



# Supercomputing the Cascade Processes of Radiation Transport

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**Abstract.** Modeling of the photon-electron cascade progress in multicomponent objects of complex geometrical structure by use of hybrid supercomputers is considered. An approach to computing the cascade processes is developed. The approach has three key properties allowing the effective use of heterogeneous structure of computers for solving the tasks of radiation transport in complex multi-scale geometries. Firstly, two different discrete geometrical description of an object being under radiation is used: triangulated model for photon transport and voxel model for electron transport. Secondly, small parameter of the problem is explicitly taking into account for modeling surface effects (for instance, electron emission). Thirdly, the effective calculation decomposition between CPU and GPU is developed for significant increasing the speed of calculations of processes in question. Modeling of experiment on researching the bremsstrahlung generated by electron beam in Ta target is carried out. Comparison of computing and experimental results shows satisfactory consent.

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## 1 Introduction

Photon-electron fluxes of high energy generate particle cascade when moving through matter. Photons produce electrons as a result of Compton scattering or atom ionization, and electron-positron pairs as a result of the pair production process. Electrons may produce photons when bremsstrahlung occurs. If atom ionization happens by electrons also secondary electrons are produced. Modeling the photon transport on hybrid supercomputers is implemented using the CUDA (<https://developer.nvidia.com/cuda-toolkit>) technology [1]. Simulating the electron transport in homogeneous matter is based on the model of individual collisions [2]. The corresponding algorithm is implemented on supercomputers with heterogeneous architecture [3]. The simulation of the joined photon-electron transport is difficult due to the difference of the numbers of particle collisions. Photons have usually tens of collisions while electrons have tens of thousands. The technique of ray-tracing used for photon transport [4] is not applicable for electron transport because of the huge number of electron interactions. Therefore, the description of the irradiated object by means of separated surfaces when photon transport is computed [4] is not effective for simulating the electron transport. A joined description of the object is developed for modeling the cas-



ades of the coupled photon-electron transport. The surface-oriented description is used for simulating the photon interactions and a voxel-oriented for the electron transport. The approach is applied for describing bremsstrahlung production. Results exploiting the proposed algorithm for the coupled photon-electron transport are shown and discussed.

## 2 Scheme for Modeling the Cascade Process

The general scheme of the photon-electron cascade process is shown in Fig. 1. Particles lose its energy due to collisions. Part of this energy is transferred to secondary particles of the same or different type as shown in the picture. There are two types of particles considered in such cascade: photon, electron (and positron). Positrons act nearly the same as electrons, that they are not treated as another type of particle from the perspective of a modeling approach.

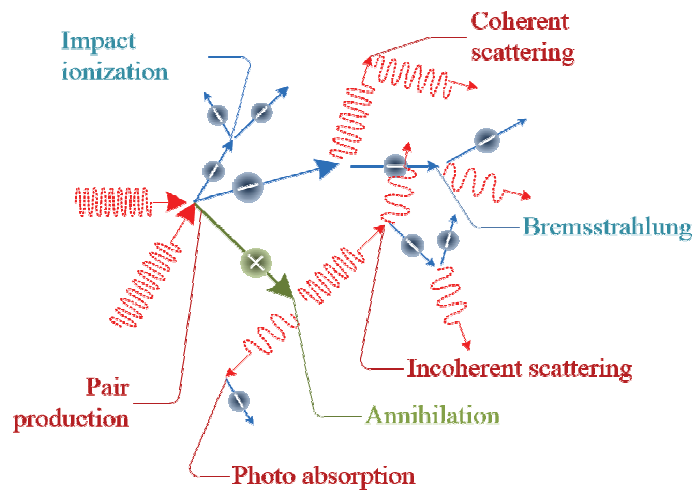


Fig. 1. General scheme of photon-electron cascade.

Every interaction with the object can produce new particles of different types. Particles of different type have different key properties that determine the approach used for modeling its transport. Two main properties are taken into account when modeling the photon trajectories: the travel path between interactions is relatively big and the number of collisions is relatively small (few tens) compared to electron transport. The first fact allows tracing the whole object for every photon trajectory to determine position of the next interaction. The second fact just says that this scheme has not to be repeated too many times. The graphics processing unit (GPU) is used to trace the photons in the object. The number of particles whose trajectories can be efficiently traced by GPU at once is about a few hundreds. At the same time modeling how the interaction affects the particle properties is executed on the central processing unit (CPU). Therefore utilizing GPU in this case, i.e. for a small number of particles traced, is inefficient.

Photons traveling through the object for long distances having only a few interactions are losing its energy rapidly on every interaction act. Therefore inefficient tracing of the whole scene is required. This is possible by using a surface oriented approach describing the objects. Sampling surfaces with triangles and utilizing GPU as mathematical co-processor allows fast tracing. The interaction itself is modeled on CPU. The registration of the photon flow through the object is mainly executed on CPU with GPU used as co-processor. GPU filters out the points of interest (POI) where the photons flow is interesting. It rejects most of the points where the current particle does not contribute to the photon

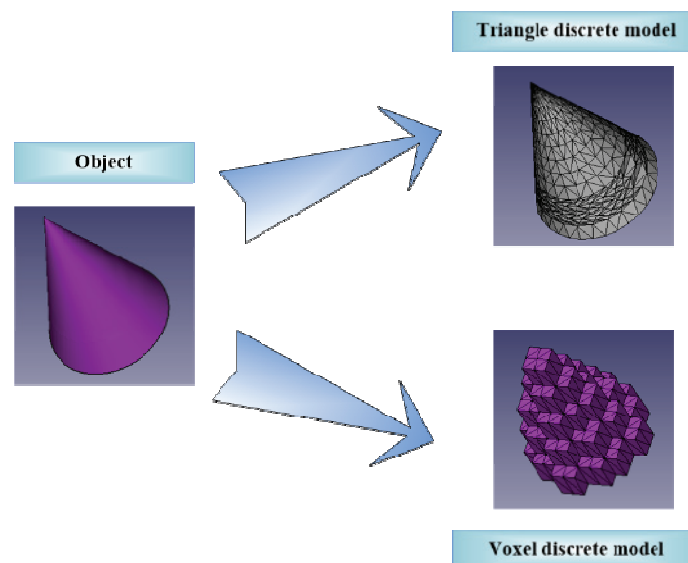
flow. So the number of POI is minimal, where the CPU has to process and calculate the exact contribution of the current chain to the flow.

The model used for the electron transport assumes modeling every single interaction with matter [2]. There are thousands of interactions for every electron. In this situation modeling of the interaction becomes a computational extensive task. Therefore using the same approach as for photons is inefficient. Therefore modeling electron trajectories is implemented on GPU. This approach solves the problem of high computational load but adds an additional problem: interaction modeling and object tracing on GPU cannot be done at the same time because these two tasks scale very differently. At the same time tens of thousands of particles have to be modeled to provide decent load to GPU while calculating the interactions. Remember, it was mentioned above that the number of particle trajectories which can effectively be traced by GPU is about few hundreds. Therefore the whole scene cannot be traced in the case of electron transport.

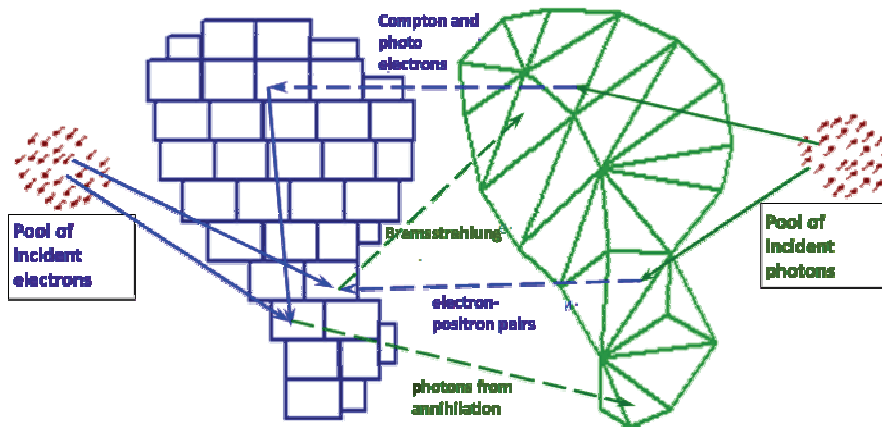
To solve this problem, the fact can be utilized that the full electron trajectory is concentrated to a relatively small area compared to the typical object sizes. Approximating the object by means of voxels allows to model most part of the electron trajectory inside each voxel assuming homogeneous material properties. Therefore object tracing after every interaction of the electron with matter is not necessary. Moreover, these parts of trajectories, being simulated on GPU solely, are processed very fast because there is no data exchange between CPU and GPU. Calculations on CPU occur only if the electron leaves the voxel. At this time the electron flow through the object is registered. Other values like the distribution of energy consumption in the object are registered directly on GPU during trajectory simulation inside one voxel to provide maximum performance.

Thus, two discrete models for the object description are applied (Fig. 2): a surface oriented model for simulating the photon interactions and a voxel model for computing the electron trajectories.

For the two different approaches of modeling different particle types two different types of object description are used: discretization by triangulated surfaces and by voxels. The first is used for photon tracing as it can easily be implemented on GPU subdividing the intersection intervals to determine the point of collision. The second is applied to model electron trajectories inside a volume element of assumed homogeneous material properties. The implementation of the calculation scheme is shown in Fig. 3.



**Fig. 2.** Used geometrical descriptions of the object.



**Fig. 3.** Usage of the two different object descriptions for photon and electron transport.

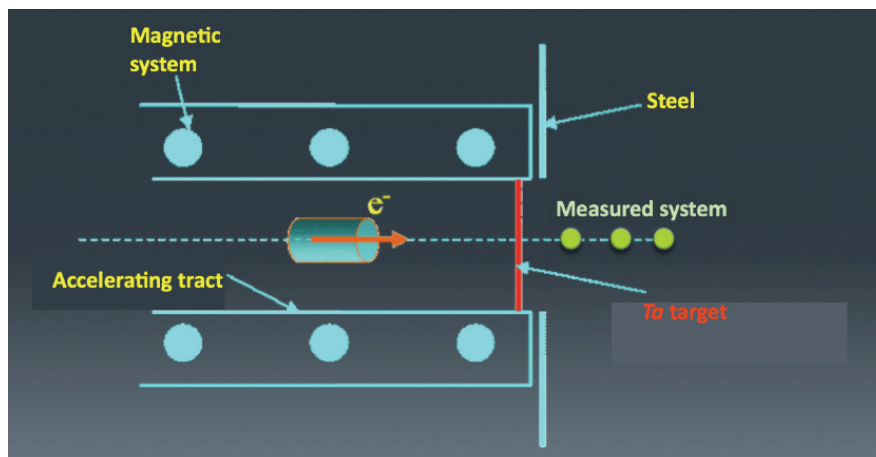
Fig. 3 shows how the two different discrete approximations of the object are used. The photon transport is modeled using the surface model of the object. During the interaction between photons and matter produced electrons (e.g. as result of Compton scattering or photoabsorption) are accumulated in the so called electron pool. When the electron pool is filled the computation is switched to the electron block using the voxel model of the object.

On the other hand, when the electron trajectories are simulated the produced photons (e.g. bremsstrahlung photons) are accumulated in so called photon pool. Again, modeling the transport of the photons from the photon pool is carried out using the surface model of the object. I.e. different particles are modeled using different descriptions of the object to achieve the best calculation performance.

The efficiency of the algorithm is increased by balancing the calculation load between CPU and GPU. Parts of the algorithm with high computing load, e.g. tracing the object, or simulation of electron trajectories, are carried out on GPU. Parts having relatively low calculation workload are performed on CPU.

### 3 Simulation of Bremsstrahlung Production

The developed technique is used to simulate the bremsstrahlung production by electrons accelerated in an electrical field, e.g. for X-ray tubes or linear accelerators. The scheme of the setup is shown in Fig. 4.



**Fig. 4.** Scheme of an experiment.

A flux of accelerated electrons of 4 MeV electrical field is impinging on a 4 mm Ta target on a 4 mm steel plate. The produced Bremsstrahlung photons are also interacting with the target material and may produce secondary electrons, scattered and fluorescence photons etc. A part of the photons are leaving the target without interaction. The used measurement system detects the dose of radiation, i.e. the photon and the electron dose leaving the Ta target. The simulation results are shown in Fig. 5 for electrons and in Fig. 6 for photons and compared to the measured dose. A thermoluminescent dosimeter is used as detector. It is made of alum phosphate glass (P 35 %, Al 5 %, Mg 6 %, O 54 %). The simulations show satisfactory agreement with the experimental data. The computation was carried out on the hybrid supercomputer K-100 at KIAM (<http://www.kiam.ru/MVS/resourses/k100.html>)

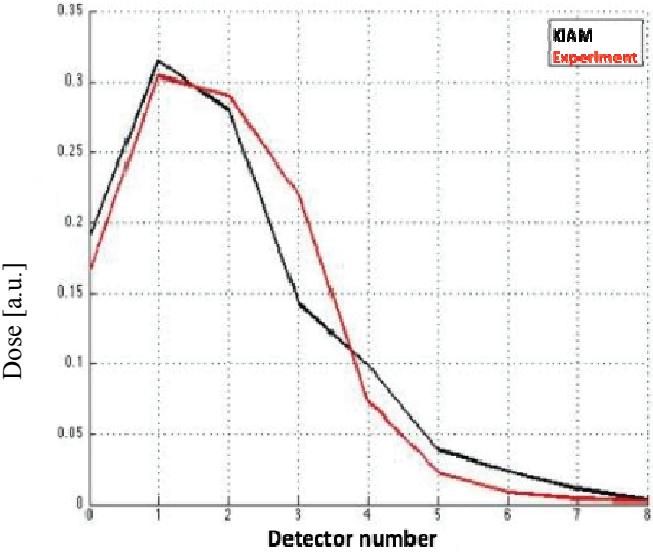


Fig. 5. Electron dose: comparison simulation and experiment for Ta target.

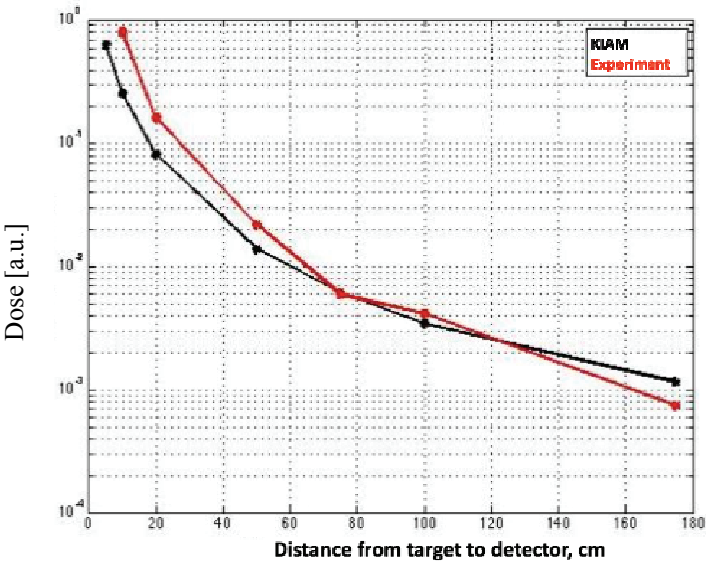


Fig. 6. Photon dose: comparison simulation and experiment for Ta target.

## 4 Conclusions

The developed approach to model the photon-electron cascade processes is highly effective for simulating the transport of particle fluxes in multi-component objects of complex geometry. The separate description of the object for different types of particles gives the possibility to optimally solve the problem of electron-photon transport on heterogeneous supercomputers using the CUDA technology in combination with MPI ([https://en.wikipedia.org/wiki/Message\\_Passing\\_Interface](https://en.wikipedia.org/wiki/Message_Passing_Interface)). The method is applicable to simulate the high-energy electron-photon fluxes through complex objects. The developed algorithm is based on separate modeling electron and photon transport. It is applicable without any changes to simulate the transport of photons and/or electrons of energy between 1 keV and 100 MeV in matter. A comparison of the simulation with experimental results has shown good agreement.

## References

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