

Neutral Particle Spectrometer Geant4 Simulation Guide for Hall C DVCS

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This document is a short guide on how to run a Neutral Particle Spectrometer (NPS) Geant4 simulation with a DVCS event generator and a photon reconstruction software. There are also short descriptions of the necessary classes. Currently, the kinematic setting exists only for the proposed Hall C DVCS. For any questions or comments, please send an email to hosanko@jlab.org.

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1 Running a simulation

1.1 Environment setting in JLab/ifarm and getting the code

The Geant4 library of this simulation is based on a version 4.10.03.p03. The environment configuration in JLab/ifarm is done by 'source site/12gev_phys/softenv.csh 2.3' (or 'softenv.sh' depending on the preference of the user). This configuration uses a Geant4 version 4.10.03.p02. Detailed configurations are shown in Fig. 1. Additional environment settings are necessary for the DVCS event generator and the photon reconstruction to work: see Fig. 2.

The codes for the simulations are on GitHub (https://github.com/gboon18/HallC_NPS/) and the directory for the simulation with the DVCS event generator and the photon reconstruction is 'DVCS_evt_gen/'.

1.2 Configuration and compiling

This section presents one of the ways to configure a Makefile and compile using 'ccmake'. You can skip this section if you know how to configure and compile the code yourself.

In the directory 'DVCS_evt_gen/', the subdirectory 'DVCS/' has source codes and 'macros/' has example macros that might be useful to some users. Make a build directory (let us name it 'build/') inside the 'DVCS_evt_gen/'. In the 'build/', configure the source with 'ccmake', by typing 'ccmake ../DVCS/'. If you set the environment 'source site/12gev_phys/softenv.csh 2.3' correctly according to the JLab user guide, all the environments needed for the simulation will be configured automatically: see Fig. 3. Type 'c' to configure and 'g' to generate the 'Makefile'. After that, type 'make' to make executable 'DVCS'.

1.3 Running a simulation

There are 4 arguments to input when running the simulation:

```

J E F F E R S O N   L A B
-----
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network owned by the Federal Government.  It is for authorized use only.
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Any or all uses of this system and all files on this system may be intercepted,
monitored, recorded, copied, audited, inspected, and disclosed to authorized
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disciplinary action and civil and criminal penalties. By continuing to use
this system you indicate your awareness of and consent to these terms and
conditions of use. LOG OFF IMMEDIATELY if you do not agree to the conditions
stated in this warning.
-----
CentOS Linux release 7.7.1908

> Common Environment Version: <2.3> (Wed October 3 2018)
> Running as hosanko on ifarm1801.jlab.org
> OS Release: Linux_CentOS7.7.1908-x86_64-gcc4.8.5
> JLAB_ROOT set to: /site/12gev_phys
> JLAB_SOFTWARE set to: /site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5

> BANKS          version: 1.4
> CCDB           version: 1.06.02
> CLHEP          version: 2.4.0.4
> EVIO           version: 5.1
> GEANT4         version: 4.10.04.p02
> GEMC           version: 2.7
> JANA           version: 0.8.0
> MLIBRARY       version: 1.3
> MYSQL          installed in /site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/mysql/lib
> QT             version: 5.10.1
> ROOT           version: 6.14.04
> SCONS          version: 1.7
> XERCE          version: 3.2.2

>> For documentation on the environment please visit https://data.jlab.org

```

Figure 1: JLab/ifarm environment configuration. The configuration is done by 'source /site/12gev_phys/softenv.csh 2.3'.

```

#ROOT ## needed (especially) when compiling the NPS photon reconstruction software
setenv ROOTSYS /apps/root/5.34.36/root
setenv LD_LIBRARY_PATH ${ROOTSYS}/lib:${LD_LIBRARY_PATH}
setenv PATH ${ROOTSYS}/bin:${PATH}
#NPS software environment
setenv NPS_SOFT /work/hallc/nps/hosan/NPS_SOFT
setenv LD_LIBRARY_PATH ${NPS_SOFT}:${LD_LIBRARY_PATH}
setenv PATH ${NPS_SOFT}:${PATH}
#DVCS event generator for NPS environment #No need to do this but just in case.
setenv DVCS_EVENT_GEN /work/hallc/nps/hosan/dvcs_gen
setenv LD_LIBRARY_PATH ${DVCS_EVENT_GEN}:${LD_LIBRARY_PATH}
setenv PATH ${DVCS_EVENT_GEN}:${PATH}
#analyzer
setenv ANALYZER /work/hallc/nps/hosan/analyzer-1.5.22
setenv LD_LIBRARY_PATH ${ANALYZER}:${LD_LIBRARY_PATH}
setenv PATH ${ANALYZER}:${PATH}

```

Figure 2: Additional environment settings for the DVCS event generator and the photon reconstruction to work. C shell based.

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```

CMAKE_BUILD_TYPE          *Release
CMAKE_INSTALL_PREFIX      */usr/local
Geant4_DIR                */site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/geant4/4.10.04.p02/lib64
Qt5Core_DIR               */site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/qt/5.10.1/5.10.1/gcc_64/
Qt5Gui_DIR                */site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/qt/5.10.1/5.10.1/gcc_64/
Qt5OpenGL_DIR             */site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/qt/5.10.1/5.10.1/gcc_64/
Qt5PrintSupport_DIR       */site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/qt/5.10.1/5.10.1/gcc_64/
Qt5Widgets_DIR            */site/12gev_phys/2.3/Linux_CentOS7.7.1908-x86_64-gcc4.8.5/qt/5.10.1/5.10.1/gcc_64/
ROOT_DIR                  */apps/root/5.34.36/root/cmake
WITH_GEANT4_UIVIS         *ON

```

Figure 3: cmake configuration

	Energy Dependence at fixed (Q^2 , x_B)										Low- x_B				High- Q^2				
x_B	0.36					0.50			0.60		0.2				0.36	0.50	0.60		
Q^2 (GeV) ²	3.0			4.0		3.4	4.8	5.1			6.0	2.0			3.0	5.5	8.1	10	
k (GeV)	6.6*	8.8	11	8.8*	11	8.8	11	11	6.6	8.8*	11	11	6.6	8.8	11	11	11		
k' (GeV)	2.2	4.4	6.6	2.9	5.1	5.2	7.4	5.9	2.1	4.3	6.5	5.7	1.3	3.5	5.7	3.0	2.9	2.4	2.1
θ_{Calo} (deg)	11.7	14.7	16.2	10.3	12.4	20.2	21.7	16.6	13.8	17.8	19.8	17.2	6.3	9.2	10.6	6.3	7.9	8.0	8.0
D_{Calo} (m)	3	3	3	4	3	3	3	3	3	3	3	3	6	4	4	6	4	4	4
I_{beam} (μA)	28	28	28	50	28	28	28	28	28	28	28	28	11	5	50	11	50	50	50
N_{evt} (10^5)	1.5	8.8	8.2	2.1	7.9	7.3	11	5.1	0.2	0.2	2.7	2.6	3.5	3.6	64	3.4	6.1	0.8	0.4
$\sigma_{M_X^2}$ (GeV ²)	0.13	0.13	0.12	0.15	0.15	0.09	0.09	0.11	0.09	0.09	0.09	0.09	0.17	0.17	0.17	0.22	0.19	0.15	0.13
Days	1	2	1	1	3	3	2	5	5	1	5	10	1	1	1	1	5	5	12
run number:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Figure 4: Run numbers. Figure extracted from the proposal PR12-13-010 [1].

- run number,
- name of the macro file,
- target type (0 for hydrogen, 1 for deuterium),
- target type (0 for proton, 1 for neutron, 2 for deuteron).

There exist 19 run numbers from 0 to 18 depending on the kinematic settings in the proposal PR12-13-010 [1]. The run numbers are given as shown in Fig. 4. In order to use the photon reconstruction software, one needs to upload the kinematic settings (beam energy, HMS/NPS angles, etc.) on MySQL server. For now, only the DVCS kinematic settings proposed in PR12-13-010 (Fig. 4) are available on the server. One can, however, select the desired target between hydrogen to deuterium in those DVCS settings.

Here is an example command to run a simulation: `./DVCS 2 macros/test.mac 1 1`. This will run kinematic settings '2' with a macro file called 'test.mac' in 'macros/' directory and use

neutron target in liquid deuterium.

Once the simulation runs, it will ask for the name of the output file and 3 random numbers for the Geant4 random engine. The output file is in ROOT format and can be designated anywhere the user wants (e.g. /u/home/hosanko/output.root).

For the simulation to run, the user needs to give several inputs which are already in the macro file (see “macros/test.mac” for an example):

- /testhadr/Physics QBBC (not necessary to run but recommended for better background generation)
- /run/initialize
- /run/beamOn 1000 (make 1000 initial electron beam events)

2 Simulation structure

2.1 DVCS.cc

The simulation is based on the Geant4 example 'AnaEx02'. This main code, located in the 'DVCS/' directory, initializes and runs the simulation.

2.2 DetectorConstruction

Located in the 'DVCS/src/' directory, the geometries of the simulation are defined in this code. There are Sensitive Detectors (ConstructSDandField), in which the user can collect desired information within the logical volume of choice. Also, the parameters needed for the optical photons, such as refractive index, are described here.

The basic geometries are the target (15 cm in length and 2.5 cm in radius) and its chamber, downstream beam pipes, and the NPS. The target is the geometrical center of the simulation. The NPS consists of a sweeper magnet and a calorimeter. The angular difference between the

sweeper magnet and the NPS is 4° or 5.5° depending on the kinematic settings. The default is 5.5° . However, for some kinematic settings, the magnet center will be tilted to 4° for the calorimeter to reach a smaller angle: see [2, 3] for more detail. The center of the magnet is positioned 1.6 m from the target.

The magnetic field of the sweeper magnet is generated by the 'SimpleField' class in 'ConstructSDandField' class. The 'SimpleField' in 'DVCS/src/' uses a magnetic field table of a 1 cm grid. The center of the magnetic field table is also similarly positioned as the sweeper magnet. The angular difference between the magnetic field table center and the NPS is 4.1° or 5.6° depending on the kinematic settings. The center of the magnetic field is positioned 1.57 m from the target.

The calorimeter consists of 30×36 PbWO_4 crystals ($20.5 \times 20.5 \times 200.5 \text{ mm}^3$) each of them wrapped with a VM2000 wrapper of a thickness of 65 μm . The carbon fiber frame is placed at the front- and backside of each of the crystal with a width of 2 cm and a thickness of 0.5 mm. There are glasses ($20.5 \times 20.5 \times 20.5 \text{ mm}^3$) attached to the backside of each of the crystal to simulate the PMT when the optical photon physics simulation is at work.

2.3 PhysicsList

The user can set physics processes. Although it is not recommended to change the physics process from 'QBBC', the user can use a command '/testhadr/Physics <name of the physics process>' to change it. The macro 'test.mac' uses 'QBBC'. The argument will be input through 'PhysicsListMessenger'. The lines for the optical photon physics are commented out because the optical photon physics increases the computation time immensely. If one needs the optical photon physics, uncomment the lines near '// Needed for optical photon physics' in 'DVCS/src/PhysicsList.cc'. To record the number of optical photons collected at the PMTs, several lines in 'HistoManager' class should also be uncommented: see the next section.

2.4 HistoManager

It creates a tree of a ROOT based output file and saves the events. There are 2 trees:

- 't' saves the deposited energy per crystal per event (beam electron).
- 't_dvcs' saves the generated (at the vertex) and reconstructed information of the electron, photon, etc. of the event.
- 'evtNb' in both trees 't' and 't_dvcs' records the event number, i.e. which beam electron it was, to allow users to match the event in 't' and 't_dvcs'

If one wants to record the number of optical photons collected at the PMT, uncomment the lines below '//temporarily disabled, no op physics' in 'DVCS/src/HistoManager.cc'

2.5 PrimaryGeneratorAction

It uses a 'G4ParticleGun' class with a DVCS event generator class 'TGenDVCS'. It generates scattered electron and DVCS photon per event (beam electron), according to the kinematic setting.

2.6 RunAction

It sets the random seeds and book the output file and saves them at the end of the run (at the end of the whole events).

2.7 EventAction

It gets the informations the user needs, such as energy deposited in each crystal, from the detectors and gives that information to HistoManager. The EventAction also gathers information from such as the PrimaryGeneratorAction, B5HadCalorimeterHit (collects deposited energy

in each crystal), and SteppingAction (identify scattered electron) to, for example, reconstruct DVCS photon and send them to HistoManager.

2.8 B5HadCalorimeterSD and B5HadCalorimeterHit, i.e. Sensitive Detector

These classes are based on Geant4 'example/basic/B5/' and one of several Sensitive Detectors (SDs). These SD and Hit classes collect information of the particle within the volume the user has set. 'B5HadCalorimeterSD' and 'B5HadCalorimeterHit' classes are one of them. The logical volume of the PbWO_4 crystals is set as a Sensitive Detector to these classes through the 'ConstructSDandField' in the 'DetectorConstruction' class. It collects the deposited energy, the number of optical photons created in the crystal.

They are one of many Sensitive Detectors in the simulation. The basic structure is the same for all the Sensitive Detectors.

References

- [1] *PR12-13-010*. https://hallaweb.jlab.org/experiment/DVCS/documents/proposals/E12-13-010_proposal.pdf
- [2] *NPS ERR Report Responses* by Tanja Horn. NPS ERR. https://wiki.jlab.org/cuawiki/images/2/26/NPS_ERR_Report_Responses_v3.pdf
- [3] *NPS: Mechanical Structures and Installation* by Steven Lessiter. NPS ERR. https://wiki.jlab.org/cuawiki/images/6/61/NPS_ERR_2019_-_Mechanical-Rev_B.pdf