

A Tool for Calculation of the Radiation Parameters on the Early Stage of Simulation Geometry Development in CATIA

Alexander Sharmazanashvili^a, Alexander Solodkov^b, Archil Surmava^a, Niko Tsutskiridze^a, Besik Kekelia^a, Salome Vashakidze^a

*a*Georgian Technical University,
Tbilisi, Georgia

*b*NRCKI IHEP,
Protvino, Russia

E-mail: lasha.sharmazanashvili@cern.ch, Sanya.Solodkov@cern.ch

The simulation is being used to produce artificial events for physics analyses. In the ATLAS experiment at LHC CERN, Geneva, Switzerland, a simulation is carried out on the GEANT4 platform. The GEANT4 uses geometry descriptions as an input for the modelling of the propagation of the particles in the material. Adding CATIA (Computer-Aided Three-dimensional Interactive Application) CAD application into simulation infrastructure brings an opportunity for the early study of the detector geometry for precise simulation. The paper describes a method of calculation of X_0/λ radiation parameters for the CATIA native geometry descriptions. The core part is the so-called scanner function, enabling the generation of the control points on the geometry, where the calculations will carry out. The algorithm contains as well, the initial transformations of geometries before scanning and output interfaces with the standard applications *Root* and *Excel*.

The Tenth Annual Conference on Large Hadron Collider Physics (LHCP2022)
16-20 May 2022
online

1. Simulation Infrastructure with CATIA

The ATLAS detector at the LHC collects data from the proton-proton collisions every 25 ns (40Mhz), providing 40 on average during the Run2 collisions per bunch crossing [1]. However, ATLAS physics analyses need to study more wide range of physics processes and scenarios. For that reason, simulation is implemented, which enables the carrier of artificial events from the Monte-Carlo generators and creates an output, identical to the real detector. The ATLAS use Geant4 as a simulation framework. The Geant4 simulation generates hits and uses geometry descriptions of the detector as input data [2]. Three main formats are implemented: Gdml, GeoModel, and XML (fig.1). The Gdml is the neutral format of Geant4. The GeoModel was developed for the description of large and complex detector geometries with minimal memory consumption [4]. The GeoModel description is formed by the ATLAS offline software framework ATHENA before starting the Geant4 simulation. The XML was mainly developed for the description of the passive materials of the Muon system [5]. It uses XML file format and the so-called AGDD - ATLAS Generic Detector Description language as a container of the geometry.

CATIA - (Computer Aided Three-dimensional Interactive Application) is an official CAD application for engineering, design, construction, and maintenance of HEP facilities at CERN,

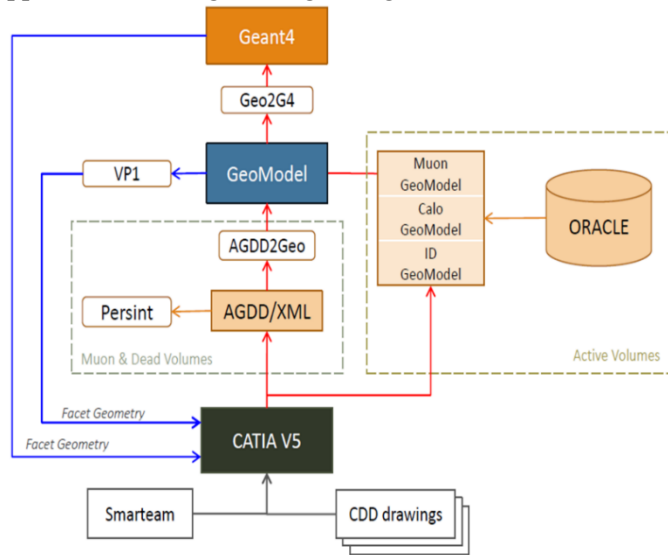


Fig.1 ATLAS Simulation infrastructure with CATIA

including detectors and subsystems. CATIA is the world's widely implemented application for engineering geometry modelling, enabling diverse methods of geometry creation and all known descriptive geometry transformations. CATIA has a powerful DMU (Digital Mock-Up) engine for the digital comparison of several types of geometries. Therefore, the implementation of CATIA in the existing ATLAS simulation infrastructure (fig.1) will bring the possibility to collect geometry descriptions from different sources into one platform and perform an early study of descriptions for the best simulation. For that purpose, it was developed special interfaces [5] - Geant_2_CATIA, GeoModel_2_CATIA, CATIA_2_XML, CATIA_2_GeoModel. At the same time, CATIA has internal links to the Enovia/Smarteam engineering databases where manufacturing drawings and as-built geometry descriptions are stored. As a result, the CATIA platform can be considered a hub for the collection of geometry descriptions from various platforms and proceed with different studies of detector geometry for the best simulation.

2. X_0/λ Calculations

The important study of geometry is concerned with the investigation of the distribution of the X_0 -radiation length alongside volumes. The X_0 -radiation length is a characteristic of a material, related to the energy loss of high-energy particles electromagnetically interacting with it [6]. This

is the average length (cm), which is necessary to change electrons' energy by the factor $1/e$. X_0 - radiation length can be calculated as follow

$$X_0 = \frac{716.4}{Z \times (Z+1) \ln \frac{287}{\sqrt{Z}}} g \cdot cm^{-3} \quad (1)$$

where Z is the atomic number of material.

For the materials from the Mendeleev table, X_0 has been calculated by the Particle Data Group [7]. Data was received experimentally. To transform X_0 into cm, the value of X_0 should be divided by material density ρ . The same calculations can be done for the λ -interaction length. For this X_0 should be substituted with the λ . Important parameters for the geometry descriptions study are $L[X_0]$ – radiation penetration length measured by X_0 and $L[\lambda]$ – particles absorption length measured by λ .

η – pseudorapidity is a spatial coordinate describing the angle of a particle relative to the beam axis. It is defined as

$$\eta = -\ln \left[\tan \left(\frac{\theta}{2} \right) \right] \quad (2)$$

where θ is the angle between the particle three-momentum P and the positive direction of the beam axis.

θ defines deviation from the protons beamline and can be changed from 0 to 180° . φ is the angle in the η plane. So, for each η the φ can be changed from 0 to 360° . Therefore, each control point has its η and φ . As was shown above $L[X_0]/L[\lambda]$ change values according to thickness (t) of geometry and materials (m). In geometry, there are fragments, where $t_i = const$ and $m_i = const$. Therefore, for those places, $L[X_0]/L[\lambda]$ will be also constant. However, if the geometry thickness or material is changed, then $L[X_0]/L[\lambda]$ values will be also changed. Changing conditions can be identified through the predicate

$$C = \forall_i (t_i \neq t_{i+1} \vee m_i \neq m_{i+1}) \quad (3)$$

Thus, predicate (3) can be considered as a condition for the creation of a control point, hereinafter called a transition point. Condition $t_i \neq t_{i+1}$ in (3) can cause a big amount of the transition points because there are many cases, where the thickness is changing constantly due to the tilted position of geometry η . Therefore, in the (3) additional condition has to be added for the expression of the functional constancy of the thickness changing. It means that if the thickness is constantly changing by the $\varphi(t)$ the function, then the new transition point will not be added. Therefore, the predicate (4) will be modified as follow

$$C = \forall_i (t_i \neq t_{i+1} \wedge \varphi(t_i) = const \vee m_i \neq m_{i+1}) \quad (4)$$

The first set of transient points must be created along $\eta - P_{1(\eta_1)} \dots P_{n(\eta_n)}$. In the second step, for each of the η_n the plane, transition points $P_{1(\varphi_1)} \dots P_{n(\varphi_n)}$ must be created along φ , considering the geometry borders and predicate (4).

Thus, the overall number of transition points for the $L[X_0]/L[\lambda]$ can be defined as follows

$$P_\Sigma = \sum_{i=1}^n \sum_{k=1}^{ij} P_{ik}(\varphi) \quad (5)$$

where n is the number of $P_{i(\eta)}$ points; ij is the number of $P_{k(\varphi)}$ points on the $P_{i(\eta)}$ plane.

Once the P_Σ transition points are known the $L[X_0]/L[\lambda]$ values can be calculated.

3.The Third-Party Application in CATIA

The VBA application CATIA2RAD was developed in CATIA to carry out $L[X_0]$ Calculations. The application creates control points on the geometry loaded in CATIA and calculates X_0/λ lengths in each control point. Therefore, the application delivers the output with calculated

values of $L[X_0]$, $\overline{L[X_0]}$, $L[\lambda]$, and $\overline{L[\lambda]}$ which is exported to the Root application for the creation of plots and radiation distribution images.

For successful calculations, geometry has to be exported according to the CATIA2RAD requirements. For this purpose, in the first step, the *function*{NewProject} creates a template in the new CATPart tree. The template consists of - a new "XOLine.CATPart"; new plane built on the Y-axis and angle to XY plane, this angle later will be assigned to the φ ; new sketch in the XOLine body; new line in the sketch, which later will be assigned to the particle path; angle constraint of the line, which later will be assigned to the θ , and new body "Geometries", where exported geometry should be placed. In the next step, geometry should be loaded in CATIA by the "Insert" function of CATIA. The geometry must be placed in the "Geometries" partbody of the template. The geometry should be built based on the solids. Both solids - with and without history are acceptable. The geometry cannot contain facets. Once the geometry is loaded, a special *function*{ImportBody} verifies all bodies inside the loaded geometry. Empty bodies, without solids, hide and the rest of the bodies are selected. Then all selected bodies are copied to the XOLine.CATPart part with the same names. In the next step, *function*{GroupBodies} grouping bodies by materials. Therefore, all bodies having the same material will be grouped in one body and assigned the name of the material. If the body doesn't contain the material description, then a special *function*{MaterialSelection} enables the manual assignment of material from the library, to the body and the manual grouping. In the next step, the control points on the geometry are detected. The *function*{GetEta} searches the transient points on the geometry by condition (5) and adds lines from Z0 on the different θ angles. As a result, a set of $\{\eta_1.. \eta_n\}$ lines created in the XOLine.CATPart body. Then the condition is checked, is it circular or rectangular scanning. For circular scanning *function*{CircGen}, for each $\{\eta_1.. \eta_n\}$ line generates lines from Z0 to φ_{min} to φ_{max} with $\Delta\varphi$ increment. The φ_{min} , φ_{max} , and $\Delta\varphi$ values are the external parameters of the function. For the rectangular scanning, *function*{RectGen}, identifies the central point of geometry and its distance from Z0 by the Z beamline axis. Then the auxiliary vertical plane adds at that distance. For each $\{\eta_1.. \eta_n\}$ lines function generates control points on the auxiliary plane, starting from φ_{min} up to φ_{max} by the $\Delta\varphi$ increment.

4. Conclusion

1. Integration of CATIA into the simulation infrastructure can significantly improve the quality of the physics analysis in the HEP experiments
2. Using the radiation and absorption length analyses in the early stages of development of geometries in CATIA delivers precise geometry descriptions for the simulation
3. The proposed tool can be used in the various studies of geometry descriptions in CATIA like, comparative analysis of descriptions; consistency checking of simulation geometries to the 'as-built', and integration conflicts checking

References

- [1] The ATLAS Collaboration *The ATLAS Simulation Infrastructure*, The European Physics Journal C 70:823-874, DOI 10.1140/epjc/s10052-010-1429-9 (2010)
- [2] Flavia Dias *The New ATLAS Fast Calorimeter Simulation*, ICHEP2016, 5 August (2016)
- [3] Geant4 Collaboration *Geant4 A Simulation Toolkit*, Book for Application Developers, r.10.4, (2017)
- [4] J.Boudreau, V.Tsulaia *The GeoModel Toolkit For Detector Description*, CHEP proceedings 2004, Interlaken, Switzerland, pp.353-356 (2004)
- [5] Sharmazanashvili A. et al. *Development of CATIA_2_GEANT Interface for Simulation of High Energy Physics Experiments*, Proceedings of TMCE2016, May 9-13, 2016, Aix-en-Provence France ISBN 978-94-6186-635-6
- [6] Marcel Demarteau, et al. *Particle and Nuclear Physics Instrumentation and Its Broad Connections*, Reviews of Modern Physics. July 20, 2016
- [7] Mukund Gupta *Calculation of radiation length in materials*, PH-EP-Tech-Note-2010-013, 2010