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MDITookit Manual

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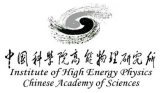

MDIToolkit Manual

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Abstract

Manual of the MDIToolkit

To be submitted to *CEPC Note*

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Contents

1 Introduction to the MDIToolkit

The MDI (Machine Detector Interface) study requires closely cooperation between accelerator experts and detector experts. The people who are studying the MDI problem should know about both the machine and the detector. For instance, in order to study the beam induced backgrounds, the people need firstly know about the lattice design and important parameters of the accelerator design, secondly he should generate different kind of beam induced backgrounds with specified generators, thirdly simulate the interaction between the background particles and the detector and finally analysis the results of different beam induced backgrounds. During this process, a lot of different software will be used. It's very difficult for one person to use all of these software. In order to improve the efficiency, we summarized all of the most important parameters of each software and packaged these software to be the MDIToolkit.

The most important features of MDIToolkit can be summarized as below:

Firstly, one can create a template for each kind of beam induced background simply by the command "mkProject.sh" with different options. This will eliminate most repetitive work and make the study process more clear.

Secondly, all of the important parameters of each kind of beam induced background can be conveniently configured in the file named as "config.txt". All of the software for the beam induced background study can be automatically invoked by the command "mkJob.sh config.txt". It makes the maintenance of the background study to be more easily.

Finally, in order to analysis the results of each kind of beam induced backgrounds, we developed an analysis software BAT (Background Analysis Tool). This software is also steered by a configure file. The command of this software is "Bat.exe config.txt".

2 The architecture of the MDIToolkit

The software architecture of the MDIToolkit is shown in Figure. 1.

The software consists of the setup of environment variables, the executable tools for simulation, the analysis tools for analysis and the templates.

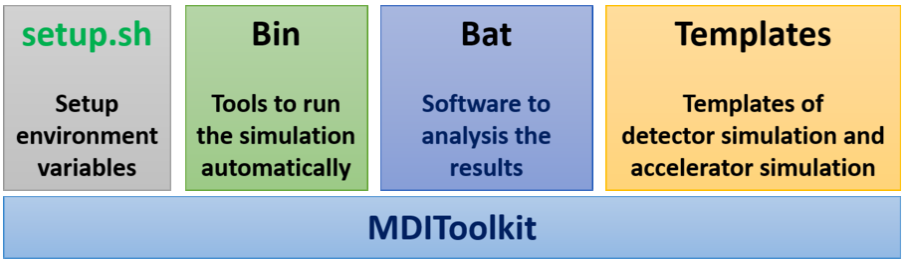

Figure 1: The software architecture of the MDITookit

The executable tools are stored in the "bin" directory of the MDIToolkit. Several important command for the MDIToolkit are "mkLattice.sh", "mkPrject.sh", "mkJob.sh", "rmLattice.sh", "rmProject.sh" and "rmJob.sh" The us-age of these commands will be introduced in the next section.

The Background Analysis Tools (BAT) is a software developed based on ROOT. It can conveniently draw most of the plots about the beam induced backgrounds at CEPC.

3 Setup of Environment for MDIToolkit

The MDIToolkit only support the bash shell environment by now. It depends on several other software. To setup the dependent libraries, one should source the mdi_env.sh

```
$source /afs/ihep.ac.cn/users/x/xiuql/higgs/config/mdi_env.sh
```

The contents of the mdi_env.sh are:

```
#########################################################################
# Environment script for MDI study
#########################################################################
#-----------------------------------------------------------------------
# GCC-4.9.3
#-----------------------------------------------------------------------
export PATH="/besfs/groups/higgs/data/workarea_xiuql/gcc-4.9.3/build/bin:$PATH"
export LD_LIBRARY_PATH="/besfs/groups/higgs/data/workarea_xiuql/gcc-4.9.3/
build/lib64:/besfs/groups/higgs/data/workarea_xiuql/gmp-4.3.2/build/lib:
/besfs/groups/higgs/data/workarea_xiuql/mpc-0.8.1/build/lib:/besfs/groups/
higgs/data/workarea_xiuql/mpfr-2.4.2/build/lib:$LD_LIBRARY_PATH"
export COMPILER_PATH="/besfs/groups/higgs/data/workarea_xiuql/gcc-4.9.3/
build/lib/gcc/x86_64-unknown-linux-gnu/4.9.3:$COMPILER_PATH"
#-----------------------------------------------------------------------
# Guinea-Pig
#-----------------------------------------------------------------------
export GUINEAPIG="/besfs/groups/higgs/data/workarea_xiuql/guinea-pig"
export PATH="$GUINEAPIG/build/bin:$PATH"
#-----------------------------------------------------------------------
# FFTW3
#-----------------------------------------------------------------------
export FFTW="/besfs/groups/higgs/data/workarea_xiuql/fftw-3.3.4"
```

```
export LD_LIBRARY_PATH="$FFTW/build/lib:$LD_LIBRARY_PATH"
#-------------------------------------------------------------------
# SAD
#-------------------------------------------------------------------
export SAD="/besfs/groups/higgs/data/workarea_xiuql/oldsad"
export PATH="$SAD/bin:$PATH"
#-------------------------------------------------------------------
# PYTHIA
#-------------------------------------------------------------------
export PYTHIA="/besfs/groups/higgs/data/workarea_xiuql/Pythia6.4"
export PATH="$PYTHIA:$PATH"
#export LD_LIBRARY_PATH="$PYTHIA:$LD_LIBRARY_PATH"
#-------------------------------------------------------------------
# PYTHON2.7
#-------------------------------------------------------------------
export PYTHON_PATH="/besfs/groups/higgs/data/workarea_xiuql/Python/Python-2.7.10/
build"
export PATH="$PYTHON_PATH/bin:$PATH"
export LD_LIBRARY_PATH="$PYTHON_PATH/lib:$LD_LIBRARY_PATH"
#-------------------------------------------------------------------
# CMAKE
#-------------------------------------------------------------------
export CMAKEPATH="/besfs/groups/higgs/data/workarea_xiuql/CMake/build"
export PATH="$CMAKEPATH/bin:$PATH"
alias cmake='cmake -DCMAKE_C_COMPILER=gcc -DCMAKE_CXX_COMPILER=g++'
#-------------------------------------------------------------------
# XercesC
#-------------------------------------------------------------------
export XercesC_HOME="/besfs/groups/higgs/data/workarea_xy/soft-slc6/v01-17-05/
xercesc/3.1.1"
export PATH="$XercesC_HOME/bin:$PATH"
export LD_LIBRARY_PATH="$XercesC_HOME/lib:$LD_LIBRARY_PATH"
#-------------------------------------------------------------------
# Geant4
#-------------------------------------------------------------------
export G4INSTALL="/afs/ihep.ac.cn/users/x/xiuql/higgs/geant4.10.02.p01/build"
export G4ENV_INIT="$G4INSTALL/bin/geant4.sh"
export G4SYSTEM="Linux-g++"
export LD_LIBRARY_PATH="/afs/ihep.ac.cn/users/x/xiuql/higgs/geant4.10.02.p01/
build/lib64:$LD_LIBRARY_PATH"
source $G4ENV_INIT
#-------------------------------------------------------------------
# CLHEP
#-------------------------------------------------------------------
export CLHEP="/afs/ihep.ac.cn/users/x/xiuql/higgs/clhep-2.3.3.1/CLHEP/build"
export CLHEP_BASE_DIR="$CLHEP"
export CLHEP_INCLUDE_DIR="$CLHEP/include"
export PATH="$CLHEP_BASE_DIR/bin:$PATH"
export LD_LIBRARY_PATH="$CLHEP_BASE_DIR/lib:$LD_LIBRARY_PATH"
#-------------------------------------------------------------------
# ROOT
#-------------------------------------------------------------------
export ROOTSYS="/afs/ihep.ac.cn/users/x/xiuql/higgs/root-6.04.18/local"
```

```
export ROOTVERS="6.04.18"
export PATH="$ROOTSYS/bin:$PATH"
export LD_LIBRARY_PATH="$ROOTSYS/lib:$LD_LIBRARY_PATH"
source $ROOTSYS/bin/thisroot.sh
#------------------------------------------------------------------------
# BDSIM
#------------------------------------------------------------------------
export BDSIM="/besfs/groups/higgs/data/workarea_xiuql/bdsim/build"
export PATH="$BDSIM/bin:$PATH"
export LD_LIBRARY_PATH="$BDSIM/lib:$LD_LIBRARY_PATH"
#------------------------------------------------------------------------
# BBBREM
#------------------------------------------------------------------------
export BBBREM="/besfs/groups/higgs/data/workarea_xiuql/BBbrem"
export PATH="$BBBREM/bin:$PATH"
```

The most important environment variables are set by the "setup.sh" in the MDIToolkit directory. One should source the "setup.sh" before use the MDIToolkit.

```
$source /afs/ihep.ac.cn/users/x/xiuqlu/workfs/MDIToolkit/setup.sh
```

Below variables will be set in the "setup.sh"

```
# The root path of MDIToolkit
export MDIPATH="/afs/ihep.ac.cn/users/x/xiuqlu/workfs/MDIToolkit"

# the bin path of useful tools for MDI study
export PATH="${MDIPATH}/bin:${PATH}"

# path to store project
export MDIPROJECTPATH="/afs/ihep.ac.cn/users/x/xiuqlu/cefs/Proj
ectRepository"

# path to store data
export MDIDATAPATH="/afs/ihep.ac.cn/users/x/xiuqlu/cefs/Data"

# version of accelerator lattice
export LATTICEVERSION="Lattice_PDR_V1"

# Marlin processor to extract hit information from detector full simulation
source ${MDIPATH}/MarlinProcessor/HitMap_Marlin/loadLDD.sh
```

4 Usage of the MDIToolkit

4.1 Procedures to Simulate the Beam Induced Backgrounds

The procedures of the beam induced background simulation can be subdivided into 4 step for a new lattice version:

1. If a new lattice version is available and there are some large modifications in the machine parameter, one should firstly create a folder for the new lattice version. The command to create the new lattice folder is ”mkLattice.sh”. The usage of this command is:

```
$ mkLattice.sh lattice_name
```

When the lattice is created, the directory structure will also be created for both the data store and job running. The command to remove the lattice folder is”rmLattice.sh”:

```
$ rmLattice.sh lattice_name
```

For the beam induced background of CEPC, the data and log files are store in the directory with such a tree structure:

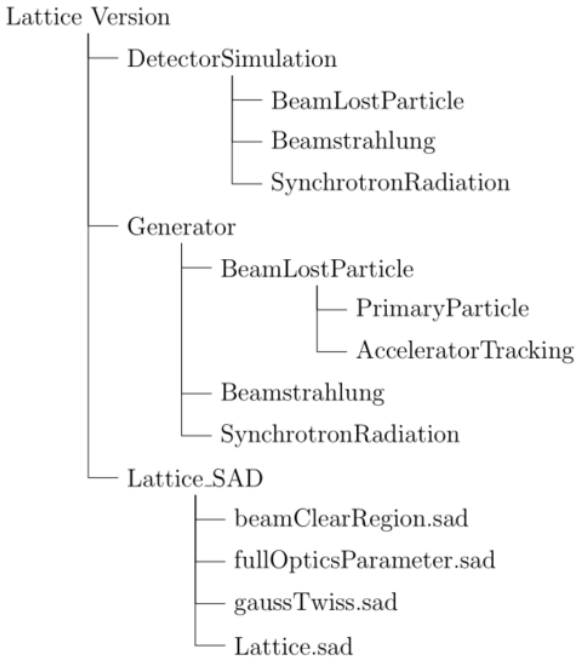

Figure 2: Tree structure of data directory

2. After the lattice folder is created, one should begin to simulate the beam induced backgrounds. Because the mechanism of each kind of backgrounds are different, we will create a project for each simulation of the background. The command to create the project is ”mkProject.sh”

```
$mkProject.sh -option project_name
$mkProject.sh -b project_name ::  Create Project for beamstrahlung
$mkProject.sh -s project_name ::  Create Project for synchrotron simulation
$mkProject.sh -d project_name ::  Create Project for detector simulation
$mkProject.sh -la project_name ::  Create Project for accelerator simulation
$mkProject.sh -lb project_name ::  Create Project to generate radiative bhabha
particles for lost tracking
$mkProject.sh -r project_name ::  Create Project just for results analysis
```

The command to remove the project folder is"rmProject.sh":

```
$ rmProject.sh project_name
```

3. When a project is created, there should be a configure file in the project folder. The most important parameters for the simulation of this kind of background should be set in this file. After the configuration has been finished, one should submit job to do the real simulation. The command to submit job is "mkJob.sh"

```
$mkJob.sh config.txt
```

The command to remove the jobs is

```
$ rmJob.sh config.txt
```

4. After all of the jobs have been finished, one should begin to analysis the results. By now, most of the analysis code have been integrated in the code name "Bat (Background Analysis Tool)". There is also a configuration file for each kind of analysis. The usage is:

```
$Bat.exe config.txt
```

All of the results will be stored in a ROOT file.

4.2 The Configure File

The configure file is used to invoke related software and set important parameters of the software. The meaning of each option in the configure files are introduced in this section.

4.2.1 General Options of the Configure File

The general options will be appeared in most of the configure files. The meaning of these options in all of the configure files are the same.

- JobType (String) : Determine which software will be invoked for this configure file. Please don't change this option.
- InputPath (String) : The path of input file for the invoked software. If the software doesn't need input, please keep the string to be empty.
- InputFileNamePattern (String) : The name pattern of the input file. The full name of the file will be "name_pattern_index.dat". The index is a number between the StartJob and FinalJob.
- OutputPath (String) : The path to store the output file.
- OutputFileNamePattern (String): The name pattern of the output file. The full name of the file will be "name_pattern_index.dat". The index is a number between the StartJob and FinalJob.

- StartJob (String) : The start index of the file name.
- FinalJob (String) : The final index of the file name.
- SafeFactor (Double) : Safe factor to estimate the background level in the detector. Usually set as 5 or 10 for final results. At current, the default value is set as 1.
- BXRate (Double) : number of bunch crossing per second. Be used to normalize the event rate.
- RunTime (Double) : Effective run time per year. The unit is second (s).

4.2.2 Options for the Synchrotron Radiation

The synchrotron radiation is simulated with a code developed based on BDSIM. The code can be obtained from the github:

https://github.com/xiuql/BDSIM4CEPC

To simulate the synchrotron radiation, the lattice design of the accelerator is required. The file format from the accelerator group are usually "mad" or "sad", however, the required format of BDSIM is "gmad". The gmad file can be converted from the mad8 file directly. The MAD8 macros to do the conversion is:

```
CALL FILENAME="lattice_file.mad"
USE, RING
SAVELINE, NAME="RING", FILENAME="lattice_file.gmad"
STRUCTURE, FILENAME="PDR.stc", ORDER=4
```

The "RING" is the name of the beam line defined in the "lattice_file.mad". It should be noticed that the letters in the output file "lattice_file.gmad" should all be converted to be lowercase.

- LatticeFile (String) : It determines which gmad file will be used
- CollimatorMaterial (String) : The material of the collimator if the collimator have been inserted in the "lattice_file.gmad". The collimator should be added in the lattice file manually according to the distribution of synchrotron radiation.
- CollimatorThickness (Double) : The thickness of the collimator. It means no collimator if the thickness of collimator is 0.
- BeamEnergy (Double) : Energy of a single beam.
- NofBeamParticles (Int) : Number of primary beam particles will be tracked in BDSIM. This number determines the CrossSectionFactor in analysis.
- StartElement (String) : Name of the element where the primary beam particles will be started to tracking in the beam line. Because only the synchrotron radiation generated near the interaction region will affected the detector, we don't need track the beam particles along the whole ring. To reduce the simulation time, we can just track the beam particles in the region around the IP.
- EndElement (String) : Name of the element where the primary beam particles will be stopped in the tracking. The StartElement and the EndElement defined the region the primary beam particles are tracked.

In order to find the name of the element, one should firstly run the BDSIM with the "–verbose" option

```
        $bdsim --file=Job_SRGen_1.gmad --output=none --circular --batch --verbose >
Job.log
```

All of the element name will be find in the "Job.log"

When tracking the primary beam particles, lots of synchrotron photons will be generated along the beam line. In order to do further analysis, these photons should be permanently stored. However, because only a small fraction of these photons will hit the interaction region. To save the storage space, only the photons will hit the interaction region will be stored. The options to do this cut is:

- HitPosCutUpstream (Double) : The position cut on the side of the IR where the beam is coming. The origin point is located at IP.
- HitPosCutDownstream (Double) : The position cut on the side of the IR where the beam is leaving. The origin point is located at IP.
- BeamPipeRadius (Double) : Radius of the beam pipe

The HitPosCutUpstream and HitPosCutDownstream defined the region where the photons will be stored if the photons hit the beam pipe. Because the origin point is located at IP, the HitPosCutUpstream is usually minus value and the HitPosCutDownstream is usually positive value.

When study the synchrotron radiation from the quadrupole, the charge distribution inside the bunch will be very important. Especially the size and distribution of the beam halo.

- Bunch.DistributionType (String) : distribution type of the bunch. The default distribution type is "gausstwiss" in our simulation. If you want to use other distribution type, please read the manual of BDSIM.
- Bunch.EmitX (Double) : Emittance of the lattice in the x direction at the StartElement
- Bunch.EmitY (Double) : Emittance of the lattice in the y direction at the StartElement
- Bunch.AlphaX (Double) : Alpha of the lattice in the x direction at the StartElement
- Bunch.AlphaY (Double) : Alpha of the lattice in the y direction at the StartElement
- Bunch.BetaX (Double) : Betatron function of the lattice in the x direction at the StartElement
- Bunch.BetaY (Double) : Betatron function of the lattice in the y direction at the StartElement
- HaloSizeRatioX (Double) : The ratio of halo size to the normal bunch size in the x direction
- HaloSizeRatioY (Double) : The ratio of halo size to the normal bunch size in the y direction

The twiss parameter of each element in the lattice can be found in the output of the SAD macros. The SAD macros can be found in the "Lattice_SAD" folder after the "mkLattice.sh" command is executed.

5 Simulation of Beamstrahlung

The beamstrahlung can be simulated following below steps:

1. Enter the generator folder of beamstrahlung

```
$cd $MDIPROJECTPATH/Lattice_Name/Generator/Beamstrahlung
```

2. Make a project for the generator of beamstrahlung. For instance, the project name is assumed to be "BS"

```
$mkProject.sh -b BS
```

3. There will be 3 folders in the new created project. Enter the folder "GuineaPig"

```
$cd projectName/GuineaPig
```

In the GuineaPig folder, there is a folder named "tmp" and a configure file "config.txt". Please modify the parameters in the "tmp" according to the machine parameter of CEPC. Please read the manual of GuineaPig to learn how to set these parameters. The configure file is used to submit jobs. In the config.txt, the option "OutputPath" have been set when you create the project, please don't change it. The option "AcceleratorModel" and "ParameterSet" are used to select the parameter set in the "tmp".

4. After all of the parameters have been modified according to the requirement of your simulation, you can submit jobs to run the simulation.

```
$mkJob.sh config.txt
```

5. When all of the jobs have been finished, one should do the hadronization for the hadron events. To do this, please enter the "Hadronization" folder of the project. Most options have been set when you create the project. Please set the number of jobs according to the number of jobs of GuineaPig. After the modification have been finished, submit hadronization jobs.

```
$mkJob.sh config.txt
```

6. After the hadronization jobs are finished, One can do the analysis in the generator level. The analysis macros are in the "Analysis" folder of the project. There are two configure files in the Analysis folder. Most analysis can be done by the configure file "configAna.txt". To do the analysis, execute below command

```
$Bat.exe configAna.txt
```

Several important options in the configAna.txt are:

- NofPhotonFile (Int) : Number of photon files will be used in the analysis. Because the number of photons are too large, we don't need use all of them in the anaysis. We can just read several files of them with this option.

- BField (Double) : Magnetic field value of the detector. The unit is Tesla.
- CrossingAngle (Double) : Crossing angle of two beams. The unit is mrad.
- NofPairHelice (Int) : Number of incoherent pair events will be used to draw the trajectories. If the value is minus, all events will be read
- HeliceFlux (Int) : When draw the trajectories of incoherent pairs, draw lines or flux.
- NofCut (Int) : Number of cut in the radius and theta when count the number of final state particles. There will be a count for each cut.
- CrossSectionFactor (Double) : Set as 1 for beamstrahlung.
- NofBeamFactor (Int) : Set as 1 for beamstrahlung.
- NofIPFactor (Int) : Set as 1 for beamstrahlung

7. The configBeamPipe.txt should be executed after the configAna.txt. The most important options in the configBeamPipe.txt are the DataSize, PzVector, PtVector. These values are read from the histogram "hPairPzPt" which is the output of configAna.txt. The PzVector and PtVector are used to fit the envelope curve in the hPairPzPt. The DataSize determines how many points will be used in the fit. To do the fit, one should select the points on the envelope curve manually.

```
$Bat.exe configBeamPipe.txt
```

6 Simulation of Synchrotron Radiation

1. Enter the generator folder of synchrotron radiation.

```
$cd $MDIPROJECTPATH/Lattice_Name/Generator/SynchrotronRadiation
```

2. Make a project for the generator of synchrotron radiation. The synchrotron radiation from dipole magnets and quadrupole magnets are studied independently, and the core and halo in the quadrupole magnets are also studied independently, thus, one should create at least 3 project to study the synchrotron radiation.

```
$mkProject.sh -b SR_D
$mkProject.sh -b SR_QC
$mkProject.sh -b SR_QH
```

There are 5 folders in each new created project. The folder "Generator" is used to generate the synchrotron photons. The folder "Interaction" is used to simulate the interaction between synchrotron photons and beam pipe material. The analysis macros are in the folder "Analysis". The folder "include" includes the lattice file in gmad format and configure templates for BDSIM. The last folder is "TrackingValid". This folder is used to compare the tracking results of primary particles between BDSIM and SAD. Because the tracking results of BDSIM will be affected by several important parameters about step length in Geant4, user should modify these parameters by themselves to obtain reasonable results. For

CEPC, I have validated these parameters and you don't need to change these parameters. However, if the software is used to study other machine, these parameters need be validated again.

3. Enter the folder "Generator"

```
$cd projectName/Generator
```

4. Modified the configure file "config.txt" according to the requirement of your simulation. The meaning of the options in the configure file have been explained in Section 4.2. After the modification, submit jobs to run the simulation.

```
$mkJob.sh config.txt
```

5. When all of the generation jobs have been finished, one should simulate the interaction between photons and beam pipe. To do this, please enter the "Interaction" folder of the project. Most options have been set when you create the project. Please set the number of jobs according to the number of jobs of generator. After the modification have been finished, submit interaction jobs.

```
$mkJob.sh config.txt
```

6. After the interaction jobs are finished, One can do the analysis in the generator level. The analysis macros are in the "Analysis" folder of the project. There are two configure files in the Analysis folder. The configure file "configAna.txt" is used to do some basic analysis. For instance, the energy distribution, power emittance and so on. The other configure file is "configFlux.txt". It's used to display the photon flux inside the beam pipe. The time consumption to display the photon flux is very long (about 48 hours). Thus, this algorithm should be optimized in the future.

```
$Bat.exe configAna.txt
```

Several important options in the configure files are:

- MaxNofEvt (Int) : Number of events will be used in the anaysis. If the value is -1, all of the photons will be used.
- Symmetry (Int) : If display the results symmetrically about the IP. 0: asymmetry. 1: symmetry
- EmitRange (Array) : Only photons emitted from this range in z axis will be used for the analysis. 0,0 means all of the photons will be used.
- HitPosCutZ (Array) : Only photons hit in this range in z axis will be used for the analysis.
- HistRangeR (Array) : Set bins for the histogram in r direction
- HistRangeZ (Array) : Set bins for the histogram in z direction
- HistEnergy (Array) : Set bins for the energy distribution
- RunMode (Int) : Select the algorithm for the analysis. 0: basic analysis. 1: analysis with more cuts (Under developing). 2: do both the basic analysis and the complex analysis
- CrossSectionFactor (Double) : the value = number of beam particles in one bunch (machine parameter) / NofBeamParticles (an option in the generator configure file)

7 Detector Simulation

The detector simulation is done by Mokka. The method to setup the Mokka can be found in the manual of ILCSoft. It should be noticed that some environment variables of ILCSoft conflict with those of MDIToolkit at current. Please don't source the MDIToolkit setup file when you have source the setup file of the ILCSoft. Because there are many kinds of beam induced background, one should create a project for each kind of beam induced background to do the detector simulation. 1. Enter the detector simulation folder of a specific background. For example, for the beamstrahlung:

```
$cd $MDIPROJECTPATH/Lattice_Name/DetectorSimulation/Beamstrahlung
```

2. Make projects for the detector simulation of beamstrahlung. Because the incoherent pair production and hadron events of beamstrahlung are studied independently, one should create at least 2 project to do the detector simulation for beamstrahlung.

```
$mkProject.sh -d BS_Pair
$mkProject.sh -d BS_Hadron
```

There are 3 folders in each new created project. The folder "Mokka" is used to do the detector simulation with Mokka, which is developed based on Geant4. The folder "Marlin" is used to extract hit information from the detector simulation results. The analysis macros are in the folder "Bat".

3. Enter the folder "Mokka"

```
$cd projectName/Mokka
```

4. Modified the configure file "config.txt" according to the requirement of your simulation. After the modification, submit jobs to run the simulation.

```
$mkJob.sh config.txt
```

5. When all of the mokka jobs have been finished, one should extract the hit information for each sub-detector. To do this, please enter the "Marlin" folder of the project. After the modification have been finished, submit interaction jobs.

```
$mkJob.sh config.txt
```

6. After the marlin jobs are finished, One can do the analysis in the detector simulation level. The analysis macros are in the "Bat" folder of the project.

```
$Bat.exe config.txt
```

Several important options in the configure files are:

- SafeFactor (Array) : Although one can set the safe factor for hit density, TID and NIEL separately, these 3 safe factors should be kept as the same.
- CrossSectionFactor (Double) : the value is the same as the that in the generator level

The geometry of each sub detectors should also be set in this configure file.