrons with 48.7 MeV exit mean electron energy (right panel) of four different incident scan angles (0°-12°) influenced by the magnetic field are shown in chain curves. The rms radii of the transmitted electrons are indicated as full curves. The incident mean electron energy is 50 MeV.*

The magnetic field components are highest where the electrons enter the pole gap. The components are also highest in the x-direction. A cross section of the field along the central axis is presented in Figure 2. The maximal magnitudes of the field components are located at the pole gap at $z = -0.007$ m. Ideally the field should be zero before the gap. However, this is not possible to construct in reality, which means that there is a fringe field above the gap of the purging magnet, $-0.007 \le z \le 0.1$ m. The resolution of the input grid in this example was 2 mm in the z-direction and 4 mm in the x- and y-directions. The range of the grid was adjusted to the geometry and physics of the example to reduce the size of the input file. The ranges used in this example was $-0.05 \le x \le 0.05$ m, $-0.05 \le y \le 0.17$ m, and $-0.26 \le z \le 0.1$ m. The whole field is covered in the z-direction, and the range in the positive y-direction is more extent than in the x-direction, as the electrons will be deviated in that direction.

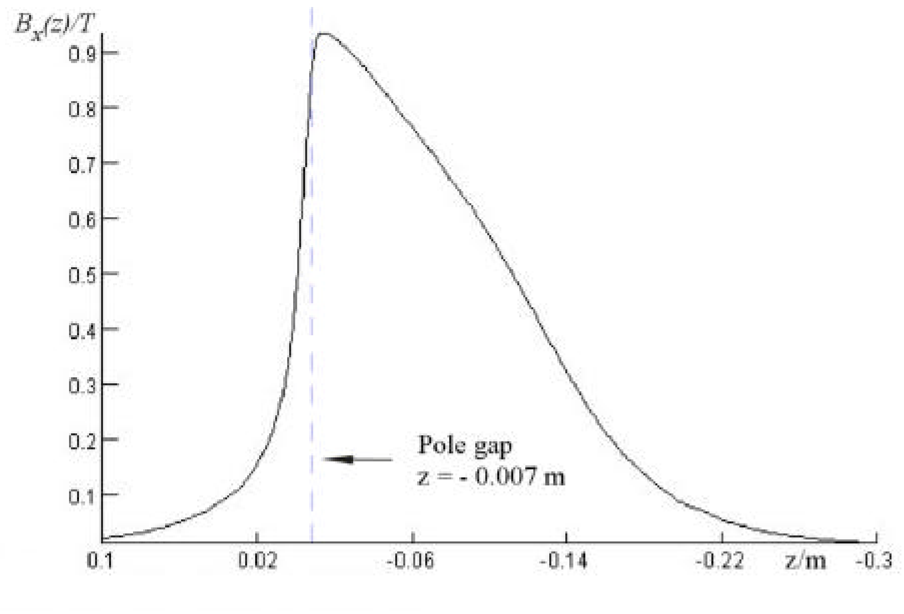

Figure 2 *Cross section of the field in the z-direction for x = 0 and y = 0.*

Linear interpolation was used to get the field values in every point of the trajectory of the electrons. The runs were made on a Linux RH 7.3 workstation with the Geant4-05 version of Geant4. The cutoff energies used in the Geant4 simulation are shown in Table 1.

Table 1 *Cuts used for particle transport in a magnetic field.*

Cut Energy	**Material**	**Gamma**	**Electron**
In range		1 µm	1 µm
In energy	Fe	990 eV	3.56 keV
	Vacuum	990 eV	990 eV

The physics processes were simulated with the standard electromagnetic classes (Table 2). In addition to the standard classes in Table 2 G4MultipleScattering and G4eplusAnnihilation are used. Collection of the position, energy and momentum of electrons were made at a distance of 50 cm from the source. A measure volume was used for the collection of the data.

Table 2 *Standard and low energy classes for photon and electron processes.*

	Low energy e.m.	**Standard e.m.**
Photon Processes	G4LowEnergyRayleigh G4LowEnergyPhotoElectric G4LowEnergyCompton G4LowEnergyGammaConversion (pair production)	 G4PhotoElectricEffect G4ComptonScattering G4GammaConversion (pair production)
Electron Processes	G4LowEnergyIonisation G4LowEnergyBremsstrahlung	G4eIonisation G4eBremsstrahlung

2. Results

A comparison between the deviation simulated in Geant4 and the deviation calculated with TOSCA analysis software was made. The setup and design of the field are described in Section 4.2.2. The magnetic field deviates the electron beam towards the positive y-direction. Therefore the comparison is made one-dimensional in the y-direction. The deviation from the Geant4 simulation was calculated as a mean value of the position of the electrons entering the measurement volume from above at a distance 50 cm from the source.

The results were as follows:
Geant4: deviation y-direction : **35.046 cm**
TOSCA: deviation y-direction : **35.112 cm**

As expected the Geant4 gave the same result as the calculation from TOSCA and this also confirms that the magnetic field has been imported geometrically correct.