GEORGIAN TECHNICAL UNIVERSITY

Simulation Loop between CAD systems, Geant4 and GeoModel: Implementation and Results

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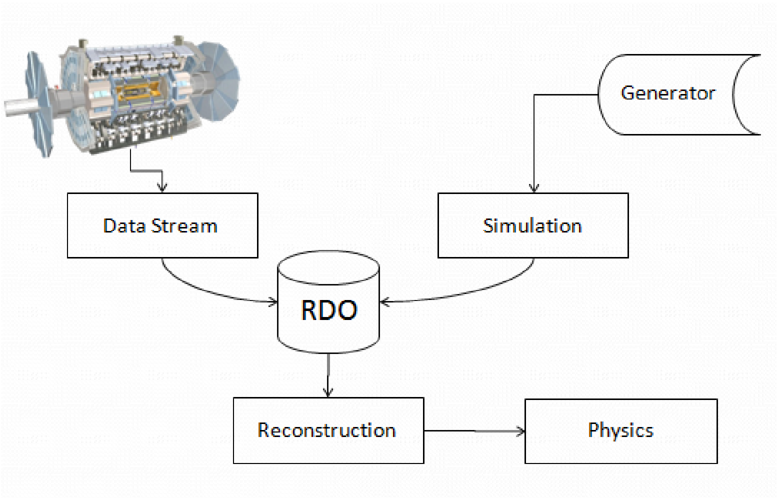
Tasks for Reconstruction / Simulation



- Reconstruction and Simulation providing data necessary for Physics analyses
- Simulation generates theoretical events
- Purpose of the Reconstruction is to derive the properties of the produced particles from the information recorded by all subdetectors

Problem:

Difference between Data vs. Monte Carlo may be caused by Geometric Discrepancies

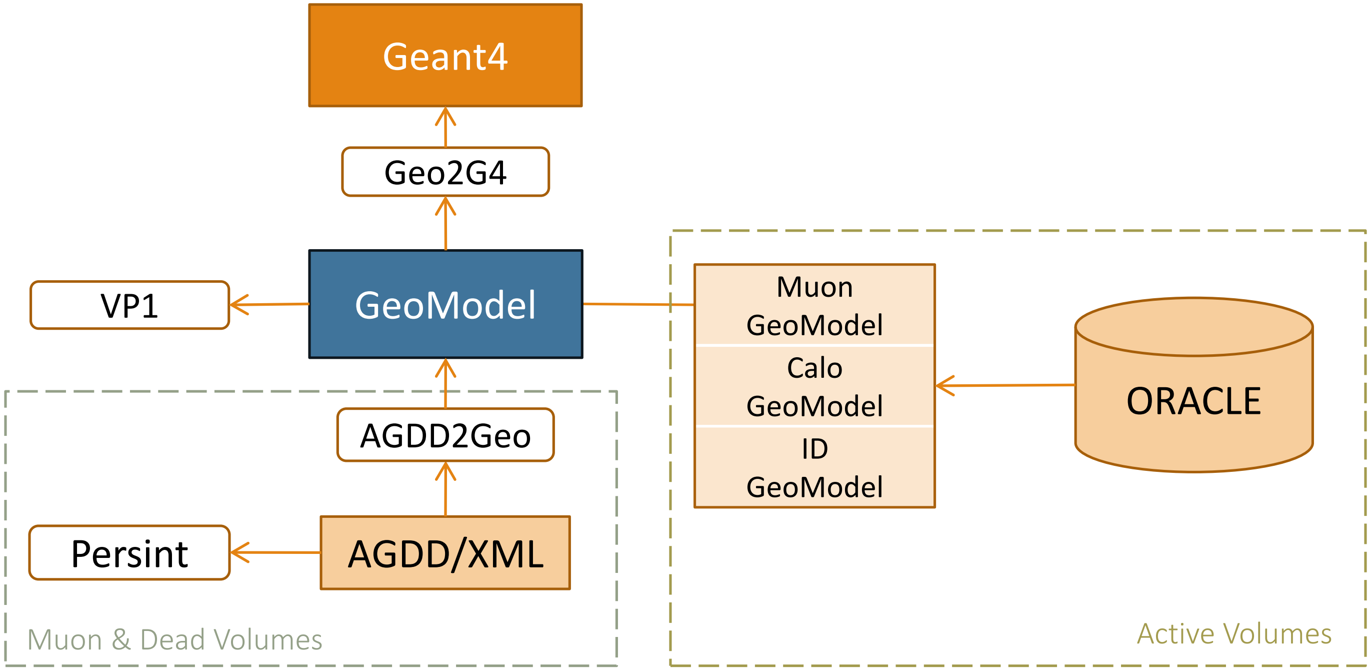
Reasons:

- Discrepancies between G4 and As-built detector Geometry
- Simulation software infrastructure quality

Main Goal:

- To determine Is there inaccuracy or not in simulation software infrastructure
- if yes, to investigate where the inaccuracy comes from

Toolkit for the simulation



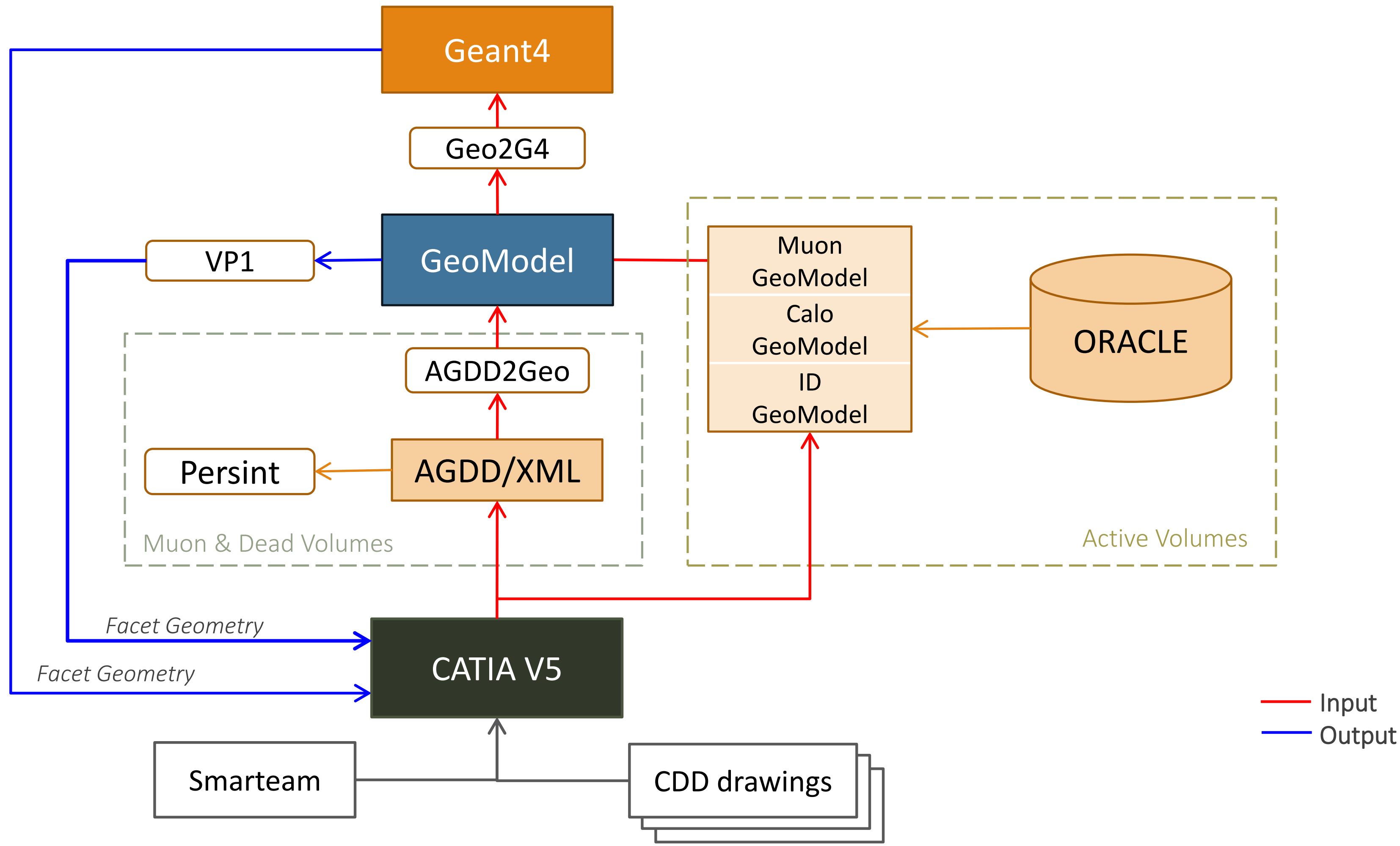
Geant4 – Toolkit for the simulation of the passage of particles through matter

GeoModel – Toolkit to describe detector geometries

AGDD – Toolkit for ATLAS generic detector description

Virtual Point 1 (VP1) – Interactive 3D event display for the ATLAS experiment

Development of Simulation Loop



CATIA – CAD System. We use CATIA for investigation of ATLAS detector geometry

SmarTeam – Official engineering database at CERN

CDD – CERN Drawing Directory

Investigation of Quality of Simulation Infrastructure

For ATLAS Detector components inaccuracies caused by transactions in the loop should be investigated:

- Checking of dimensions inaccuracies
- Checking of Forms inaccuracies
- Checking of Positioning inaccuracies

For this Purpose Test Examples for checking have to be selected

1st Step: Separation of unique cases of ATLAS detector geometry

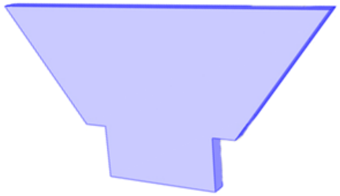
Geometric Primitives

- ✓ Shapes with vertex
- ✓ Shapes without cuts
- ✓ Both regular/irregular shapes
- ✓ Both convex/concave shapes

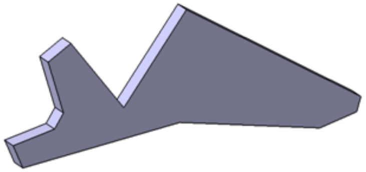
Thus: 22 geometric primitives have been separated

Examples:

Octagonal Prism



Dodecagonal Prism



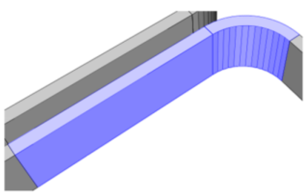
Typical Joining

- ✓ Minimum 2 objects
- ✓ Tangent touches between objects
- ✓ Surfaces touches between objects

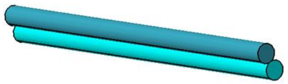
Thus: 33 geometric primitives have been separated

Examples:

Cube and Tube Joining



Tubes Joining



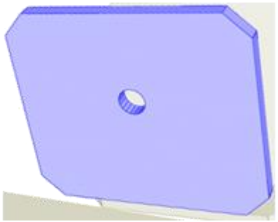
Combined Objects

- ✓ Shapes with cuts

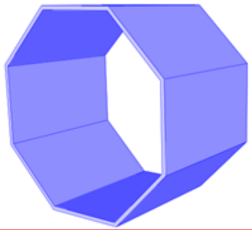
Thus: 19 geometric primitives have been separated

Examples:

Octagonal Prism with cut



Octagonal prism with cut



1st Step: Separation of unique cases of ATLAS detector geometry

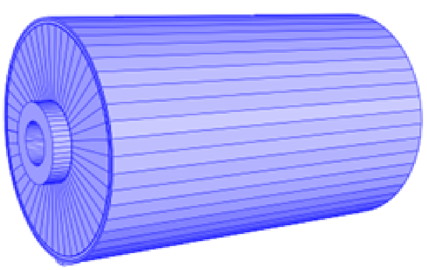
Finally, 6 classes have been received:

Muon & Dead Volumes	Geometrics Primitives	19	Total: 58
	Typical Joining	13	
	Combined Objects	26	
Active Volumes	Geometrics Primitives	3	Total: 26
	Typical Joining	16	
	Combined Objects	7	

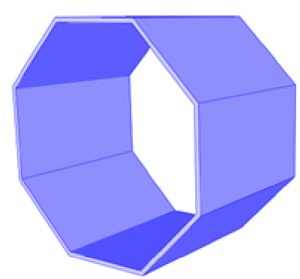
Thus, total number of cases are 84

Examples:

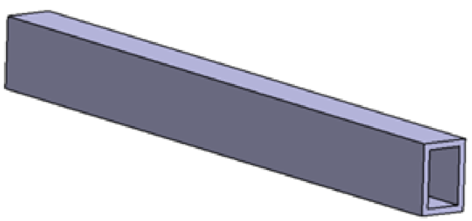
Tubes Joining



Octagonal prism with cut



Cube with Cut

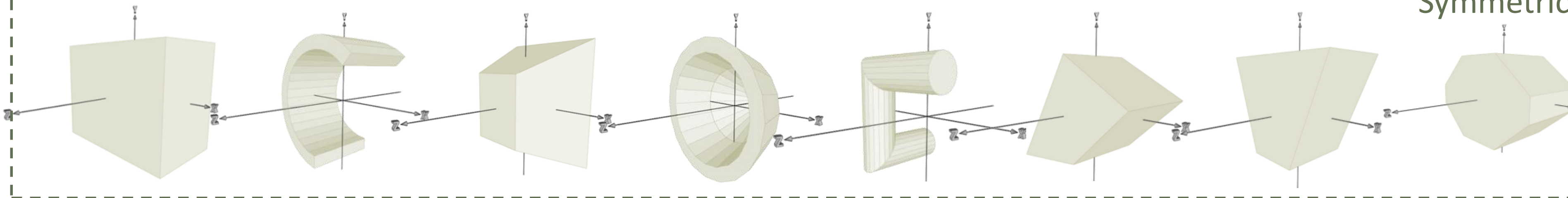


2nd Step of Selection

Ways of programming of selected geometry cases have been considered according to exiting methods in AGDD/XML and GeoModel:

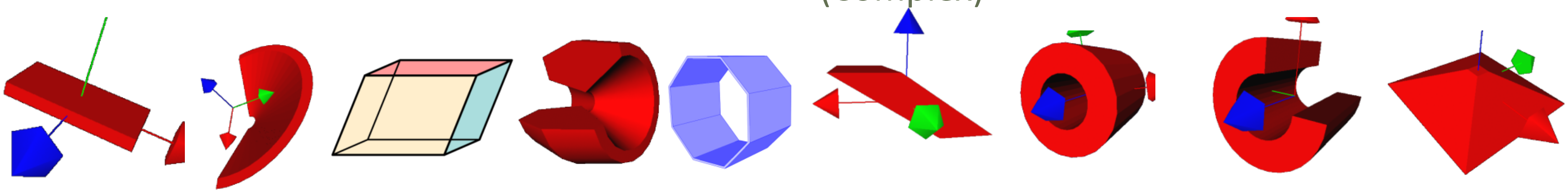
AGDD/XML

Cube | Tube | Pyramid | Cylinder | chain | Arbitrary | Symmetric | Double Symmetric



GeoModel

Box | Cone | Polycone | Trapezoid (Complex) | Tube | Trapezoid (Simple)



Parallelepiped | Polygon | Tube Section

2nd Step of Selection

As a result following number of programming cases have been separated:

		Geo Cases	Prog. Cases		
XML	Geometrics Primitives	17	3’ 871		
	Typical Joining	8	446		
	Combined Objects	23	5’ 215		
	Total:	48	9’ 532		Total: 15’ 675
GeoModel	Geometrics Primitives	3	589		
	Typical Joining	16	4’ 190		
	Combined Objects	7	1’ 364		
	Total:	26	6’ 143		

3rd Step of Selection

Criteria #1: Separate programming cases with Arbitrary polygon method from others. because of:

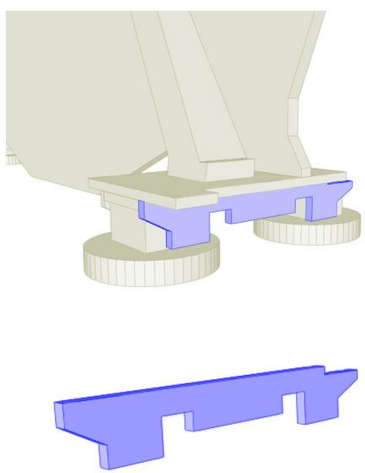
1) Arbitrary Polygon method permits to create volume in final position by only Z displacement

2) Only rotation on Z axes is needed

3) Number of necessary Boolean operation is minimal

Example:

Octadecagonal Prism



```
Arbitrary
Move (Z)
Rotation
```

```
Cube
Arbitrary
Subtraction
Move
rotation
```

```
Cube
Pyramid
Move
Subtraction
Cube
Move
Subtraction
Cube
Move
Cube
Move
Cube
Move
Cube
Pyramid
Move
Subtraction
Union
Move
Rotation
```

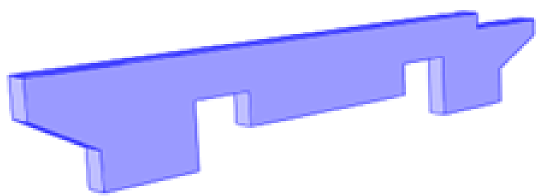
3rd Step of Selection

Criteria #2: Minimization of number of used methods.   Ensure:

1) Compactness of code
2) Reduce number of received clashes, contacts and inaccuracies of positioning
3) Better performance by reducing number of regions for consideration during the tracking

Example:

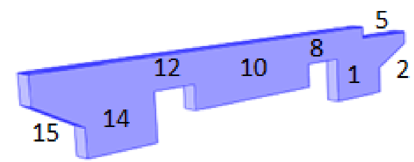
Octadecagonal Prism



```
Cube
Arbitrary
Subtraction
Move
rotation
```

Octadecagonal Prism

```
Cube
Pyramid
Move
Subtraction
Cube
Move
Subtraction
Cube
Move
Cube
Move
Cube
Move
Cube
Pyramid
Move
Subtraction
Union
Move
Rotation
```



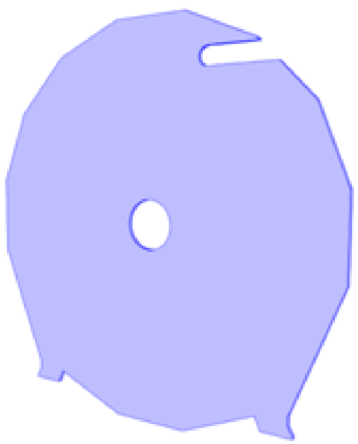
3rd Step of Selection

Criteria #3: Sameness of used methods. Because of:

1) Brings same geometry
2) Difference in performance is negligible
    1) **Criteria #3.1:** Similarity of Method and Geometry

Example:

Icositetrahedronal Prism with Cuts



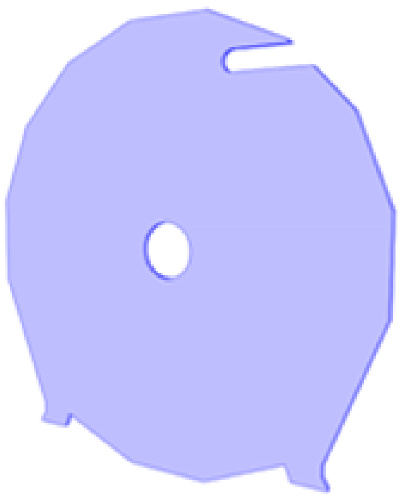
Cube	Pyramid
Symmetric	Symmetric
Move	Move
Subtraction	Subtraction
Move	Move
Subtraction	Subtraction
Arbitrary	Arbitrary
Subtraction	Subtraction
Tube	Tube
Move	Move
Subtraction	Subtraction
Cube	Cube
Move	Move
Subtraction	Subtraction
Tube	Tube
Move	Move
Subtraction	Subtraction

3rd Step of Selection

Criteria #4: Similarity of code Structures

Example:

Icositetrahedronal Prism with Cuts



Cube	Pyramid
Symmetric	Symmetric
Move	Move
Subtraction	Subtraction
Move	Move
Subtraction	Subtraction
Arbitrary	Arbitrary
Subtraction	Subtraction
Tube	Tube
Move	Move
Subtraction	Subtraction
Cube	Cube
Move	Move
Subtraction	Subtraction
Tube	Tube
Move	Move
Subtraction	Subtraction

3rd Step of Selection

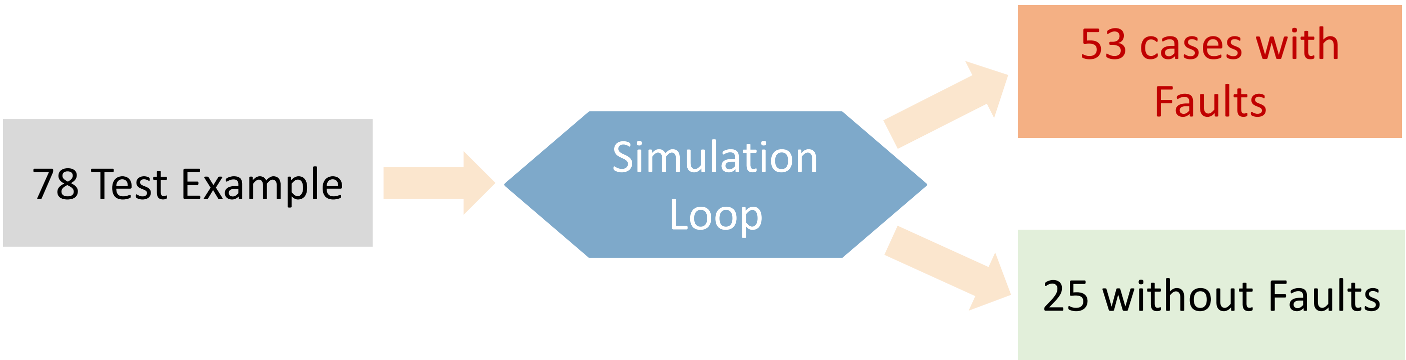
For each geometry case programming cases have been selected according to above mentioned criteria.

As a result:

		Number of Cases		
XML	Geometrics Primitives	8		
	Typical Joining	17		
	Combined Objects	33		
	Total:	58		Total: 78
GeoModel	Geometrics Primitives	3		
	Typical Joining	12		
	Combined Objects	5		
	Total:	20		

78 unique test examples have been separated:

Testing of Simulation Infrastructure

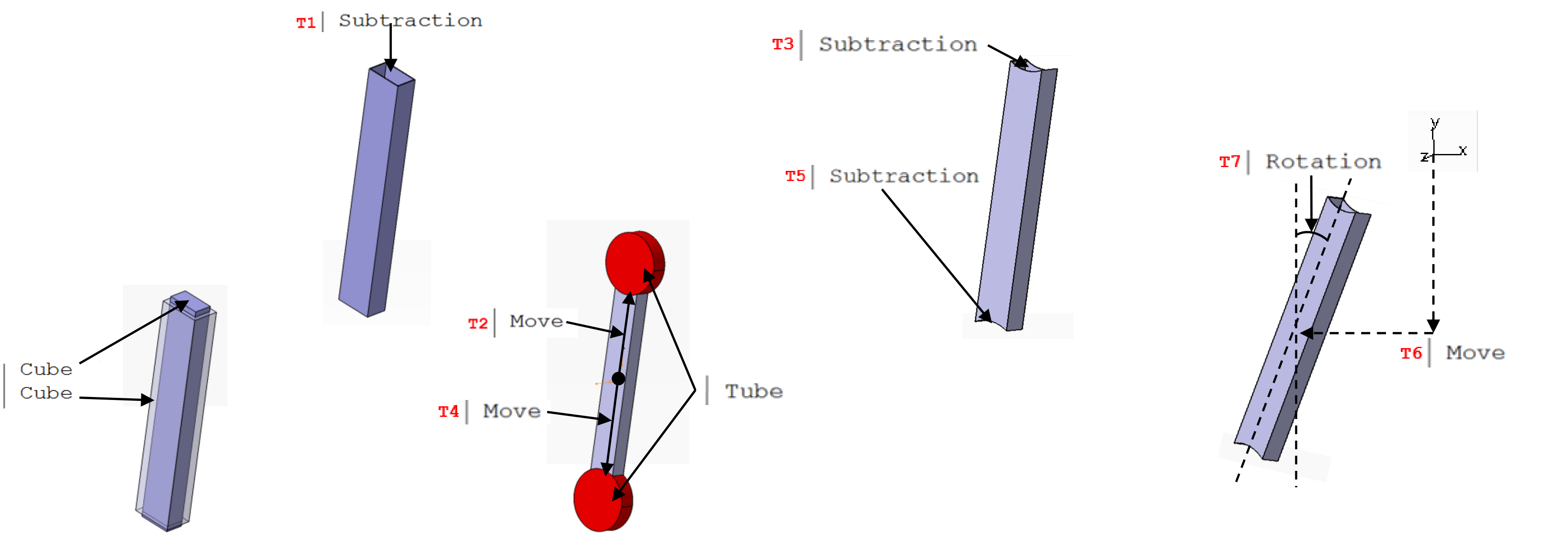


#	TestExample N	Inaccuracies	Comment
1	1	Yes	Maximal Inaccuracy 0.23 mm
2	2	Yes	Maximal Inaccuracy 0.03 mm
3	3	No	
4	4	Yes	Maximal Inaccuracy 0.51 mm
5	5	No	
6	6	Yes	Maximal Inaccuracy 0.2 mm
7	7	Yes	Maximal Inaccuracy 0.18 mm
8	8	Yes	Maximal Inaccuracy 0.01 mm
9	9	Yes	Maximal Inaccuracy 0.01 mm
10	10	Yes	Maximal Inaccuracy 0.03 mm
11	11	Yes	Maximal Inaccuracy 0.09 mm
12	12	Yes	Maximal Inaccuracy 0.09 mm
13	13	Yes	Maximal Inaccuracy 0.04 mm
14	14	Yes	Maximal Inaccuracy 0.05 mm
15	15	Yes	Maximal Inaccuracy 0.01 mm
16	16	Yes	Maximal Inaccuracy 0.03 mm
17	17	Yes	Maximal Inaccuracy 0.04 mm
18	18	Yes	Maximal Inaccuracy 0.19 mm
19	19	Yes	Maximal Inaccuracy 0.06 mm
20	20	Yes	Maximal Inaccuracy 0.15 mm
21	21	No	
22	22	Yes	Maximal Inaccuracy 0.03 mm
23	23	Yes	Maximal Inaccuracy 0.22 mm
24	24	Yes	Maximal Inaccuracy 0.06 mm
25	25	Yes	Maximal Inaccuracy 0.18 mm
26	26	Yes	Maximal Inaccuracy 0.19 mm
27	27	Yes	Maximal Inaccuracy 0.12 mm
28	28	Yes	Maximal Inaccuracy 0.12 mm
29	29	Yes	Maximal Inaccuracy 0.05 mm
30	30	Yes	Maximal Inaccuracy 0.03 mm
31	31	Yes	Maximal Inaccuracy 0.03 mm
32	32	Yes	Maximal Inaccuracy 0.06 mm
33	33	Yes	Maximal Inaccuracy 0.06 mm
34	34	Yes	Maximal Inaccuracy 0.01 mm
35	35	Yes	Maximal Inaccuracy 0.01 mm
36	36	Yes	Maximal Inaccuracy 0.01 mm
37	37	Yes	Maximal Inaccuracy 1.52 mm
38	38	Yes	Maximal Inaccuracy 0.03 mm
39	39	Yes	Maximal Inaccuracy 0.04 mm
40	40	Yes	Maximal Inaccuracy 0.14 mm
41	41	Yes	Maximal Inaccuracy 0.14 mm
42	42	Yes	Maximal Inaccuracy 0.08 mm
43	43	No	
44	44	Yes	Maximal Inaccuracy 0.01 mm
45	45	Yes	Maximal Inaccuracy 0.01 mm
46	46	Yes	Maximal Inaccuracy 0.07 mm
47	47	No	
48	48	No	
49	49	Yes	Maximal Inaccuracy 0.12 mm
50	50	No	
51	51	Yes	Maximal Inaccuracy 1.05 mm
52	52	No	
53	53	No	
54	54	No	
55	55	Yes	Maximal Inaccuracy 0.08 mm
56	56	Yes	Maximal Inaccuracy 0.03 mm
57	57		Clash 0.29 mm
58	58	No	
59	59	No	
60	60	No	
61	61	No	
62	62	No	
63	63	Yes	Maximal Inaccuracy 0.12 mm
64	65	No	
65	66	Yes	Maximal Inaccuracy 0.01 mm
66	67	No	
67	68	No	
68	69	No	
69	70	No	
70	71	Yes	Maximal Inaccuracy 0.38 mm
71	72	No	
72	73	No	
73	74	No	
74	75	Yes	Clash 0.89 mm
75	76	Yes	Clash 2.27 mm
76	77	Yes	Clash 0.04 mm
77	78	No	
78	79	No	

Test Example of Analysis

```
<box  name="Box1"  material="Aluminium"  X_Y_Z="500.; 3240.; 290." />
<box  name="Box2"  material="Aluminium"  X_Y_Z="480.; 3300.; 270." />
<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN26" >
   <posXYZ  volume="Box1"   X_Y_Z=" 0; 0. ; 0.  "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Box2"   X_Y_Z=" 0; 0. ; 0.  "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; 2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN26" X_Y_Z=" -2750. ; -6792. ; 9540." rot=" 0.; 0.; -22.5 " />
</composition>
```

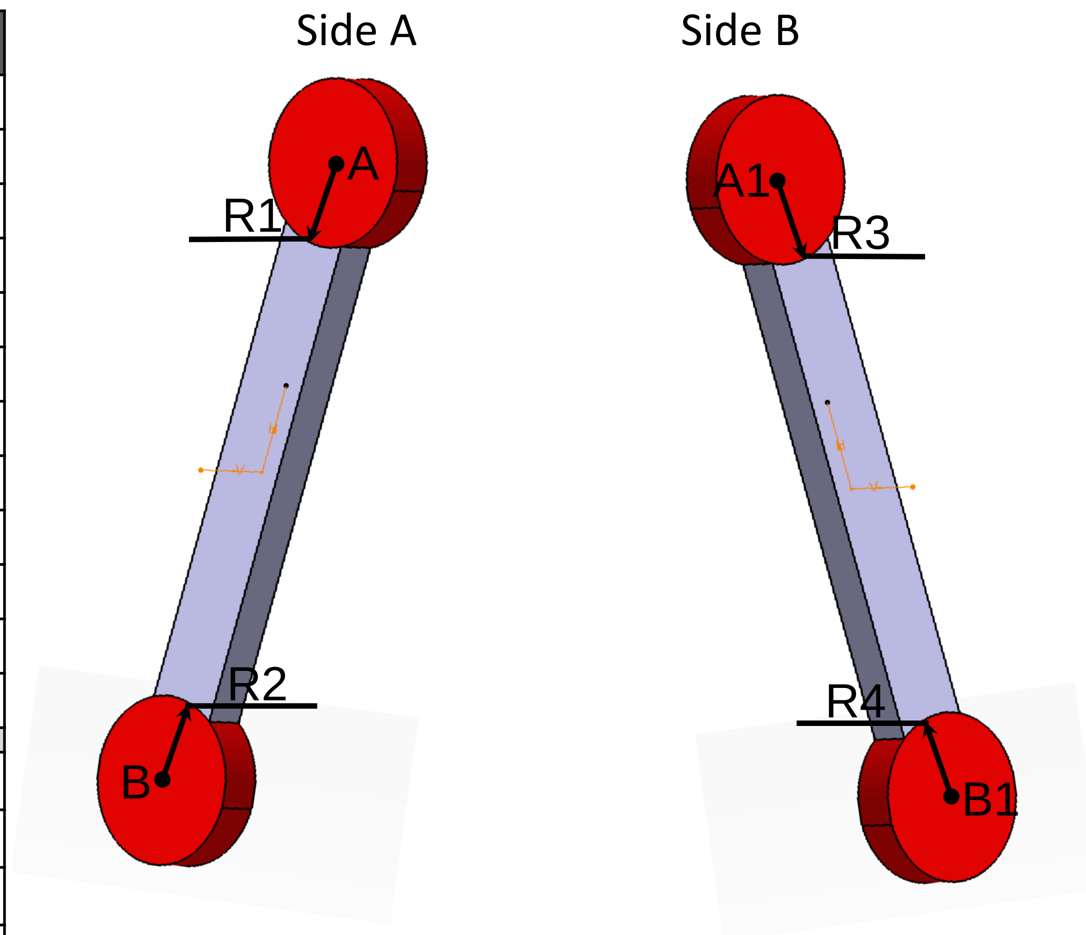
	Cube
	Cube
T1	Subtraction
	Tube
T2	Move
T3	Subtraction
T4	Move
T5	Subtraction
T6	Move
T7	Rotation



All units are in millimeters

Test Example of Analysis

		CATIA	Geant4	Δ
A	x	-1946.37	-1946.48	0.11
	y	-4851.85	-4852.04	0.19
	z	9685	9685	0
A1	X	-1946.36	-1946.47	0.11
	Y	-4851.85	-4852.04	0.19
	z	9395	9395	0
B	x	-3553.64	-3553.69	0.05
	y	-8732.15	-8732.22	0.07
	z	9685	9685	0
B1	x	-3553.64	-3553.69	0.05
	y	-8732.15	-8732.22	0.07
	z	9395	9395	0
R1		544.5	544.31	0.19
R2		544.5	544.6	-0.1
R3		544.5	544.31	0.19
R4		544.5	544.6	-0.1
Volume		0.049	0.049	0

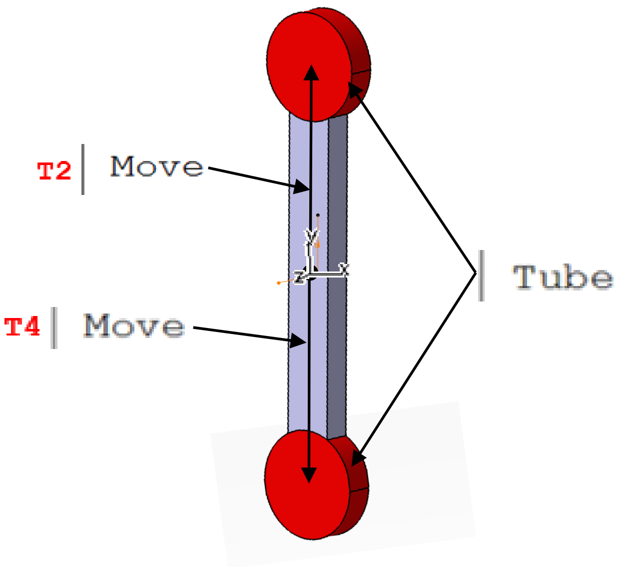


Here are positioning (A, A1, B, B1) and form (R1, R2, R3, R4) inaccuracies (Δ)

All units are in millimeters

Investigation where inaccuracies are coming from

Case Study #01: Volume In the Axes Origin (without T1/T3/T5/T6/T7)



	Cube
	Cube
T1	Subtraction
	Tube
T2	Move
T3	Subtraction
T4	Move
T5	Subtraction
T6	Move
T7	Rotation

```
<box  name="Box1"  material="Aluminium"  X_Y_Z="500.; 3240.; 290." />
<box  name="Box2"  material="Aluminium"  X_Y_Z="480.; 3300.; 270." />
<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<composition name="TestExampleN26" >
   <posXYZ  volume="Box1"   X_Y_Z=" 0; 0. ; 0.  "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Box2"   X_Y_Z=" 0; 0. ; 0.  "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; 2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</composition>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN26" X_Y_Z=" 0. ; 0. ; 0." rot=" 0.; 0.; 0. " />
</composition>
```

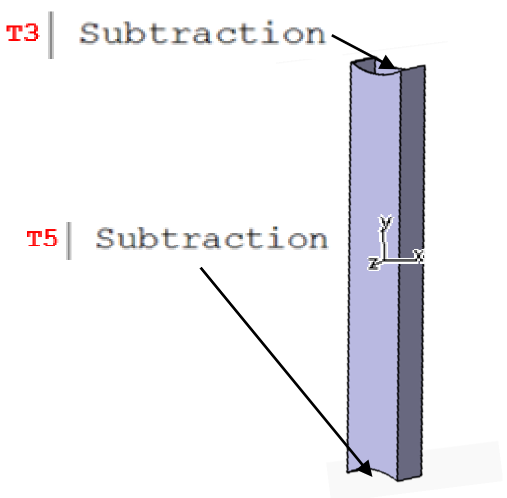
		GeoM Δ_1	G-4 Δ_2	Total Δ
A	*x*	0	0	0
	y	0	-0.1	-0.1
	z	0	0	0
A_1	*x*	0	0	0
	y	0	-0.1	-0.1
	z	0	0	0
B	*x*	0	0	0
	y	0	0.1	0.1
	z	0	0	0
B_1	*x*	0	0	0
	y	0	0.1	0.1
	z	0	0	0
R1		0	-0.1	-0.1
R2		0	-0.1	-0.1
R3		0	-0.1	-0.1
R4		0	-0.1	-0.1
Volume		0	0	0

- Positioning and form inaccuracies for tube are caused by move operation of Geant4 (G-4/Δ_2)

All units are in millimeters

Investigation where inaccuracies are coming from

Case Study #02: Volume In the Axes Origin (without T6/T7)




```
   Cube
   Cube
T1 Subtraction
   Tube
T2 Move
T3 Subtraction
T4 Move
T5 Subtraction
T6 Move
T7 Rotation
```

		GeoM Δ_1	G-4 Δ_2	Total Δ
A	*x*	0.03	0	0.03
	y	0.02	0.2	0.22
	z	0	0	0
A_1	*x*	0.03	0	0.03
	y	0.02	0.2	0.22
	z	0	0	0
B	*x*	0.03	0	0.03
	y	-0.02	0.1	0.08
	z	0	0	0
B_1	*x*	0.03	0	0.03
	y	-0.02	0.1	0.08
	z	0	0	0
R1		0	-0.19	-0.19
R2		0	0.1	0.1
R3		0	-0.19	-0.19
R4		0	0.1	0.1
Volume		0	0	0

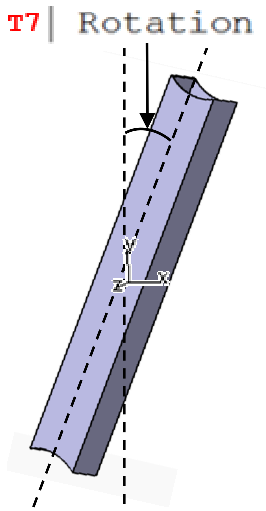
```
<box  name="Box1"  material="Aluminium"  X_Y_Z="500.; 3240.; 290." />
<box  name="Box2"  material="Aluminium"  X_Y_Z="480.; 3300.; 270." />
<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN26" >
   <posXYZ  volume="Box1"   X_Y_Z=" 0; 0. ; 0.   "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Box2"   X_Y_Z=" 0; 0. ; 0.   "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; 2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN26" X_Y_Z=" 0. ; 0. ; 0." rot=" 0.; 0.; 0. " />
</composition>
```

- Positioning inaccuracies are caused by subtraction operation of GeoModel (GeoM/Δ_1)
- Positioning and form inaccuracies are caused by subtraction operation of Geant4 (G-4/Δ_2)

All units are in millimeters

Investigation where inaccuracies are coming from

Case Study #03: Volume In the Axes Origin (without T6)




```
     Cube
     Cube
T1   Subtraction
     Tube
T2   Move
T3   Subtraction
T4   Move
T5   Subtraction
T6   Move
T7   Rotation
```

		GeoM Δ_1	G-4 Δ_2	Total Δ
A	*x*	0.05	0.09	0.14
	y	0.01	0.23	0.24
	z	0	0	0
A_1	*x*	0.05	0.09	0.14
	y	0.01	0.23	0.24
	z	0	0	0
B	*x*	0.01	0.01	0.02
	y	-0.03	0.02	-0.01
	z	0	0	0
B_1	*x*	0.01	0.01	0.02
	y	-0.03	0.02	-0.01
	z	0	0	0
	R1	0	-0.24	-0.24
	R2	0	0.02	0.02
	R3	0	-0.24	-0.24
	R4	0	0.02	0.02
Volume		0	0	0

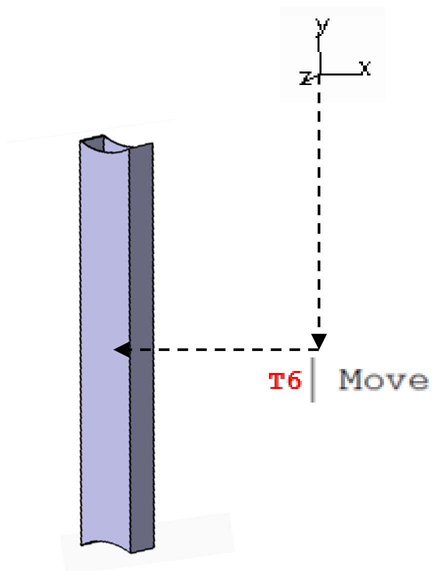
```
<box  name="Box1"  material="Aluminium"  X_Y_Z="500.; 3240.; 290." />
<box  name="Box2"  material="Aluminium"  X_Y_Z="480.; 3300.; 270." />
<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN26" >
   <posXYZ  volume="Box1"   X_Y_Z=" 0; 0. ; 0.   "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Box2"   X_Y_Z=" 0; 0. ; 0.   "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; 2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN26" X_Y_Z=" 0. ; 0. ; 0." rot=" 0.; 0.; -22.5 " />
</composition>
```

- Positioning inaccuracies are caused by rotation operation of GeoModel (GeoM/Δ_1)
- Positioning and form inaccuracies are caused by rotation operation of Geant4 (G-4/Δ_2)

All units are in millimeters

Investigation where inaccuracies are coming from

Case Study #04: Volume without Rotation (without T7)



	Operation
	Cube
	Cube
T1	Subtraction
	Tube
T2	Move
T3	Subtraction
T4	Move
T5	Subtraction
T6	Move
T7	Rotation

```
<box  name="Box1"  material="Aluminium"  X_Y_Z="500.; 3240.; 290." />
<box  name="Box2"  material="Aluminium"  X_Y_Z="480.; 3300.; 270." />
<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN26" >
   <posXYZ  volume="Box1"   X_Y_Z=" 0; 0. ; 0.  "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Box2"   X_Y_Z=" 0; 0. ; 0.  "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; 2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -2100. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN26" X_Y_Z="-2750. ; -6792. ; 9540." rot=" 0.; 0.; 0. " />
</composition>
```

		GeoM Δ_1	G-4 Δ_2	Total Δ
A	*x*	0.03	0.01	0.04
	y	0.02	0.2	0.22
	z	0	0	0
A_1	*x*	0.03	0.01	0.04
	y	0.02	0.2	0.22
	z	0	0	0
B	*x*	0.03	0	0.03
	y	-0.03	0.1	0.07
	z	0	0	0
B_1	*x*	0.03	0	0.03
	y	-0.03	0.1	0.07
	z	0	0	0
	R1	0.01	-0.2	-0.19
	R2	-0.01	0.1	0.09
	R3	0.01	-0.2	-0.19
	R4	-0.01	0.1	0.09
Volume		0	0	0

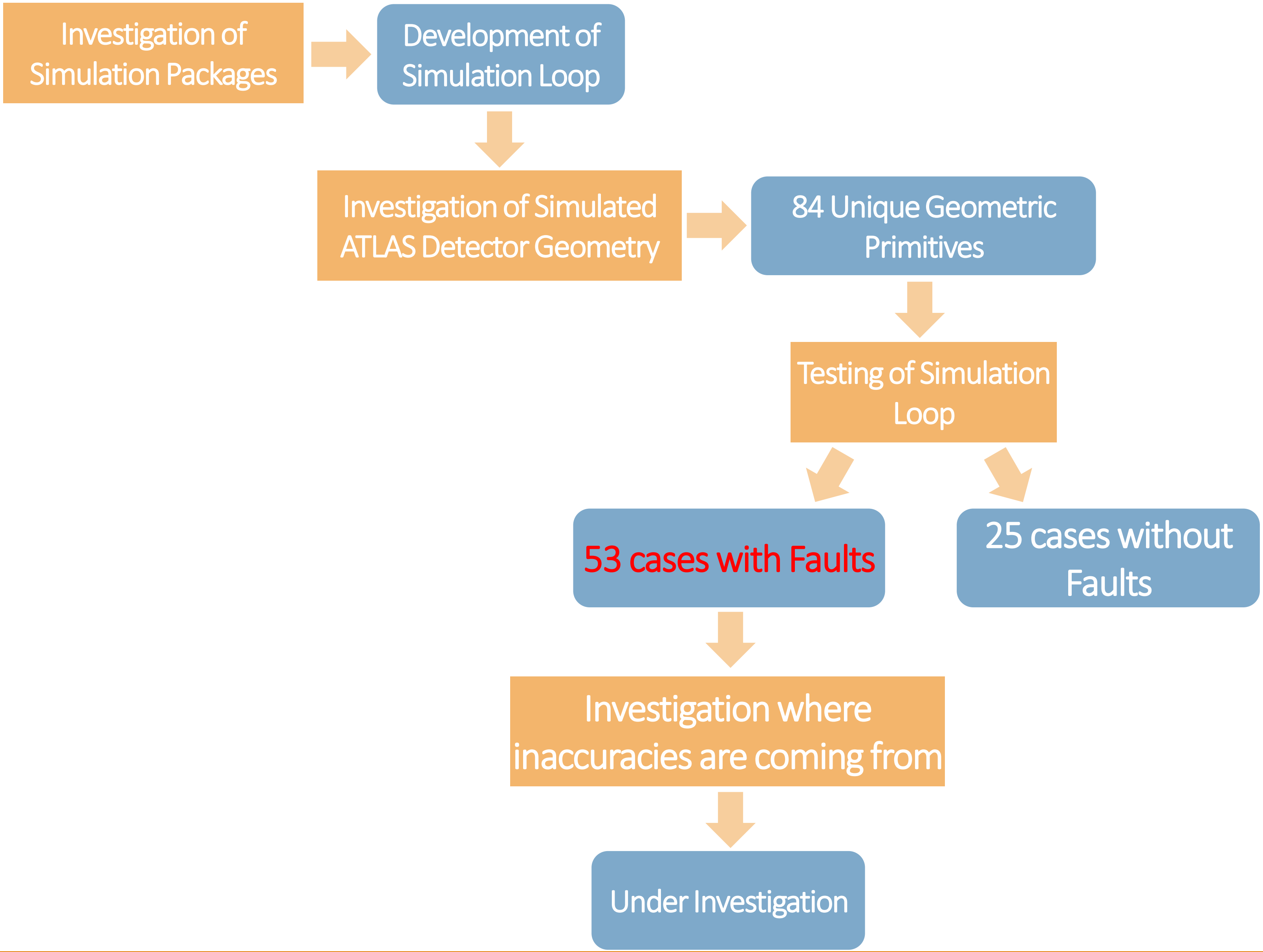
- Positioning and form inaccuracies are caused by move operation of GeoModel (GeoM/Δ_1)
- Positioning and form inaccuracies are caused by move operation of Geant4 (G-4/Δ_2)

All units are in millimeters

Final Results of Test Example

1. Positioning (Δy=0.1 mm) and form (Δr=0.1 mm) inaccuracies for cylinder are caused by move transaction along y axis in Geant4 (Case Study #01)
2. 0.1 mm inaccuracies are repeatable which might be computational errors (Case Study #01)
3. Positioning (Δy=0.1 mm) and form (Δr=0.09 mm) inaccuracies are caused by Subtraction operation in Geant4 (Case Study #02)
4. Positioning (Δx=0.03 mm, Δy=0.02 mm) inaccuracies are caused by Subtraction operation in GeoModel (Case Study #02)
5. Positioning (Δx=0.09 mm, Δy=0.03 mm) and form (Δr=0.05 mm) inaccuracies are caused by Rotation operation toward z axis (22.5^o) in Geant4 (Case Study #03)
6. Positioning (Δx=0.02 mm, Δy=0.01 mm) inaccuracies are caused by Rotation operation toward z axis (22.5^o) in GeoModel (Case Study #03)
7. Positioning (Δx=0.01 mm) and form (Δr=0.01 mm) inaccuracies are caused by Move operation along x, y, z axes in Geant4 (Case Study #04)
8. Positioning (Δy=0.01 mm) and form (Δr=0.01 mm) inaccuracies are caused by Move operation along x, y, z axes in Geant4 (Case Study #04)

Conclusion


Investigation of Simulation Packages
Development of Simulation Loop
Investigation of Simulated ATLAS Detector Geometry
84 Unique Geometric Primitives
Testing of Simulation Loop
53 cases with Faults
25 cases without Faults
Investigation where inaccuracies are coming from
Under Investigation

Thank you for your attention

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