TOOLS FOR FLEXIBLE OPTIMISATION OF IR DESIGNS WITH APPLICATION TO FCC

H. Burkhardt, CERN, Geneva, Switzerland
Manuela Boscolo, INFN-Frascati, Italy

Abstract

The interaction regions of future high-luminosity colliders require well balanced designs, which provide both for a very high luminosity and at the same time keep backgrounds and radiation at tolerable levels. We describe a set of flexible tools, targeted at providing a first evaluation of losses in the interaction region as part of the design studies, and their application to FCC.

INTRODUCTION

Studies on "Future Circular Colliders" FCC with emphasis on a hadron collider at centre-of-mass energies of the order of 100 TeV and as possible intermediate step an e^+e^- collider for the 90 to 400 GeV energy centre-of-mass energy range, to be installed in a new 80 to 100 km long tunnel, were recently launched by CERN in worldwide global collaboration [1].

Combining the requirements for very high luminosity at high beam energies with the need for low or at least tolerable background and radiation levels to the experiments at the interaction regions will be particularly challenging and require a well balanced machine detector interface design and optimization.

The FCC studies are currently in an early design stage. In this phase, the machine description can be expected to change frequently, and detailed aperture and material information will not always be available.

TOOL SET FOR MACHINE DETECTOR INTERFACE SIMULATIONS

We have started to develop a tool set "MDISim" for **M**achine **D**etector Interface **SIM**ulations. MDISim can be subdivided in three different steps.

1. Read machine lattice description, generate twiss, survey and geometry files
2. Visualization of the geometry and analytic estimates including calculation of synchrotron radiation
3. Detailed simulation of the passage of particles through materials

We use and combine the existing standard tools, MAD-X [2], ROOT [3] and GEANT4 [4]. We will now describe the steps in more details.

1 – MACHINE LATTICE

The basis and starting point for the studies is the magnetic lattice machine description in the form of MAD-X input files. In the first step, we run the MAD-X program using "MDISim" default twiss and survey selections and attributes, to produce detailed twiss and survey tfs-files for the magnetic lattice and accelerator geometry description. R-matrix or sector map information can optionally be selected for output in the twiss file to enable tracking by mapping in the second step. Running MAD-X to generate the twiss and survey files is very fast. It takes less than 10 seconds to generate the files for a 100 km machine with 50 000 elements. The two files contain tables with all relevant information element by element, as required as input for the second step.

The global parameters relevant for the whole machine like the beam energy, particle type and number of particles are provided in the header of the twiss table. The twiss file uses local *Courant Snyder* coordinates s, x, y where s is the position along the circumference and x, y the horizontal and vertical distance from the design orbit. The transverse coordinates (x, y) can be increased using a scalefactor. The survey file specifies the element positions x, y, z in a global Euclidian coordinate system.

2 – VISUALIZATION OF THE GEOMETRY AND ANALYTIC ESTIMATES

The second step starts by reading and merging the twiss and survey files generated by MAD-X. Both local "Courant Snyder" as well as global Euclidian coordinates (with transverse Euclidian coordinates renamed to $x2, y2$) are now available at the end of each element. In addition translation from local to global coordinates and vice versa is made available by linear transformation (shift plus rotation) for any arbitrary position. This makes it straightforward to add tracks from beam loss simulations [5] or magnetic lattice tracking, given in local coordinates, to the geometry display which uses Euclidian coordinates.

For the second step we use ROOT, linked to our MDISim library package which deals with tfs-file reading and merging, ROOT geometry generation and analytic estimates.

The graphics capabilities (zoom, rotation, selection or deselection of components) of ROOT with EVE and OpenGL are used to display the geometry [6] as shown in Fig. 1.

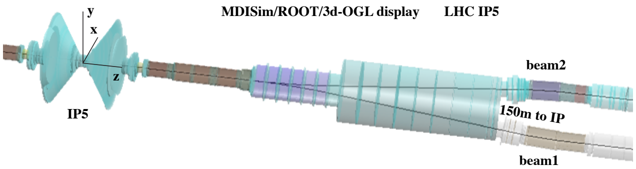

Figure 1: Display of the LHC IP5 geometry. Transverse (x,y) dimensions were increased by a factor of 100.

The program is designed to already start to work with only a minimum amount of information required. Any section

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V14_IR_6-13-2 by Anton Bogomyagkov et al.
iele   NAME      S       L       Angle     Ecrit  ngamBend      rho       B     BETX      SIGX     divx     Power frac>10MeV
                 m       m                   keV                  m       T     m         mm       mrad      kW

  13   L.MB0   43.5    10.5      0.001      1132    3.607   10500.0   0.0556  60.2966   0.2771   0.0130    33.61     1.e-05
  15   L.MB1     55    10.5      0.003      3397    10.82    3500.0   0.1668  16.9198   0.1468   0.0130    302.5   0.007505
  39   L.MB2  104.2    14.5   0.004167      3416    15.03    3480.0   0.1677  22.4885   0.1692   0.0105    422.6   0.007653
  59   L.MB3  141.7      15   0.005586      4428    20.15    2685.1   0.2174   6.8157   0.0932   0.0151    734.3    0.01695
  65   L.MB4  159.5      15   0.005586      4428    20.15    2685.1   0.2174  63.5433   0.2844   0.0152    734.3    0.01695
  91   L.MB5    224    21.5   0.002202      1218    7.943    9763.7   0.0598  20.1852   0.1603   0.0083     79.6     2.e-05
 105   L.MB6  262.5    10.5  0.0007305     827.1    2.635   14373.7   0.0406  34.6148   0.2099   0.0061    17.94     4.e-07

tlep_v12a_cern_full_ring by Roman Martin et al.
   14    BMVC    129   47.26     0.002     503.1    7.214   23629.2   0.0247 315.4373   0.5597   0.0056   7.368    1.3e-10
   24    BMVC  273.8   47.26     0.002     503.1    7.214   23629.2   0.0247 101.8127   0.3180   0.0056   7.368    1.3e-10
```

Figure 2: Synchrotron radiation information for the bending magnets up to 300 m from the IP. Calculated for the display in step 2.

of a magnetic lattice that can produce MAD-X twiss and survey output is sufficient to start the visualization.

Default values are provided for any further parameters. When apertures are not specified, we assume circular apertures of few centimetre radius with slightly different values for different element types, such that different element types can easily be distinguished in the display.

The example shown in Fig. 1 is LHC IP5. For the LHC, detailed aperture information is defined by the MAD-X input and used to automatically construct the geometry and display on the MDISim/ROOT level.

Synchrotron Radiation, Application to FCC

Synchrotron radiation is very important for FCC, both for the hh and ee options.

For FCC-hh, the critical photon energy reaches $E_{\rm cr}$ = 5.4 keV which is comparable to B-factories. The total power radiated will reach 3 MW at a proton beam energy of 50 TeV for 20 T bending fields.

For the electron option FCC-ee, synchrotron radiation dominates the energy loss and is a major source of beam induced backgrounds to the experiments.

We calculate the main synchrotron radiation parameters like critical energy and number of photons radiated by beam particles element by element at the MDISim/ROOT level. Detailed information is displayed in tabular form, as shown in Fig. 2 for bending magnets, for two alternative designs discussed in [7–9]. The geometry of the synchrotron radiation-fans is calculated and displayed together with the machine geometry, as shown in Fig. 3 for the design described in [7]. In simplified, sketched form, the command sequence to generate Fig. 3 is:

- Start MIDSim/ROOT
- Read and merge FCC-ee twiss and survey tfs files
- Construct and write ROOT geometry files
- Setup beam information from twiss file header
- Calculate beam sizes and divergence at each element
- Calculate synchrotron radiation in magnets
- Display the ROOT geometry
- Draw synchrotron radiation fans

A lot of crucial information for the interaction region design is already available at this level. The procedure is very fast and can quickly be applied to compare several lattice versions.

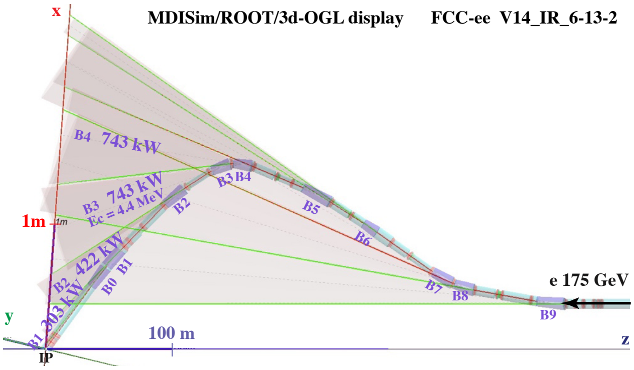

Figure 3: Visualisation of an FCC-ee IR geometry, with synchrotron radiation fans and analytical power estimates at a beam energy of E_b = 175 GeV.

For the design shown in Fig. 3, the synchrotron radiation power generated by the bending magnets within 250 m from the interaction region would be over 2 MW / beam on each side of the IP. For the incoming beam, the synchrotron radiation is pointing into the detector region.

Critical energies reach 4.4 MeV, implying that a non-negligible fraction (1.7%) of the photons has energies above 10 MeV resulting in a significant flux of neutrons by GDR (giant dipole resonance).

Absorption of MeV photons requires thick collimators. Photon scattering from the collimator surfaces is significant and makes it difficult to reduce the photon flux into the detector region significantly. The detailed simulation of scattering and absorption is obtained in the third step.

3 – DETAILED SIMULATION OF THE PASSAGE OF PARTICLES THROUGH MATTER

We use GEANT4 for the detailed simulation of the passage of particles through matter. GEANT4 includes a detailed simulation of synchrotron radiation for electrons [10], which we have recently extended to deal with any long lived charged particle. As an example we show the synchrotron

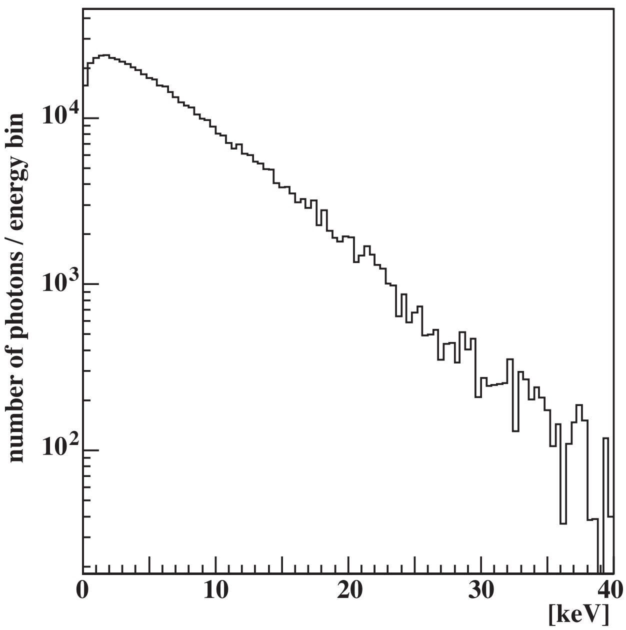

Figure 4: Synchrotron radiation spectrum generated with GEANT4 for 50 TeV protons in a 20 T field.

radiation spectrum generated with GEANT4 for 50 TeV protons in a 20 TeV magnetic field in Fig. 4.

The geometry is written from ROOT and imported into GEANT4 in GDML format [11]. Several geometry files, like one describing the machine and another the detector can be read and combined. Magnetic field strengths are directly read from the twiss output, which allows for different fields corresponding to different beam energies for the same accelerator geometry.

Fig. 5 shows an example of detailed tracking with synchrotron radiation and absorption of the synchrotron radiation in the beam pipe.

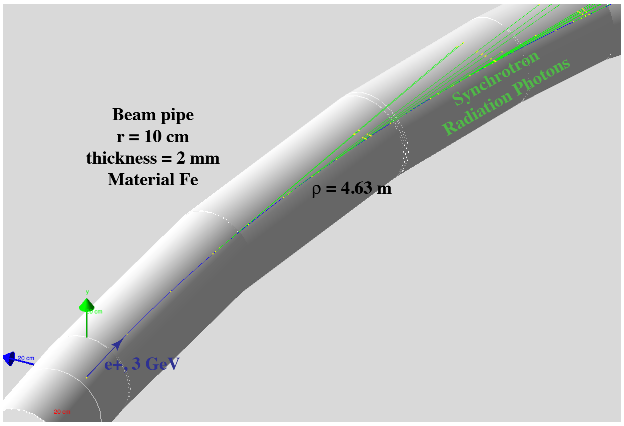

Figure 5: Example of detailed tracking with Geant4.

Essential information like the direction and power of synchrotron radiation is directly made available at the lattice and

SUMMARY

Based on existing tools, and motivated by the requirements for FCC, we have been setting up a framework for machine detector interface studies.

geometry level. This makes it possible to include machine detector interface requirements into an overall optimisation from the beginning of design studies.

Detailed geometries are generated and displayed using ROOT. The geometry information can be exported in several formats, suitable as input for detailed shower Monte Carlo programs like GEANT4.

We have started to apply our package to FCC-ee design studies and presented a first comparison at the recent FCC-week [12], showing that the minimisation of synchrotron radiation in the interaction region will be important and particularly challenging at the top beam energies.

ACKNOWLEDGMENT

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