Development of CATIA_2_GEANT Interface for Simulation of High Energy Physics Experiments

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ATLAS Collaboration

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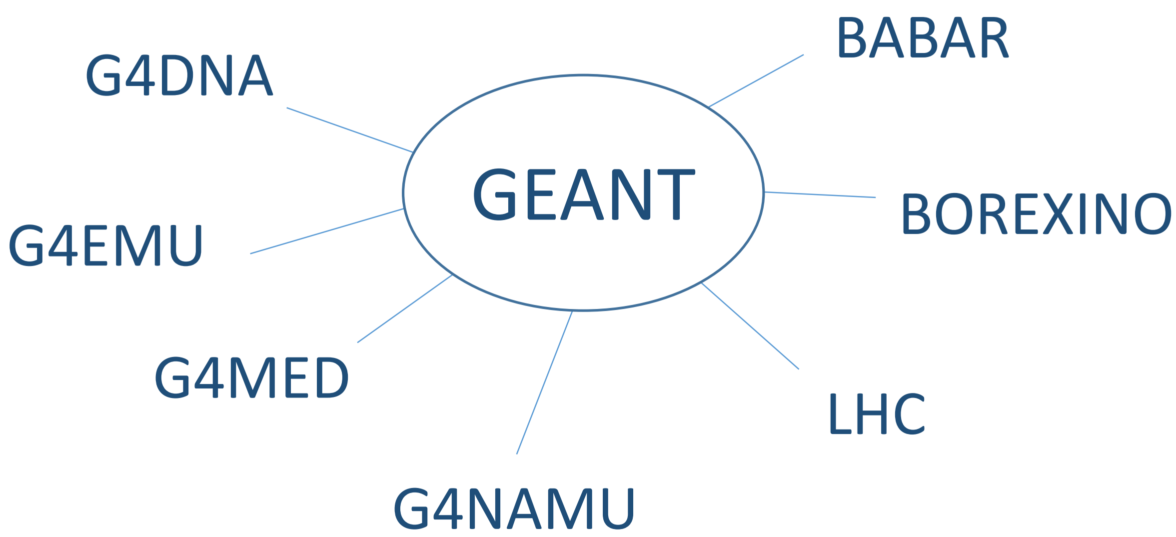
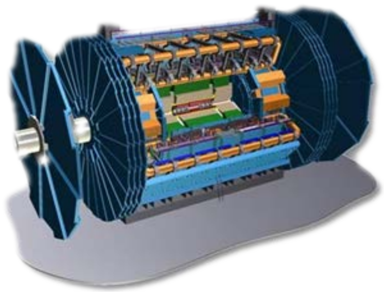
- GEANT is a platform for simulation of facilities and physical events by modelling of the passage of particles through the matter
- GEANT implementing in High Energy, nuclear and Accelerator physics as well for studies in medical and in space science

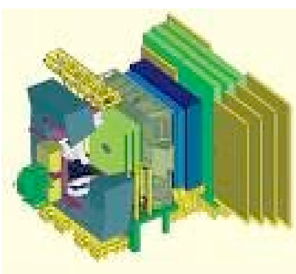


LHC Machine at CERN



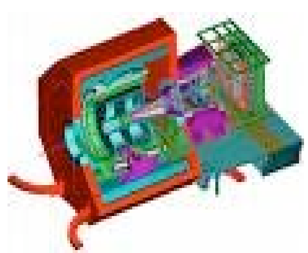
ATLAS Detector length ~40 m, height ~22 m, weight ~7'000 tonnes

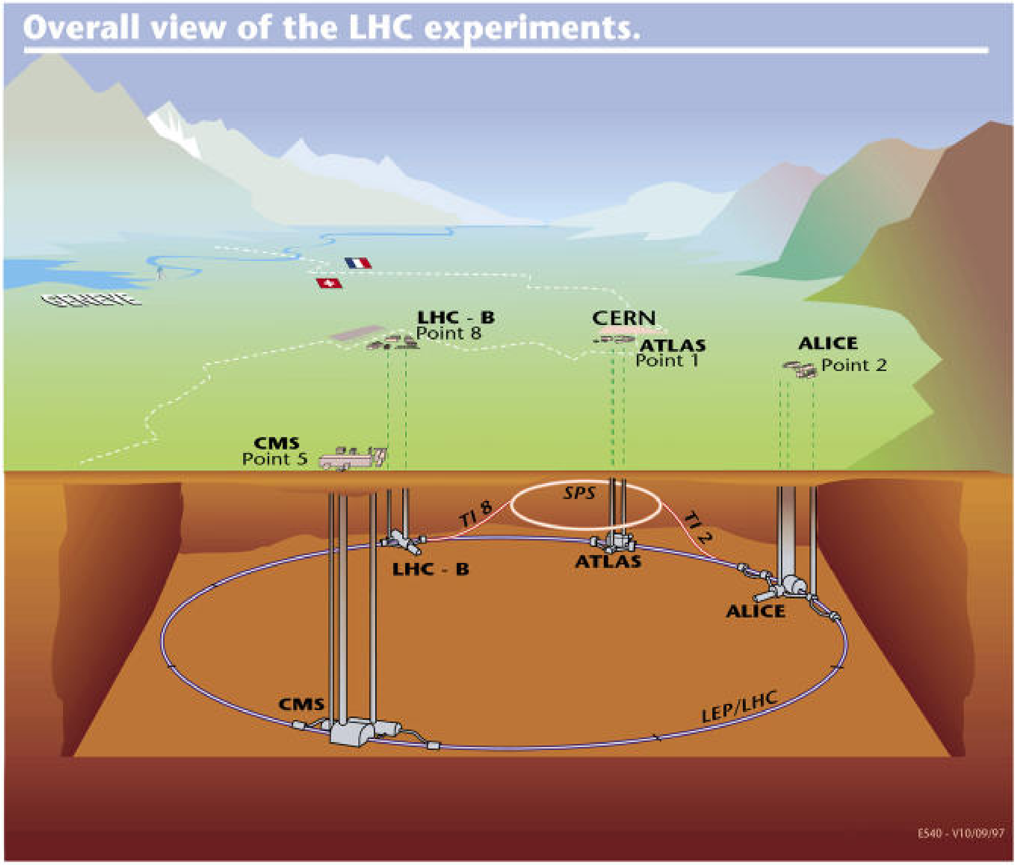
CMS Detector length ~22 m, height ~15 m, weight ~14'000 tonnes



ALICE Detector

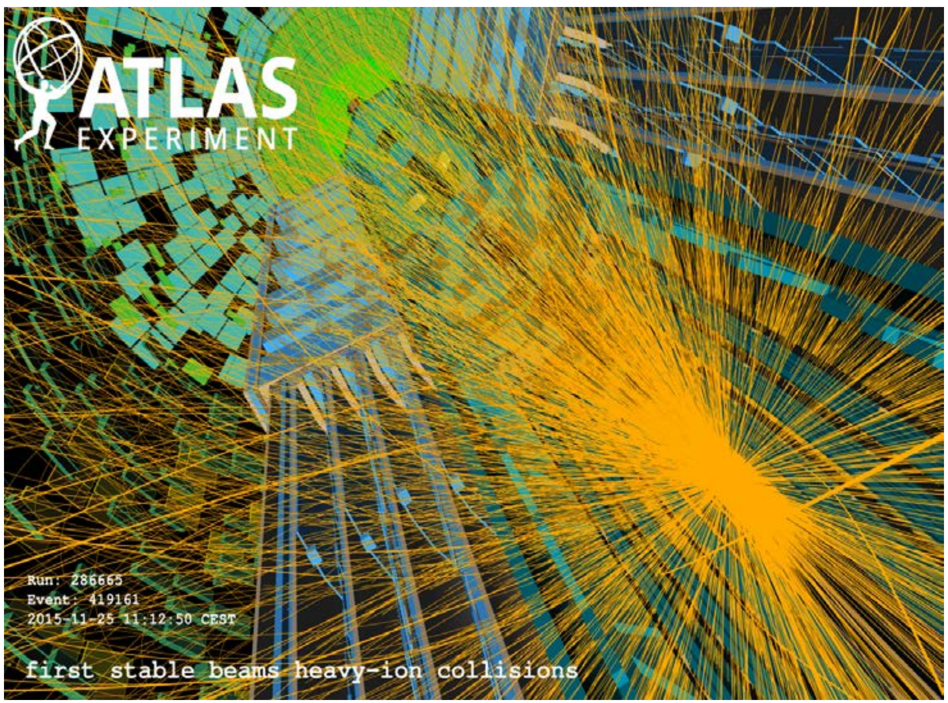
LHCB Detector

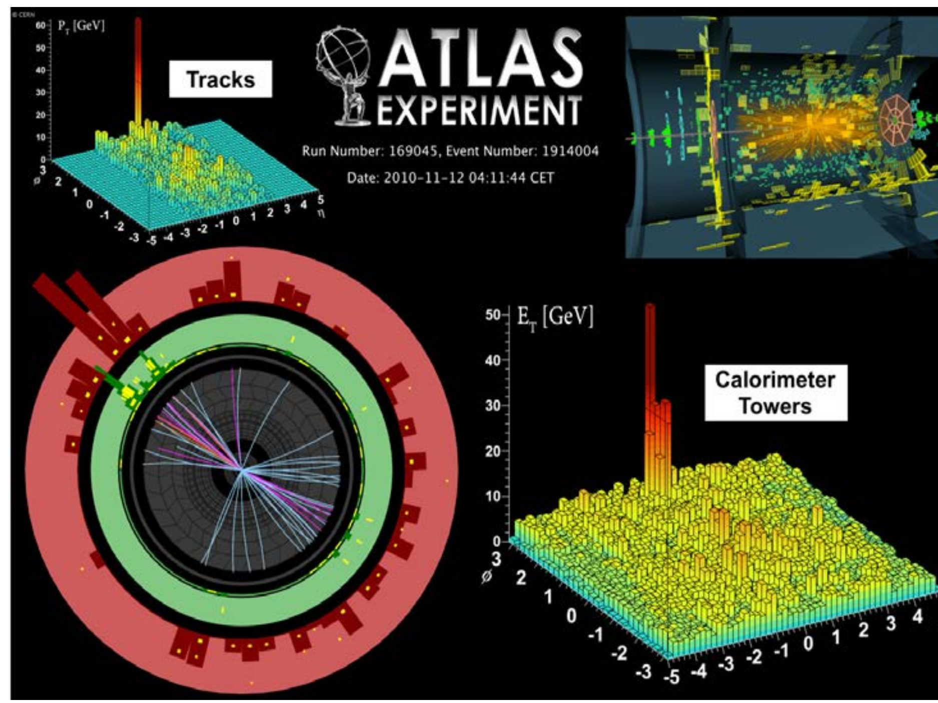




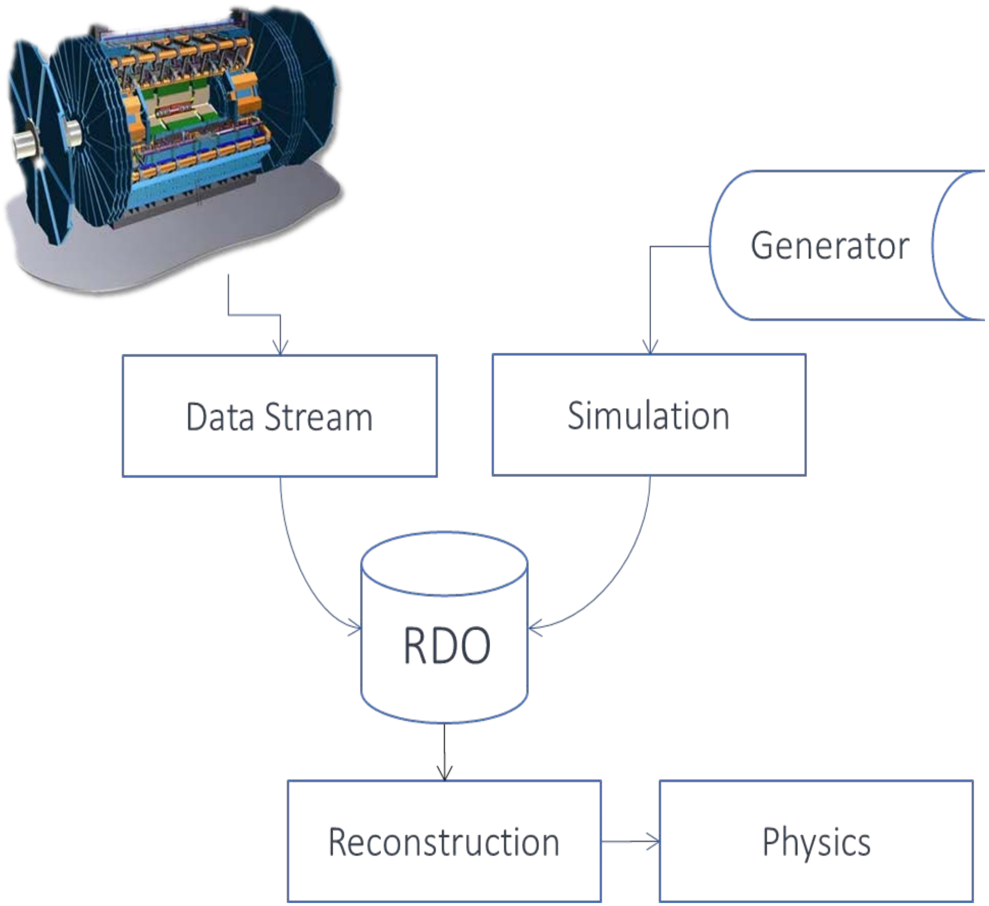
ATLAS Experiment

- ATLAS implements simulation for deep and wide range investigation of physics experiments by generating artificial events from the event generator in a format which is identical to the output of the detector data acquisition system

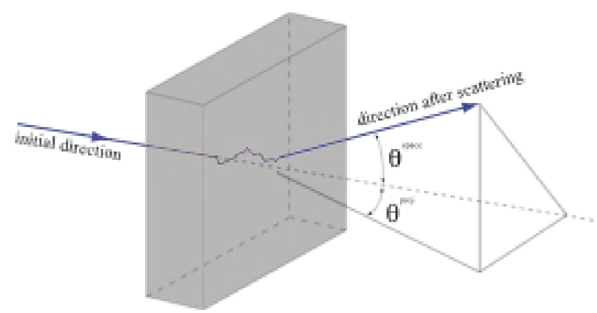




ATLAS Experiment



- The passage of a particle through matter

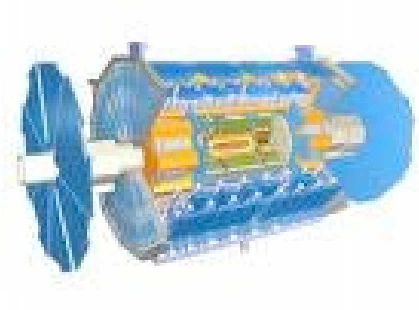


$$\langle \Theta^2_{\mathrm{proj}} \rangle = \langle \Theta^2_{\mathrm{space}} \rangle / 2$$
$$= \frac{(21\ \mathrm{MeV})^2 (m^2 + p^2)}{2 p^4 \beta^2} \frac{x}{X_0} \left(1 + 0.038 \log \frac{x}{X_0}\right)^2$$

Problem of Data Discrepancy

Reality

Monte Carlo Simulation



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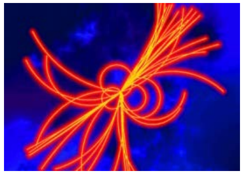
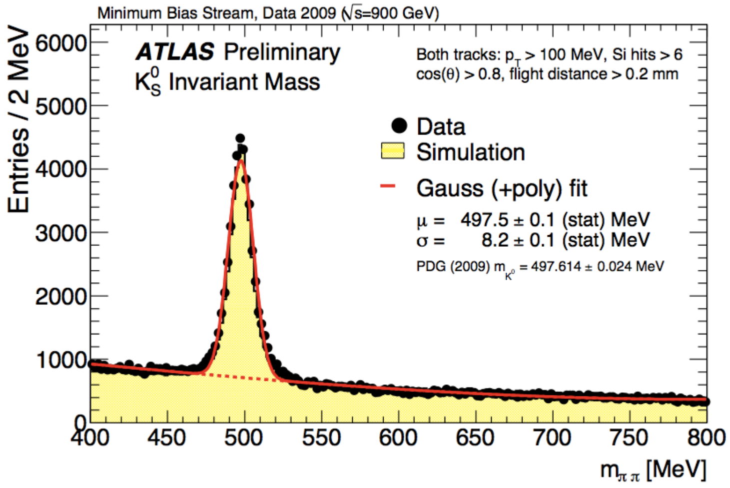
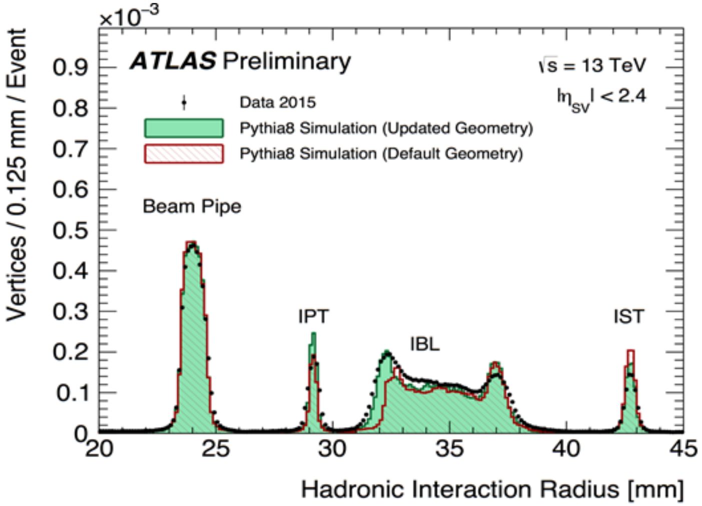




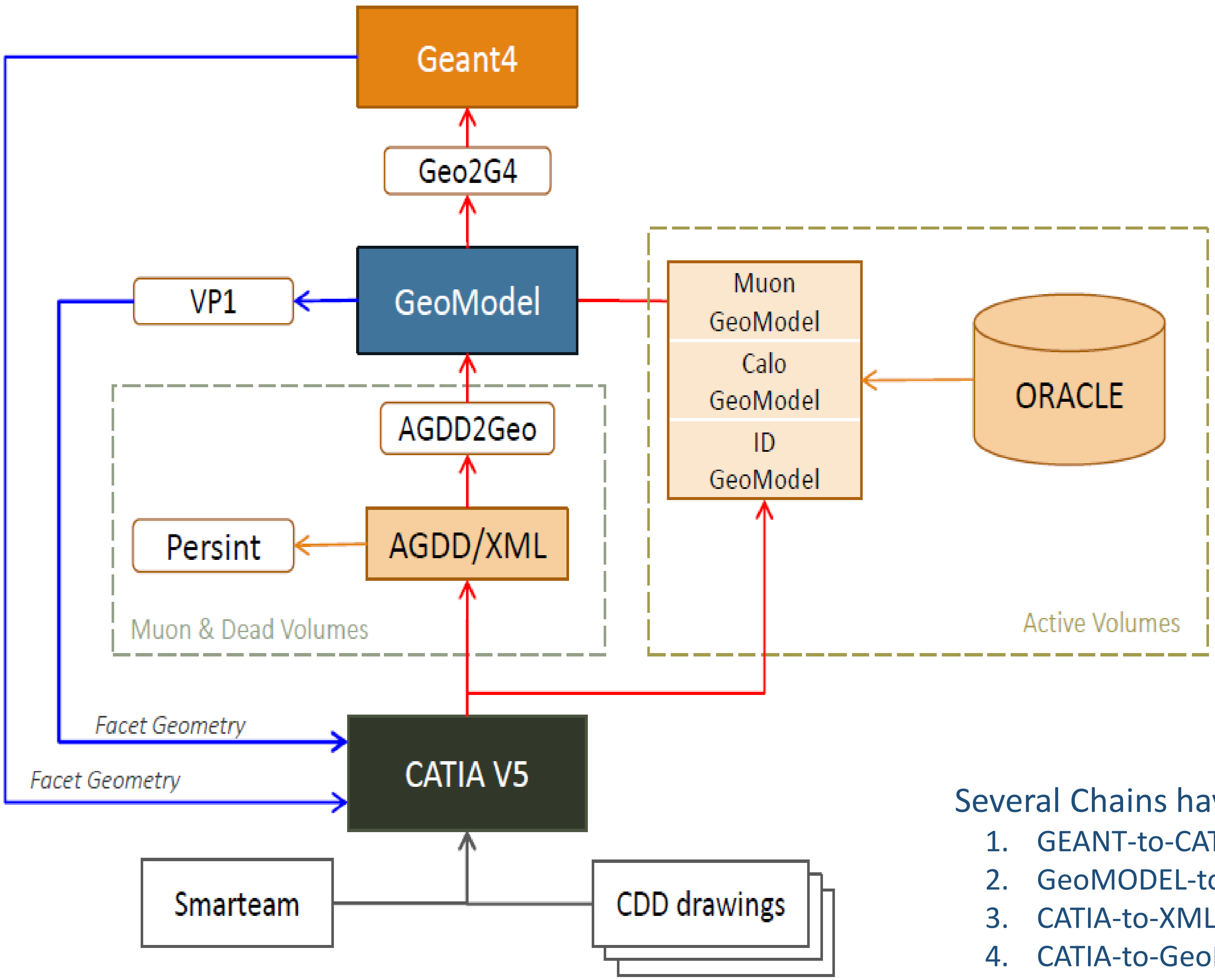


Analyze & Compare

Research Hypothesis

- Several reasons can cause discrepancies between Data and Monte-Carlo. Several investigations show that they are coming by the reason of geometry descriptions in simulation
- It is possible to predict 2 hypothesis why faults are exist in geometry descriptions:
  - Hypothesis #01: Inaccuracies added by geometry transactions of simulation software infrastructure
  - Hypothesis #02: Inaccuracies added by difference of as-built geometry descriptions with geometry descriptions of simulation

Geometry Simulation Loop



Several Chains have been developed:

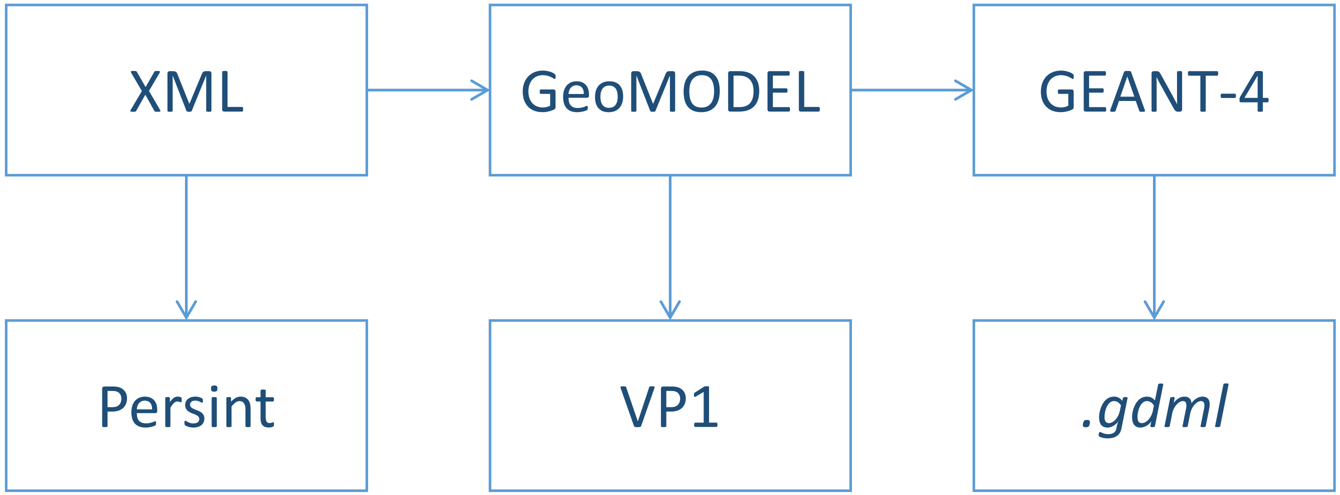
1. GEANT-to-CATIA
2. GeoMODEL-to-CATIA
3. CATIA-to-XML
4. CATIA-to-GeoMODEL

Checking Hypothesis 01:

Investigation of Simulation Infrastructure

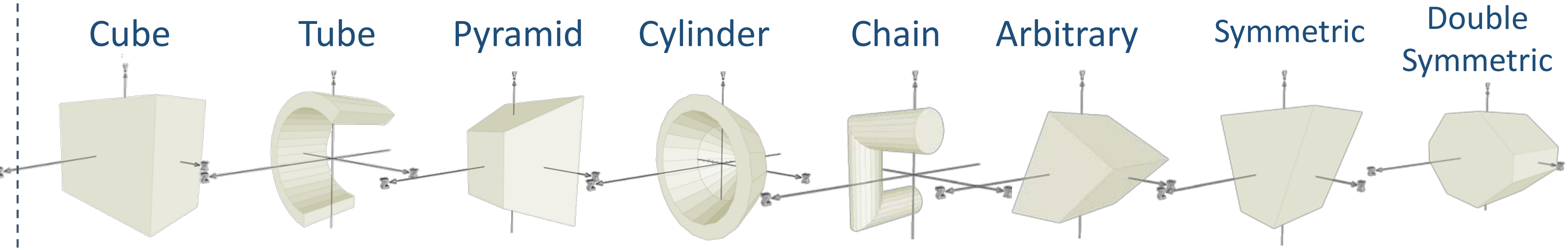
Investigation of Simulation Infrastructure

- ATLAS simulation infrastructure use 3 platforms for description of detector geometry: GEANT, GeoMODEL and XML.
- Geometry descriptions on GEANT and GeoMODEL are generating at run-time during the simulation session, while XML descriptions stored in database



XML Platform

- Standard Primitives and Polygon Methods

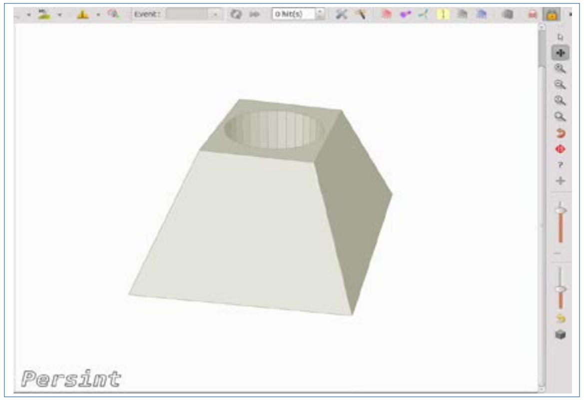


- Transactions: Move, Rotate
- Boolean Operations: Subtraction, Union, Intersection

Code Example for *Pyramid* with cut

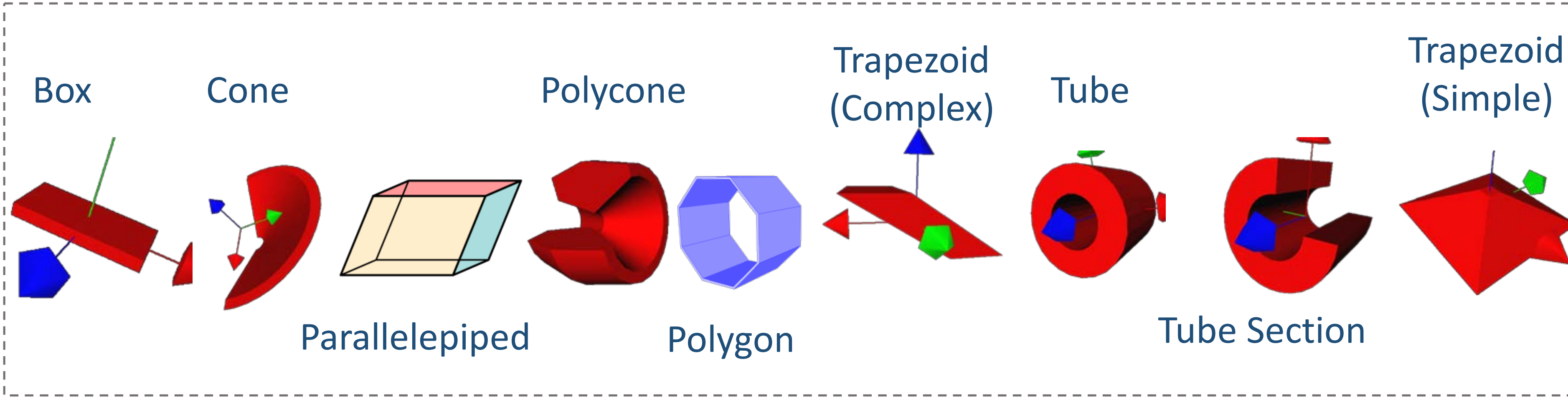
```
<trd name="Pyramid"  material="Aluminium"  Xmp_Ymp_Z="4000.; 2000.; 5000.; 2500.; 3000." />
<tubs name="Tube" material="Aluminium" Rio_Z="0.; 900.; 5200."   nbPhi="32"  />

<subtraction name="Pyramid_Test" >
   <posXYZ  volume="Pyramid"    X_Y_Z=" 0; 0. ; 0.   "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube"  X_Y_Z=" 0. ; 0. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>
```

Persint Screenshot



GeoMODEL Platform

- Standard Primitives and Polygon Methods

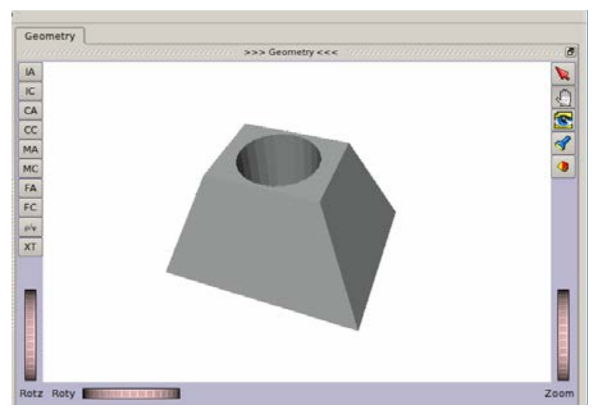


- Transactions: Move, Rotate
- Boolean Operations: Subtraction, Union, Intersection

Code Example for *Pyramid* with cut

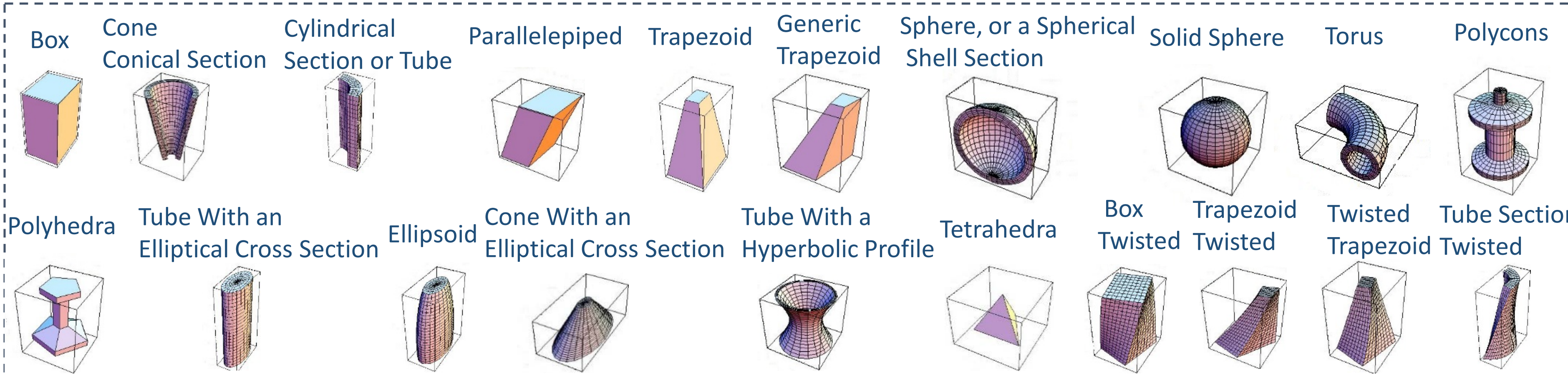
```
GeoTrd * Trapezoir_Pr = new GeoTrd(2000.*CLHEP::mm, 1000.*CLHEP::mm,2500.*CLHEP::mm,
                                   1250.*CLHEP::mm, 1500.*CLHEP::mm );
GeoTube * Tube = new GeoTube( 0.*CLHEP::mm, 900.*CLHEP::mm, 2600.*CLHEP::mm);

const GeoShape & ExampleN55_subtr = Trapezoir_Pr->subtract((*Tube));

GeoLogVol* ExampleN55_Log = new GeoLogVol("ExampleN55",&ExampleN55_subtr,Aluminium);
GeoPhysVol* ExampleN55_Log_Phis = new GeoPhysVol(ExampleN55_Log);
```

VP1 Screenshot



GEANT-4 Platform

- Standard Primitives and Polygon Methods

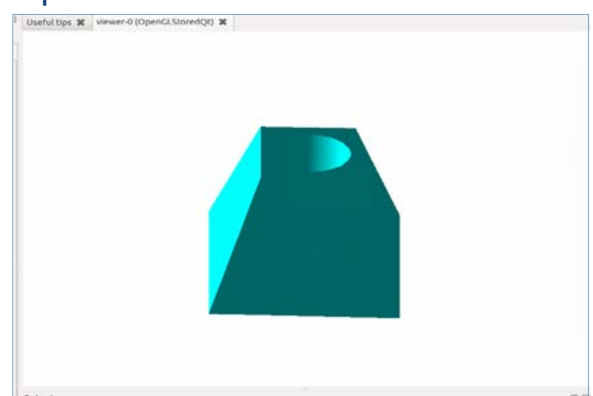


- Transactions: Move, Rotate
- Boolean Operations: Subtraction, Union, Intersection

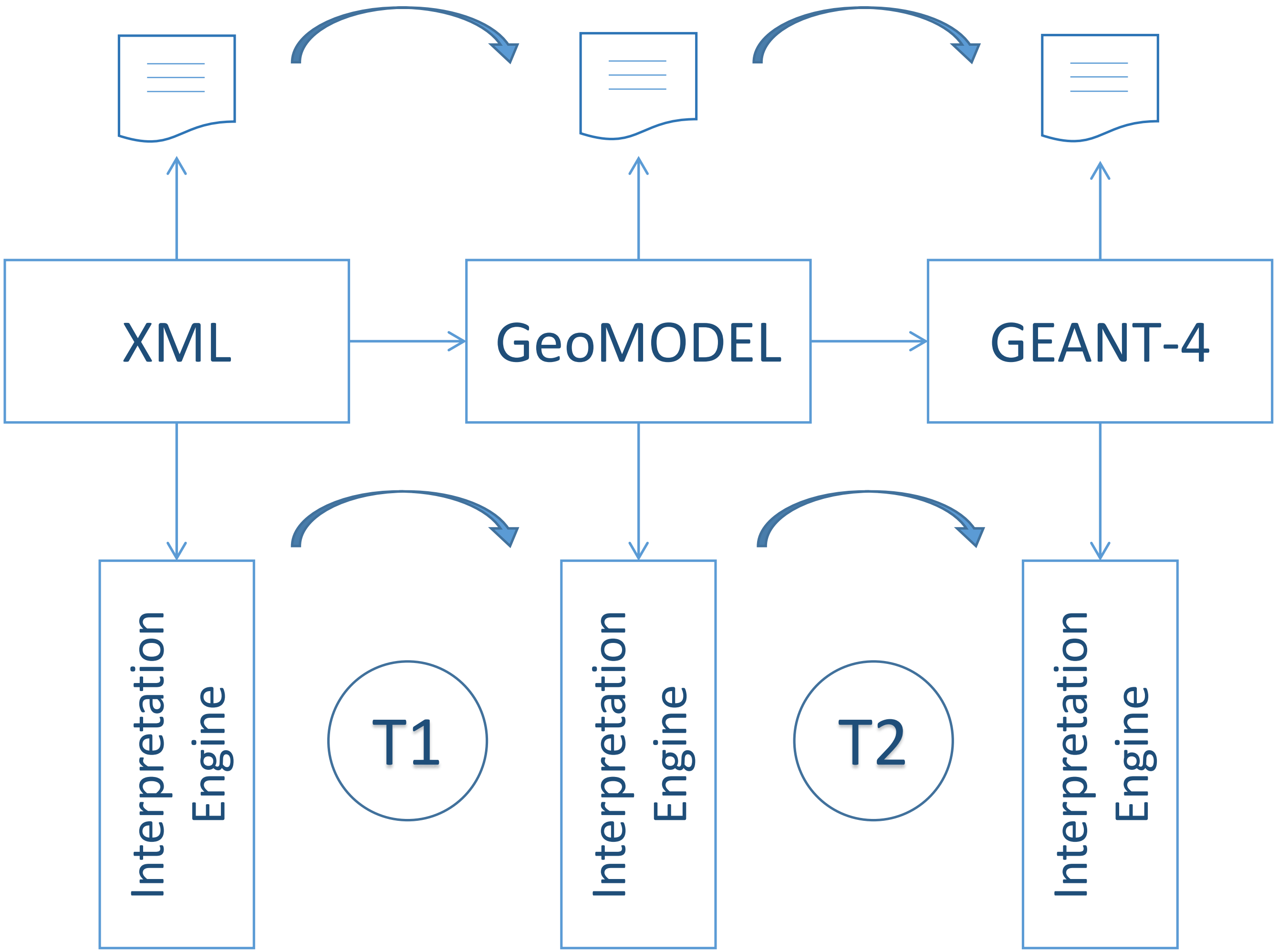
Code Example for *Pyramid* with cut

```
G4Tubs* solidShape1 = new G4Tubs("Shape1", 0.*mm, 900.*mm,  5200.*mm, 0.*deg, 360.*deg);

G4Trd* solidShape2 = new G4Trd("Shape2",
             2000.*mm, 1000*mm,
             2500*mm, 1250*mm, 1500*mm);
G4SubtractionSolid* b1minusC12 =   new G4SubtractionSolid("Box-Cylinder", solidShape2, solidShape1);

G4LogicalVolume* b1minusC1 = new G4LogicalVolume(b1minusC12,
                      shape2_mat,
                      "Shape2");

new G4PVPlacement(0, pos2, b1minusC1,"Shape2", logicEnv, false, 0, checkOverlaps);
```

OpenGL Screenshot



Geometry Transformations



Objectives of Analyses

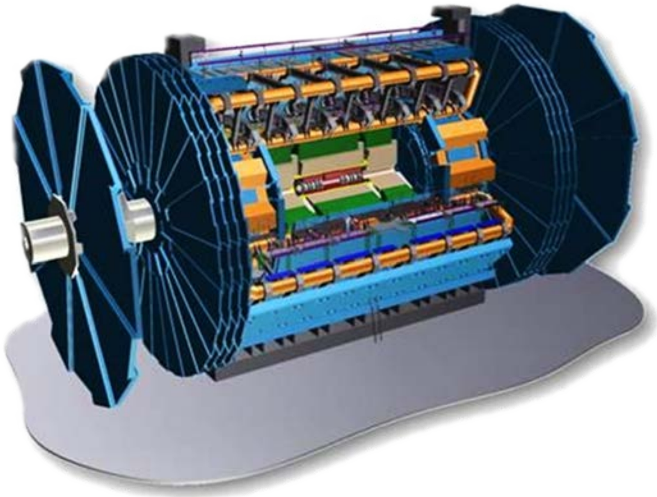
- Investigation quality of T1/T2 geometry Transformations

Methodology of Analyses

1. Categorization of geometry of Detector components
2. Selection Methods for description
3. Test runs of test examples
4. Case study of transactions
5. Systematization and learning of results

Part I. Categorization of Geometry

I. Categorization of Geometry



- Total number of Mechanical assemblies > 3’700
- Total number of Mechanical features > 10’000’000
- Disk size of geometry 62Gb

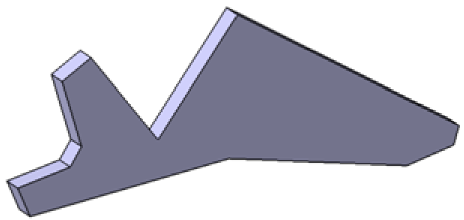
- **Purpose** of categorization is finding groups of detector components similar by geometry and identification of typical group representatives.

- **3 criteria** can be implemented for categorization of detector geometry:
  1. Correspondence of detector components to standard geometry primitives – shapes with vertex; shapes without cuts; both, regular and irregular shapes; both, convex and concave shapes
  2. Grouping components with typical joining’s
  3. Grouping components with cuts

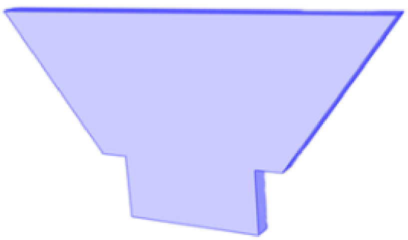
I. Categorization of Geometry

- 22 typical primitives have been separated in 1st class of objects

Dodecagonal Prism

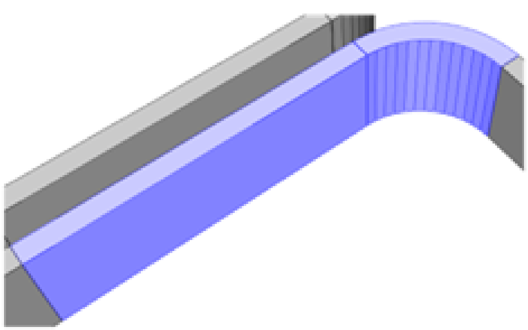


Octagonal Prism

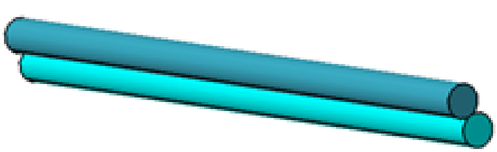


- 29 combined objects with typical joining's have been found for 2nd class

Cube and Tube Joining



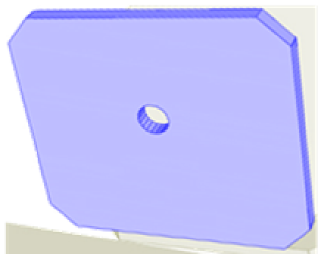
Tubes Joining



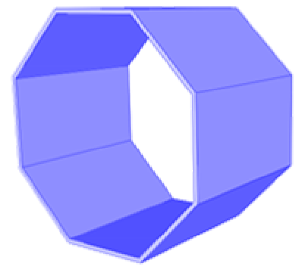
I. Categorization of Geometry

- 3. 33 objects with cuts were separated for 3rd class

Octagonal Prism with cut



Octagonal prism with cut

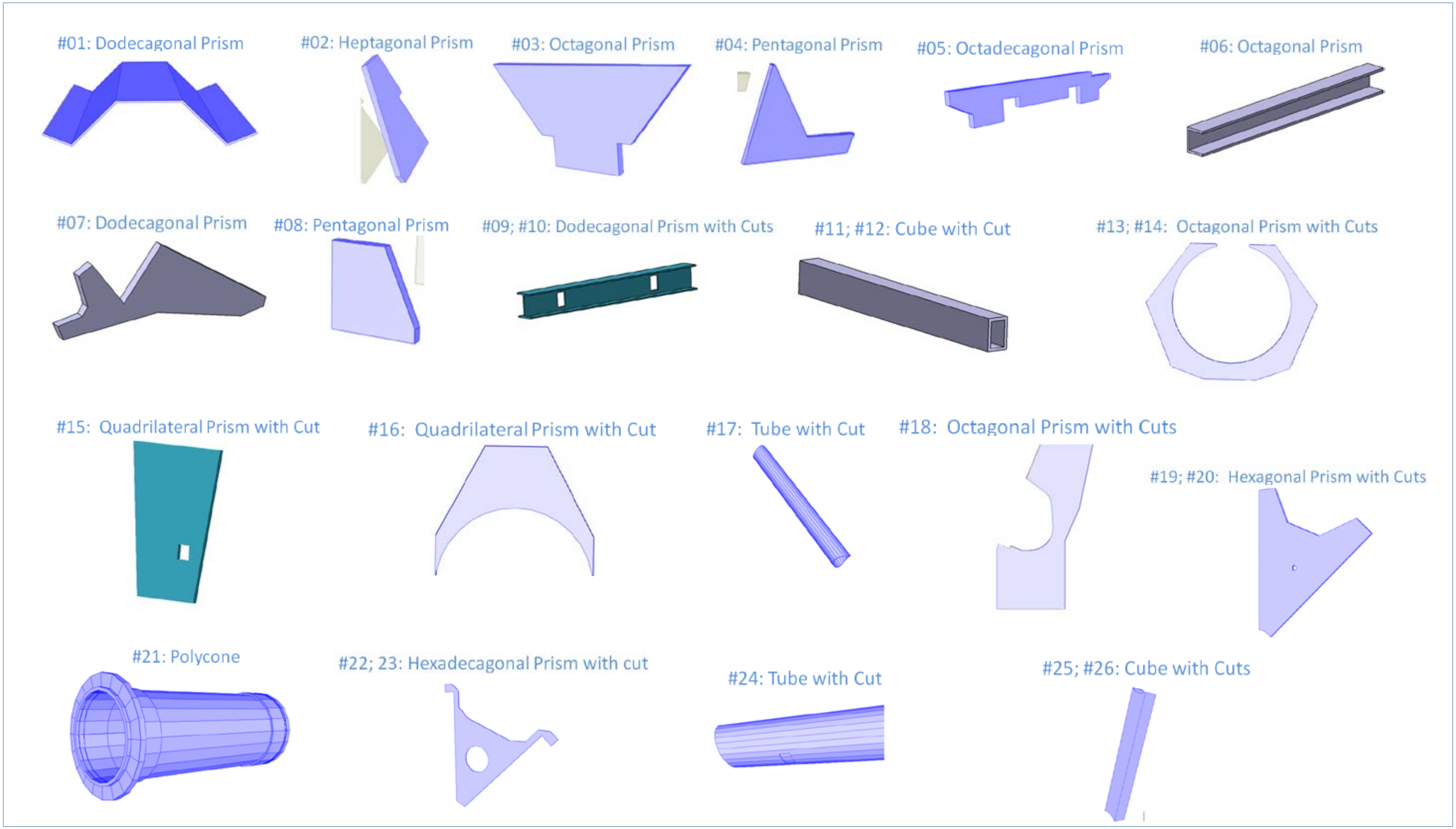


Conclusion: ATLAS detector geometry can be described by 84 typical representors of class of objects

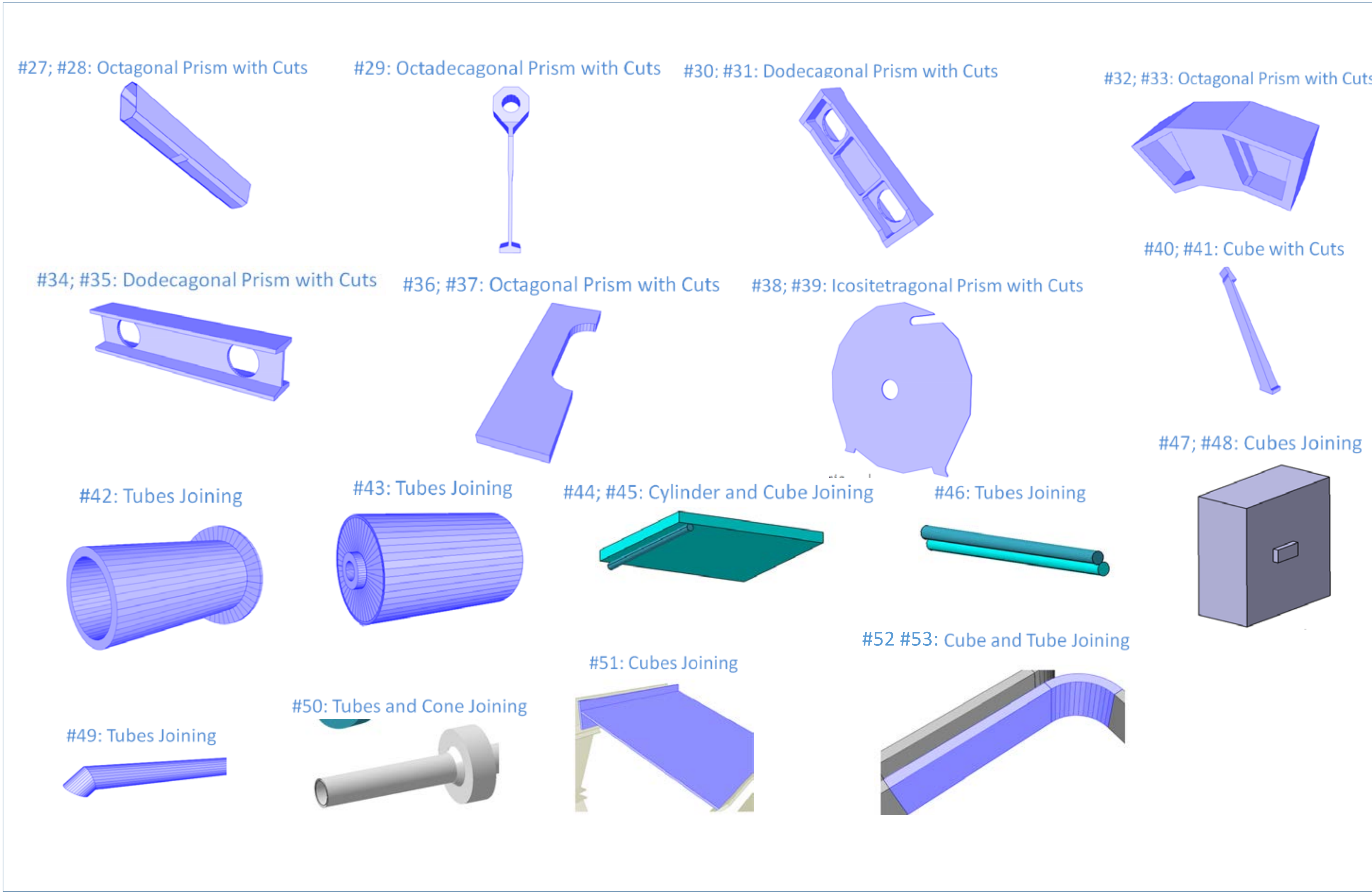
Muon & Dead Volumes	Geometry Primitives	19	Total: 58
	Typical Joining	13	
	Combined Objects	26	
Active Volumes	Geometry Primitives	3	Total: 26
	Typical Joining	16	
	Combined Objects	7	

I. Categorization of Geometry

84 typical representors of class of objects

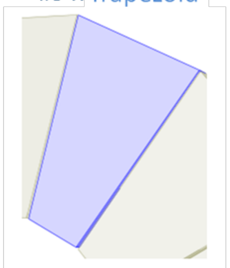


I. Categorization of Geometry

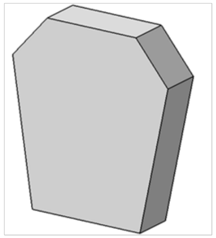


I. Categorization of Geometry

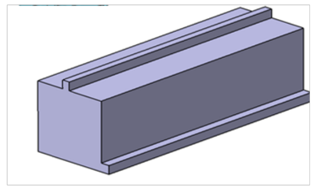
#54: Trapezoid



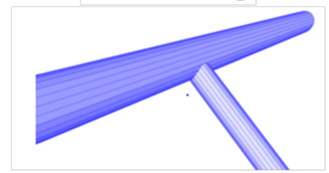
#55: Hexagonal Prism



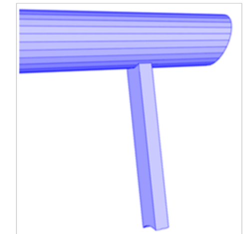
#56: Decagonal Prism



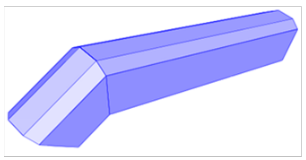
#57: Tubes Joining



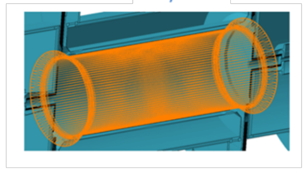
#58 #59: Cube and Tube Joining



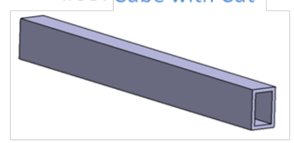
#60 #61: Octagonal Prisms with Cuts Joining



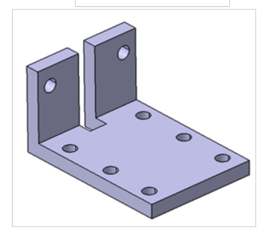
#62: Polycone



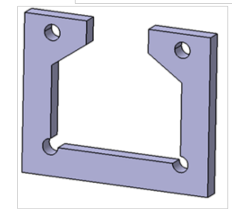
#63: Cube with Cut



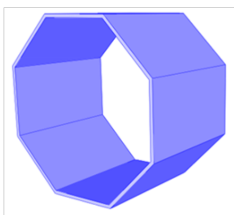
#64: Box with cuts



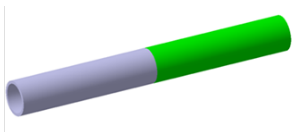
#65: Box with cuts



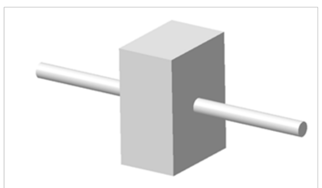
#66: Octagonal prism with cut



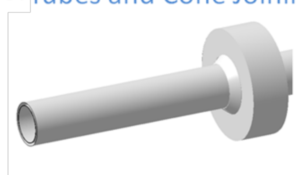
#67: Tubes joining



#68: Tube and Box joining

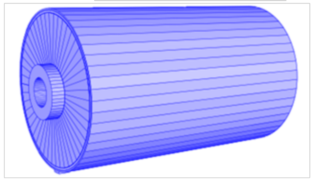


#69: Tubes and Cone Joining

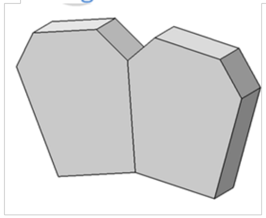


I. Categorization of Geometry

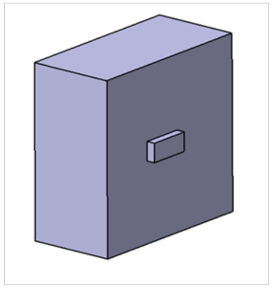
#70: Tubes Joining



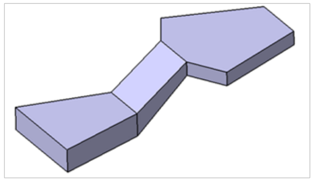
#71: Hexagonal Prism Joining



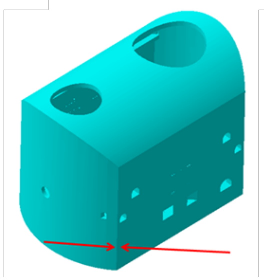
#72: Boxes Joining



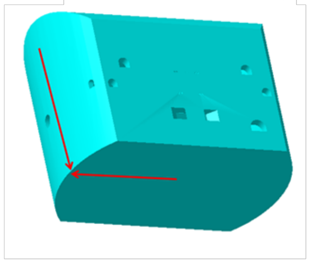
#73: Trapezoid, tetragonal and Hexagonal Prism Joining



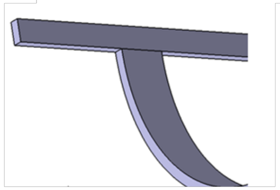
#74: Tubs and Box Joining



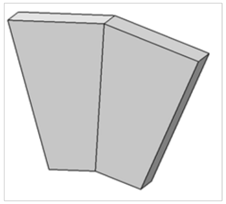
#75: Tubs and Box Joining



#76: Tubs and Box Joining



#77: Trapezoids Joining

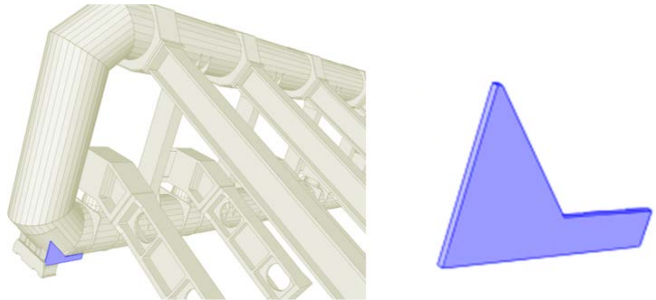


Part II. Selection of Methods for Description

II. Selection of Methods for Description

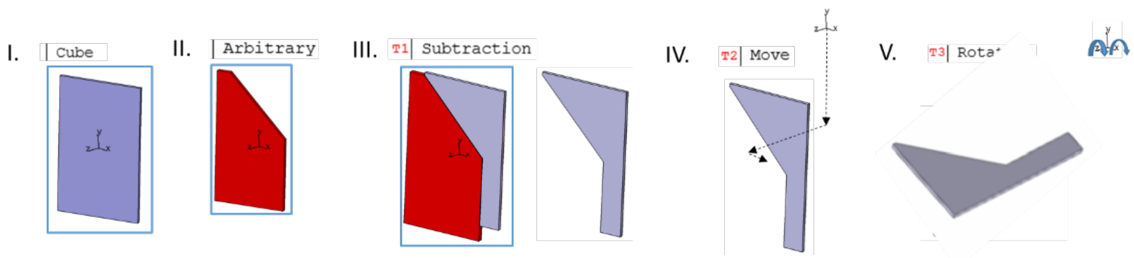
- Several Methods can be implemented for description of one single object

Pentagonal Prism



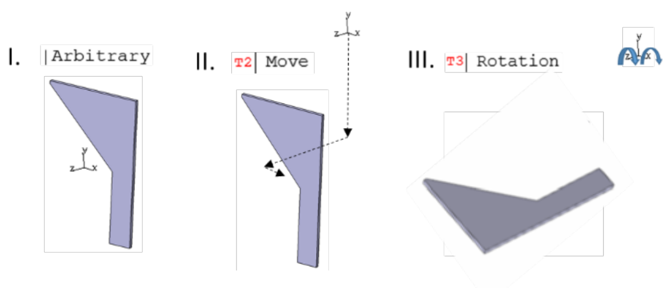
Method 01

Cube
Arbitrary
T1 Subtraction
T2 Move
T3 Rotation



Method 02

Arbitrary
T1 Move
T2 Rotation



II. Selection of Methods for Description

Finally, for all above selected typical representatives of object classes of ATLAS detector, full set of possible methods of description were selected:

1st class of 22 objects: 4’460 methods

2nd class of 22 objects: 4’636 methods

3rd class of 33 objects: 6’579 methods

Total: **15’675** methods

II. Selection of Methods for Description

Criteria #01: *Arbitrary_polygon* method should be separated as a standalone method, while

1. Geometry description requires minimal number of Boolean operations and Move/Rotation transactions
2. Geometry can be described directly in position by only Z axis displacement and Z axis rotation.

Example: Descriptions of Octadecagonal Prism

I.

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

II.

```
Cube
Arbitrary
Subtraction
Move
rotation
```

III.

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

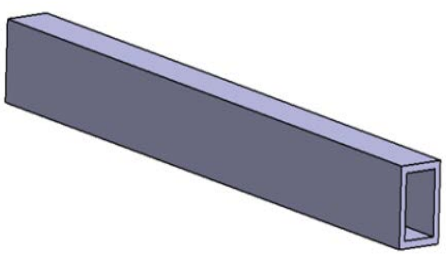
Conclusion: Exclude Methods II and III

II. Selection of Methods for Description

Criteria #02: Minimization of number of used methods in description

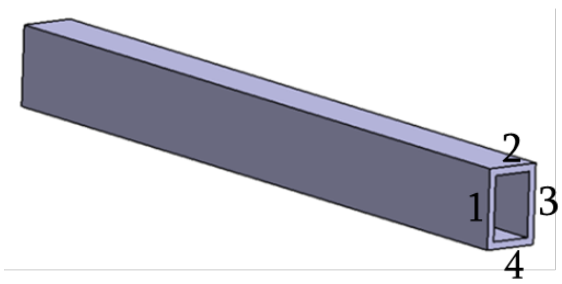
1. Ensure compactness of code
2. Reduce number received clashes, contacts and inaccuracies of positioning
3. Ensure better performance by reducing number of regions for consideration during the tracking

Example: Descriptions of Cube with Cut



I.

```
Cube
Cube
Subtraction
Move
Rotation
```



II.

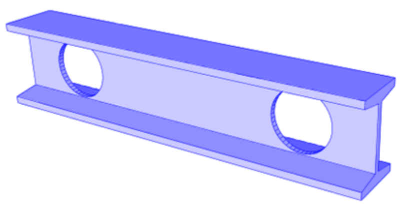
```
Cube
Move
Cube
Move
Cube
Move
Cube
Move
Union
Move
Rotation
```

Conclusion: Exclude Method II

II. Selection of Methods for Description

Criteria #03: Exclude descriptions which are using same transactions and methods

Example: Descriptions of Dodecagonal Prism with Cuts



I.

```
Arbitrary
Tube
Rotation
Move
Subtraction
Rotation
Move
Subtraction
Move (Z)
Rotation
```

II.

```
Symmetric
Tube
Rotation
Move
Subtraction
Rotation
Move
Subtraction
Move (Z)
Rotation
```

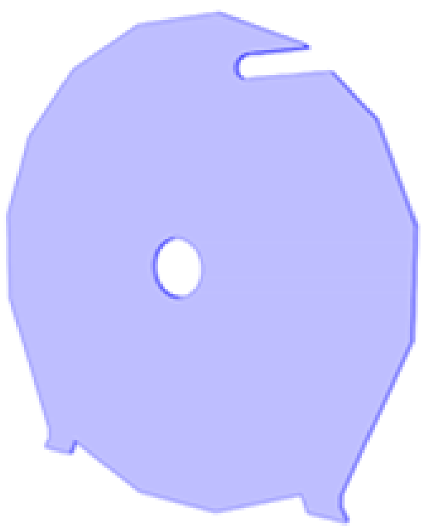
Conclusion: Either I or II should be excluded

II. Selection of Methods for Description

Criteria #04: Exclude descriptions with same consequence of methods

Example: Descriptions of Icositetrahedronal prism with cuts

Icositetrahedronal Prism with Cuts



I.	II.
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

Conclusion: Either I or II should be excluded

II. Selection of Methods for Description

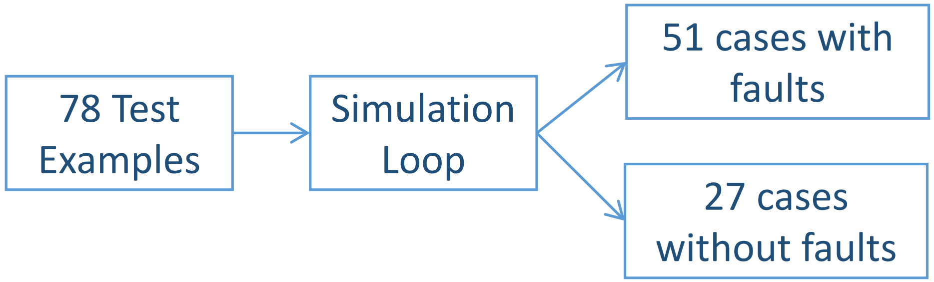
- Total number of methods has been analysed and just unique cases of descriptions were selected:

Before Separation	After Separation
1st class of 22 objects: 4’460 methods	*1st class* of 22 objects: 11 methods
2nd class of 22 objects: 4’636 methods	*2nd class* of 22 objects: 29 methods
3rd class of 33 objects: 6’579 methods	*3rd class* of 33 objects: 38 methods
Total: **15’675** methods	Total: **78** methods

Conclusion: 78 unique examples have been formed for the investigation of quality of geometry transformations doing by simulation software.

Part III. Test Runs

III. Test Runs



#	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		
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	Inaccuracies on the X and Y Z axes
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		
43	43	No	
44	44	Yes	Maximal Inaccuracy 0.01 mm
45	45	Yes	Maximal Inaccuracy 0.01 mm
46	46		
47	47	No	
48	48	No	
49	49		
50	50	No	
51	51	Yes	Maximal Inaccuracy 1.05 mm
52	52	No	
53	53	No	
54			
55	54	No	
56	55	Yes	Maximal Inaccuracy 0.08 mm
57	56	Yes	Maximal Inaccuracy 0.03 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	

T1: XML->GeoMODEL transformation : 43 cases

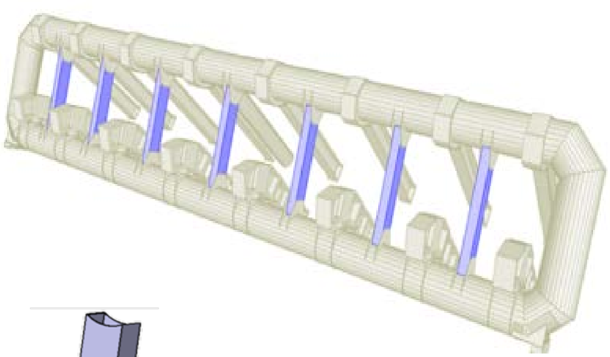
T2: GeoMODEL->GEANT-4 transformation : 8 cases

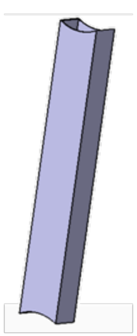
Part IV. Case Study of Transactions

IV. Case Study of Transactions

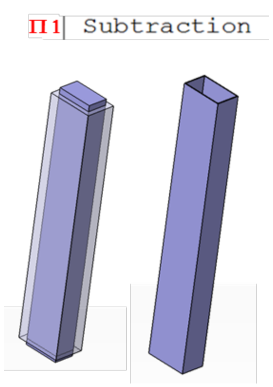
- Further investigations have done in order to understand reasons which caused inaccurateness
- Geometry transactions *move/rotation* and *Boolean* operations were considered separately and together to discover any kind of correlations between them

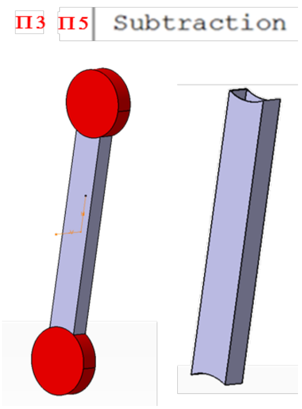
<u>*Example:*</u> Case study of transactions for Tube with cuts

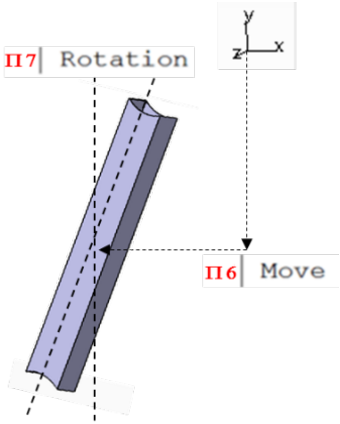




Cube
Cube
Π1 Subtraction
Tube
Π2 Move
Π3 Subtraction
Π4 Move
Π5 Subtraction
Π6 Move
Π7 Rotation

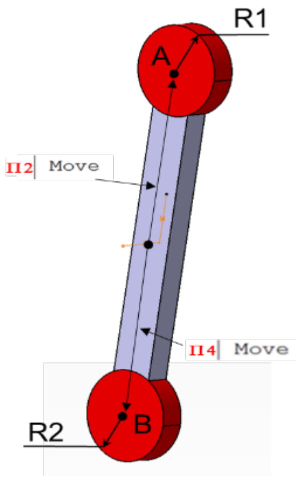


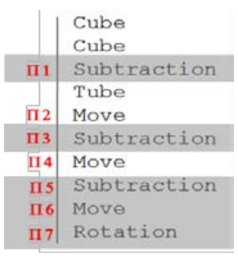




IV. Case Study of Transactions

<u>Sub-Case #01:</u> П2/П4 movement of A and B center points of auxiliary tubes along Y axis from origin

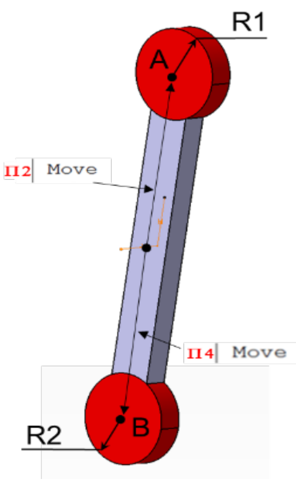


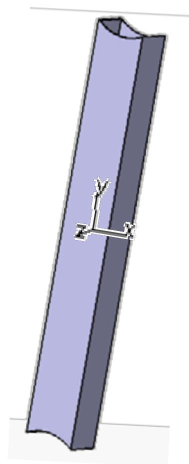


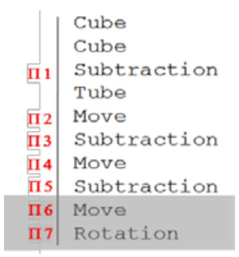
```
<gvxy name="Box1" material="Aluminium" dZ="290.">
    <gvxy_point X_Y="-250.; -8947."/>
    <gvxy_point X_Y="-250.; -5707."/>
    <gvxy_point X_Y="250.; -5707."/>
    <gvxy_point X_Y="250.; -8947."/>
</gvxy>

<gvxy name="Box2" material="Aluminium" dZ="270.">
    <gvxy_point X_Y="-240.; -8977."/>
    <gvxy_point X_Y="-240.; -5677."/>
    <gvxy_point X_Y="240.; -5677."/>
    <gvxy_point X_Y="240.; -8977."/>
</gvxy>

<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<composition name="TestExampleN25" >
   <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. ; -5227. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -9427. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</composition>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN25" X_Y_Z=" 0. ; 0. ; 0." rot=" 0.; 0.; 0. " />
</composition>
```

<u>Results:</u> There are no inaccuracies

Sub-Case #02: Π2/Π4 movement together with Boolean subtractions







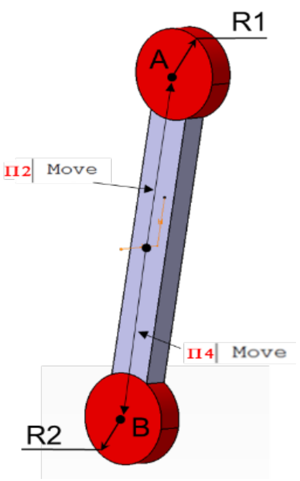

```
<gvxy name="Box1" material="Aluminium" dZ="290.">
    <gvxy_point X_Y="-250.; -8947."/>
    <gvxy_point X_Y="-250.; -5707."/>
    <gvxy_point X_Y="250.; -5707."/>
    <gvxy_point X_Y="250.; -8947."/>
</gvxy>

<gvxy name="Box2" material="Aluminium" dZ="270.">
    <gvxy_point X_Y="-240.; -8977."/>
    <gvxy_point X_Y="-240.; -5677."/>
    <gvxy_point X_Y="240.; -5677."/>
    <gvxy_point X_Y="240.; -8977."/>
</gvxy>

<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN25" >
   <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. ; -5227. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -9427. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN25" X_Y_Z=" 0. ; 0. ; 0.." rot=" 0.; 0.; 0. " />
</composition>
```

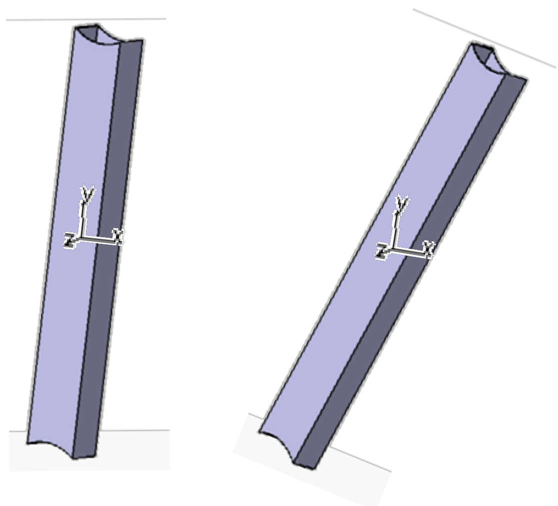
Results:

		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
B	*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
Volume		-0.0005	0.0004	-0.0001

IV. Case Study of Transactions

Sub-Case #03: Π7 rotation together with Π2/Π4 movement and Π1/Π3 subtractions





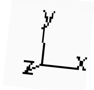

```
    Cube
    Cube
Π1  Subtraction
    Tube
Π2  Move
Π3  Subtraction
Π4  Move
Π5  Subtraction
Π6  Move
Π7  Rotation
```

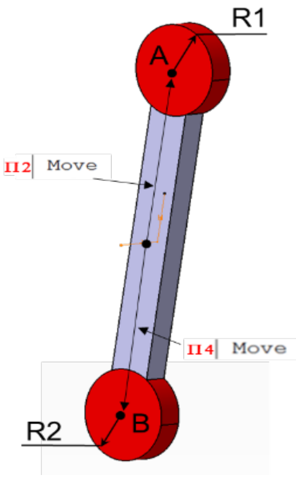

```
<gvxy name="Box1" material="Aluminium" dZ="290.">
    <gvxy_point X_Y="-250.; -8947."/>
    <gvxy_point X_Y="-250.; -5707."/>
    <gvxy_point X_Y="250.; -5707."/>
    <gvxy_point X_Y="250.; -8947."/>
</gvxy>

<gvxy name="Box2" material="Aluminium" dZ="270.">
    <gvxy_point X_Y="-240.; -8977."/>
    <gvxy_point X_Y="-240.; -5677."/>
    <gvxy_point X_Y="240.; -5677."/>
    <gvxy_point X_Y="240.; -8977."/>
</gvxy>

<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN25" >
   <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. ; -5227. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -9427. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN25" X_Y_Z=" 0. ; 0. ; 0." rot=" 0.; 0.; -22.5 " />
</composition>
```

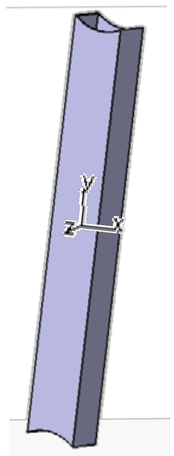

Results:

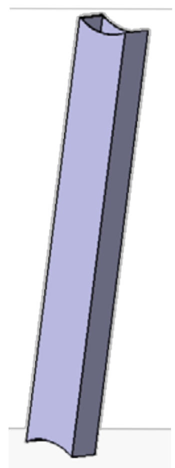
		GeoM Δ_1	G-4 Δ_2	Total Δ
A	*x*	0.05	0.09	0.14
	y	0.01	0.23	0.24
	z	0	0	0
B	*x*	0.01	0.01	0.02
	y	-0.03	0.02	-0.01
	z	0	0	0
	R1	0	-0.24	-0.24
	R2	0	0.02	0.02
Volume				-0.0001

Sub-Case #04: Π6 movement together with Π2/Π4 and Π1/Π3 subtraction









Cube
Cube
Π1 Subtraction
Tube
Π2 Move
Π3 Subtraction
Π4 Move
Π5 Subtraction
Π6 Move
Π7 Rotation

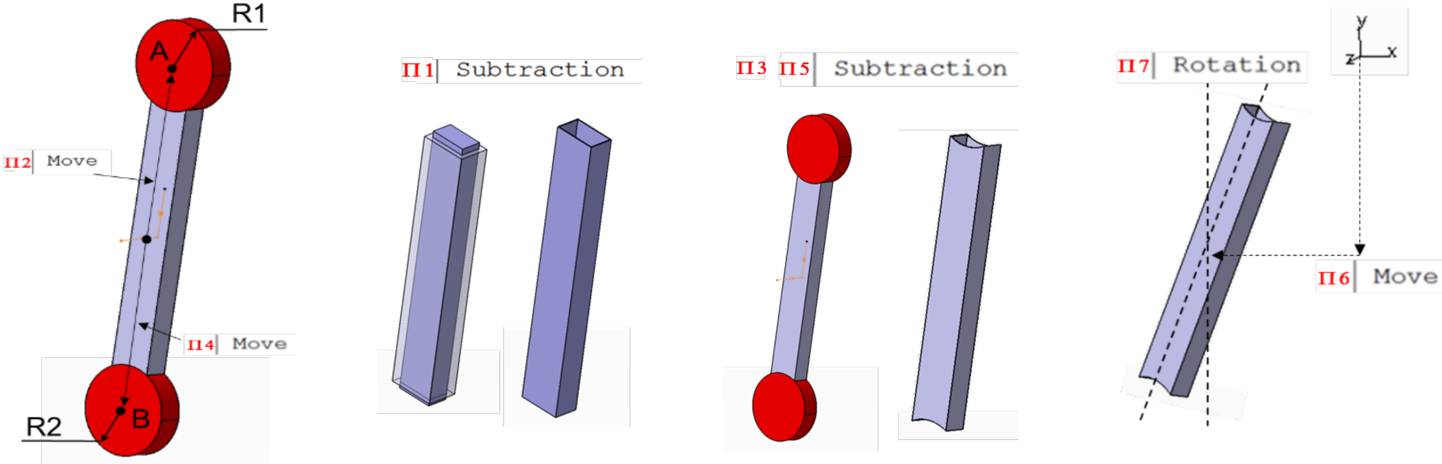
```
<gvxy name="Box1" material="Aluminium" dZ="290.">
    <gvxy_point X_Y="-250.; -8947."/>
    <gvxy_point X_Y="-250.; -5707."/>
    <gvxy_point X_Y="250.; -5707."/>
    <gvxy_point X_Y="250.; -8947."/>
</gvxy>

<gvxy name="Box2" material="Aluminium" dZ="270.">
    <gvxy_point X_Y="-240.; -8977."/>
    <gvxy_point X_Y="-240.; -5677."/>
    <gvxy_point X_Y="240.; -5677."/>
    <gvxy_point X_Y="240.; -8977."/>
</gvxy>

<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN25" >
   <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. ; -5227. ; 0. "  rot=" 0. ; 0. ; 0. "/>
   <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -9427. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
  <posXYZ  volume="TestExampleN25" X_Y_Z=" 0. ; 0. ; 9540." rot=" 0.; 0.; 0. " />
</composition>
```

Results:

		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
B	*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
Volume				-0.0001

IV. Case Study of Transactions

Sub-Case #05: П6 movement together with П2/П4 ; П1/П3 subtractions and П7 rotation



- Cube
- Cube
- П1 Subtraction
- Tube
- П2 Move
- П3 Subtraction
- П4 Move
- П5 Subtraction
- П6 Move
- П7 Rotation

```
<gvxy name="Box1" material="Aluminium" dZ="290.">
    <gvxy_point X_Y="-250.; -8947."/>
    <gvxy_point X_Y="-250.; -5707."/>
    <gvxy_point X_Y="250.; -5707."/>
    <gvxy_point X_Y="250.; -8947."/>
</gvxy>

<gvxy name="Box2" material="Aluminium" dZ="270.">
    <gvxy_point X_Y="-240.; -8977."/>
    <gvxy_point X_Y="-240.; -5677."/>
    <gvxy_point X_Y="240.; -5677."/>
    <gvxy_point X_Y="240.; -8977."/>
</gvxy>

<tubs name="Tube1" material="Aluminium" Rio_Z="0.; 544.5; 300." nbPhi="32" />

<subtraction name="TestExampleN25" >
  <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. ; -5227. ; 0. "  rot=" 0. ; 0. ; 0. "/>
  <posXYZ  volume="Tube1"  X_Y_Z=" 0. ; -9427. ; 0. "  rot=" 0. ; 0. ; 0. "/>
</subtraction>

<composition  name="ECT_Toroids" >
 <posXYZ  volume="TestExampleN25" X_Y_Z=" 0. ; 0. ; 9540." rot=" 0.; 0.; 0. " />
</composition>
```

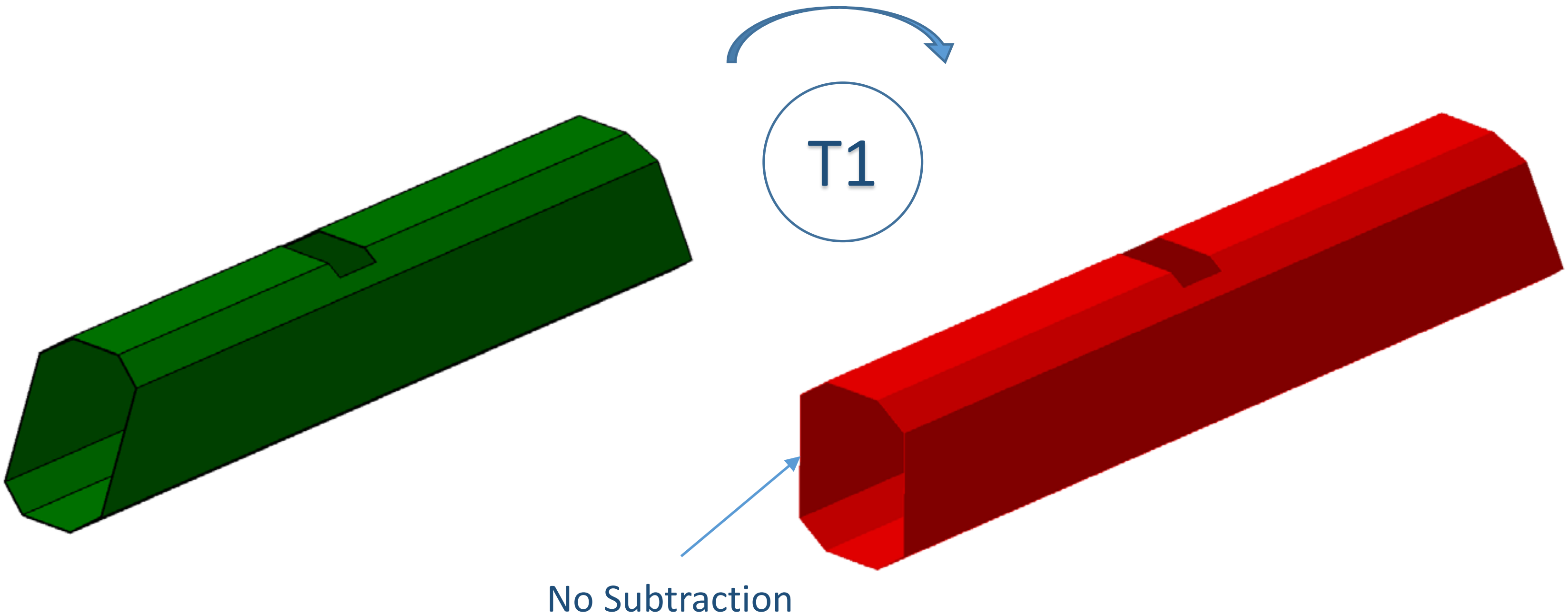
Results:

		GeoM Δ_1	G-4 Δ_2	Total Δ
A	*x*	0.03	0	0.03
	y	0	-0.02	-0.02
	z	0	0	0
B	*x*			0.02
	y			0
	z			0
	R1	-0.01	0.18	0.17
	R2			-0.03
Volume		-0.0005	0.0004	-0.0001

IV. Case Study of Transactions

- Direct Faults have been detected

Example: GeoMODEL Boolean Subtraction failure



Part V. Systematization and Learning of Results

V. Systematization and Learning of Results

	Ex. №	Geometric Primitives										Transactions					CATIA vs GeoModel (VP1)						CATIA vs Geant4					
							GeoModel																					
		Cube	Tube	Pyr	Trap.	Cone	PolyC.	PolyG.	Arbitr.	Sym.	Dsym	M	R	Subt.	M	R	M	R	Subtr.	M	R	Conf	M	R	Subt	M	R	Conf
1	1			3X								5X	4X	5X	X	X	0	0	ΔX=0.25 ΔY=-0.15 Δ_V=0.0014	ΔX=-0.02 ΔY=0.01	ΔX=0.07 ΔY=-0.18		0	0	ΔX=0.25 ΔY=-0.15 Δ_V=0.0014	ΔX=-0.02 ΔY=0.01	ΔX=0.06 ΔY=-0.17	
2	2	2X										2X	X	2X	X	X	0	0	ΔY=0.01 ΔZ=-0.02	0	ΔX=0.01		0	0	ΔY=0.01 ΔZ=-0.02	ΔZ=0.03	ΔX=-0.01 ΔY=-0.02	
3	4	X							X					X	X	X			ΔX=-0.03 ΔY=-0.02	0	ΔX=0.02 ΔY=-0.02 ΔZ=-0.02				ΔX=-0.03 ΔY=-0.02	0	ΔX=0.02 ΔY=-0.02	
4	6	2X										X		X	X	X	0		ΔX=-0.23 ΔZ=-0.13 ΔV=0.0002	0	ΔX=0.03 ΔY=0.1 ΔZ=0.01		0		ΔX=-0.23 ΔZ=-0.13 ΔV=0.0002	ΔZ=0.03	ΔX=0.03 ΔY=0.1 ΔZ=0.01	
5	7	X							X					2X	X	X			ΔX=-0.07 ΔY=-0.05	ΔX=0.01 ΔY=0.05	ΔX=-0.02 ΔY=0.09				ΔX=-0.07 ΔY=-0.05	ΔX=0.01 ΔY=0.05	ΔX=0.04 ΔY=0.09	
6	8	2X										X	X	X	X	X	0	0	ΔZ=-0.01	0	0		0	0	ΔZ=-0.01	0	0	
7	9								2X			2X		2X	X	X	0		0	0	ΔX=-0.01		0		0	0	0	
8	10	3X										4X		4X	X	X	0		ΔX=0.03 ΔY=0.03	ΔX=0.03 ΔY=0.03	ΔX=-0.04 ΔY=-0.02		0		ΔX=0.03 ΔY=0.03	ΔX=0.03 ΔY=0.03	ΔX=-0.04 ΔY=-0.02	
9	11	2X												X	X	X			ΔY=-0.09 ΔZ=-0.06	0	ΔX=0.03 ΔY=0.01				ΔY=-0.09 ΔZ=-0.06	ΔY=-0.01 ΔZ=-0.01	ΔX=0.03 ΔY=0.02	
10	12								2X					X	X	X			ΔX=-0.09 ΔY=-0.06	ΔY=-0.02	ΔX=0.03 ΔY=0.01				ΔX=-0.09 ΔY=-0.06	ΔY=-0.03	ΔX=0.03 ΔY=0.02	
11	13	X	X							X		X		2X	X	X	0		ΔX=0.01 Δ_V=0.0002	ΔX=-0.03 ΔY=-0.02	ΔX=-0.01 ΔY=0.02		0		ΔX=0.01 Δ_V=0.0002	ΔX=0.03 ΔY=-0.03	ΔX=-0.01 ΔY=0.03	
12	14	X	X						X			2X		2X	X	X	0		ΔX=-0.03 ΔY=-0.02 Δ_V=0.0002	0	ΔX=-0.01 ΔY=0.02		0		ΔX=-0.03 ΔY=-0.02 Δ_V=0.0002	0	ΔX=-0.01 ΔY=0.03	
13	15	X		X								X		X	X	X	0		0	0	ΔX=0.01		0		0	0	ΔX=0.01 ΔY=-0.01	
14	16		X						X			X		X	X	X	0		ΔX=-0.03 ΔY=-0.02	0	ΔX=-0.01 ΔY=0.02		0		ΔX=-0.04 ΔY=-0.03	0	ΔX=-0.01 R=0.01	
15	17		2X									2X	2X	2X	X	X	0	0	ΔX=0.04 ΔY=0.02 ΔV=0.002	ΔX=0.01	ΔX=0.02 ΔY=0.03 R=0.01		0	0	ΔX=0.04 R=0.02 ΔV=0.002	ΔX=0.01 ΔY=0.01 ΔZ=0.01	ΔX=0.02 ΔY=0.03 R=0.05	
16	18		2X						X	X		2X		3X	X		0		ΔX=-0.11 ΔY=0.19 Δ_V=0.0003	0			0		ΔX=-0.11 ΔY=0.19 R=0.01 Δ_V=0.0003	ΔX=-0.07 ΔY=-0.04 R=0.08		

V. Systematization and Learning of Results

		Geometric Primitives										Transactions					CATIA vs GeoModel (VP1)						CATIA vs Geant4					
							GeoModel																					
	Ex. №	Cube	Tube	Pyr	Trap.	Cone	PolyC.	PolyG.	Arbitr.	Sym.	Dsym	M	R	Subt.	M	R	M	R	Subtr.	M	R	Conf	M	R	Subt	M	R	Conf
17	19		2X						X			2X		2X	X	X	0		ΔX=0.06 ΔY=0.04 ΔV=0.0003	0	ΔY=-0.03		0		ΔX=0.06 ΔY=0.01 R=0.03 ΔV=0.0003	ΔX=-0.03 ΔY=-0.04 R=0.05	ΔX=0.04 ΔY=0.06 R=0.09	
18	20		2X	X						X		3X	X	3X	X	X	0	0	ΔX=-0.14 ΔY=-0.08 Δ_v=0.0003	ΔX=0.01 ΔY=0.01	ΔX=-0.03 ΔY=0.06		0	0	ΔX=-0.14 ΔY=-0.08 R=0.03 Δ_v=0.0003	ΔX=0.01 ΔY=-0.04 R=0.03	ΔX=-0.03 ΔY=0.06 R=0.01	
19	22		X						X			X		X	X	X	0		ΔX=-0.03 ΔY=-0.02 Δ_v=0.0001	0	ΔY=0.02		0		ΔX=-0.03 ΔY=-0.02 Δ_v=0.0001	0	ΔY=0.02	
20	23		X	X					2X			X	2X	4X	X	X	0	0	ΔX=0.23 ΔY=-0.09 Δ_v=0.0001	0	ΔX=-0.03 ΔY=-0.09		0	0	ΔX=0.23 ΔY=-0.09 Δ_v=0.0001	0	ΔX=-0.03 ΔY=-0.09	
21	24	X	X									X		X	X	X	0		ΔX=-0.02 ΔY=0.01 ΔZ=-0.01	ΔX=-0.01 ΔY=-0.01 ΔZ=-0.01	ΔX=0.02 ΔY=0.01		0		ΔX=-0.02 ΔY=0.01 ΔZ=-0.01	ΔX=-0.02	ΔX=0.01 ΔY=0.02	
22	25		X						2X			2X		3X	X	X	0		ΔX=0.03 ΔY=0.02 Δ_v=0.0005 R=0.01	0	ΔY=-0.02		0		ΔX=0.03 ΔY=0.21 Δ_v=0.0001 R=0.17	0	ΔY=0.23 R=0.05	
23	26	2X	X									2X		3X	X	X	0		ΔX=0.03 ΔY=0.02	ΔY=-0.02 R=0.01	ΔX=0.02		0		ΔX=0.03 ΔY=0.2 R=0.02	ΔY=-0.01 R=0.02	ΔX=0.07 ΔY=-0.03 R=0.05	
24	27								4X			3X	2X	4X	X	X	0	0	ΔX=0.15 ΔY=-0.22 ΔZ=-0.06	ΔX=0.01 ΔZ=-0.02	ΔX=-0.09 ΔY=0.07		0	0	ΔX=0.15 ΔY=-0.16 ΔZ=0.08	ΔX=0.26 ΔY=0.03 ΔZ=-0.02	ΔX=-0.07 ΔY=-0.04	
25	28	2X									2X	3X	2X	4X	X	X	0	0	ΔX=0.15 ΔY=-0.22 ΔZ=-0.06	ΔX=0.01 ΔZ=-0.02	ΔX=-0.09 ΔY=0.07		0	0	ΔX=0.15 ΔY=-0.16 ΔZ=0.08	ΔX=0.26 ΔY=0.03 ΔZ=-0.02	ΔX=-0.07 ΔY=-0.04	
26	29		X						2X			X	2X	3X	X	X	0	0	ΔX=0.01 ΔY=-0.03 ΔZ=0.01 Δ_v=0.0002	ΔY=-0.01 ΔZ=0.01	ΔX=-0.01 ΔY=0.01 ΔZ=0.01		0	0	ΔX=0.01 ΔY=-0.03 ΔZ=0.01 Δ_v=0.0002	ΔY=0.01 ΔZ=0.03	ΔX=0.01 ΔY=0.03 ΔZ=-0.01	
27	30		X						2X			8X	7X	8X	X	X	0	0	ΔX=0.03 ΔY=-0.03 ΔZ=-0.02 Δ_v=0.0003	ΔY=-0.03 ΔZ=0.03	ΔY=0.01 ΔZ=0.04		0	0	ΔX=0.03 ΔY=-0.03 ΔZ=0.03 Δ_v=0.0003	ΔY=0.03 ΔZ=-0.03 R=0.01	ΔX=0.01 ΔY=-0.03 ΔZ=0.02 R=0.01	

V. Systematization and Learning of of Results

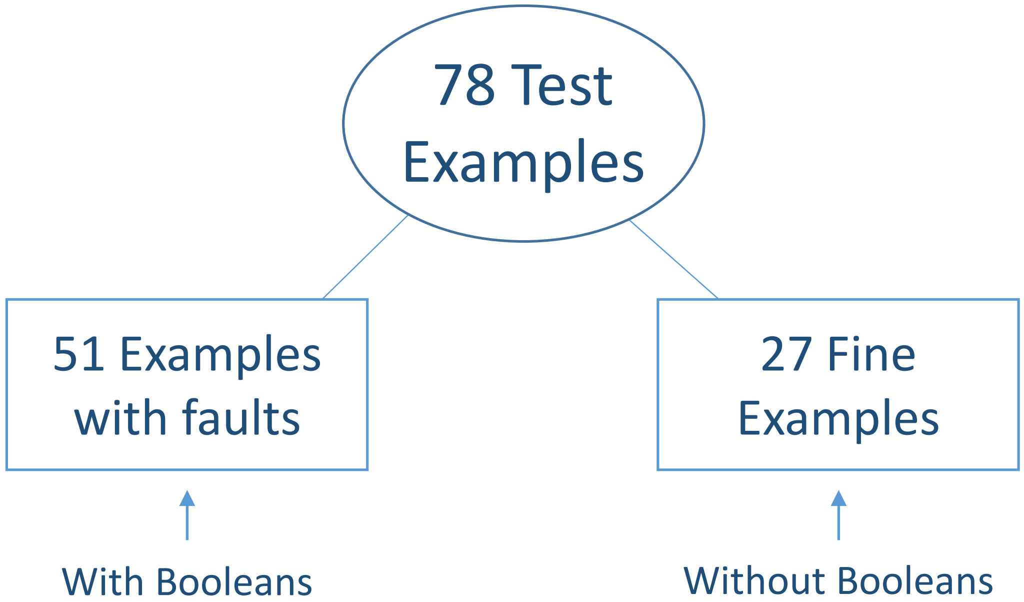
		Geometric Primitives										Transactions					CATIA vs GeoModel (VP1)						CATIA vs Geant4					
							GeoModel																					
	Ex. №	Cube	Tube	Pyr	Trap.	Cone	PolyC.	PolyG.	Arbitr.	Sym.	Dsym	M	R	Subt.	M	R	M	R	Subtr.	M	R	Conf	M	R	Subt	M	R	Conf
28	31		X							X	X	8X	8X	8X	X	X	0	0	ΔX=0.03 ΔY=-0.03 ΔZ=-0.03 Δ_V=0.00031	ΔY=-0.03 ΔZ=0.03	ΔY=0.01 ΔZ=0.04		0	0	ΔX=0.03 ΔY=-0.03 ΔZ=-0.03 Δ_V=0.00031	ΔX=0.02 ΔY=0.03 R=0.01	ΔX=-0.02 ΔY=-0.03 ΔZ=0.03 R=0.01	
29	32					X			3X			7X	5X	7X	X	X	0	0	ΔX=0.03 ΔY=0.03 ΔZ=0.03 Δ_V=0.0016	ΔX=-0.03 ΔZ=-0.02 Δ_V=0.003 3	ΔX=0.01 ΔZ=0.02		0	0	ΔX=-0.05 ΔY=0.03 ΔZ=-0.03 Δ_V=0.0016 R=0.01	ΔX=0.04 ΔY=0.06 ΔZ=-0.05 Δ_V=0.0033 R=0.02	ΔX=0.05 ΔY=-0.08 ΔZ=-0.02 R=0.04	
30	33					X			2X	X		7X	5X	7X	X	X	0	0	ΔX=0.03 ΔY=0.03 ΔZ=0.03 Δ_V=0.0016	ΔX=-0.03 ΔZ=-0.02 Δ_V=0.003 3	ΔX=0.01 ΔZ=0.02		0	0	ΔX=-0.05 ΔY=0.03 ΔZ=-0.03 Δ_V=0.0016 R=0.01	ΔX=0.04 ΔY=0.06 ΔZ=-0.05 Δ_V=0.0033 R=0.02	ΔX=0.05 ΔY=-0.08 ΔZ=-0.02 R=0.04	
31	34		X						X			2X	2X	2X	X	X	0	0	Δ_V=0.0001	0	0		0	0	ΔY=0.01 Δ_V=0.0001	0	0	
32	35		X							X		2X	2X	2X	X	X	0	0	Δ_V=0.0001	0	0		0	0	ΔY=0.01 Δ_V=0.0001	0	0	
33	36		X						X			2X		2X	X	X	0		ΔX=0.02 Δ_V=0.00001	0	ΔX=-0.01 ΔZ=-0.01		0		ΔX=0.02 ΔZ=0.01 Δ_V=0.00007	ΔX=0.02 ΔZ=-0.02 R=0.03	ΔX=-0.17 ΔZ=0.17 R=0.25	
34	37	2X	2X									3X		3X	X	X	0		ΔX=0.01 ΔZ=0.01 Δ_V=0.00007	0	ΔZ=0.02		0		ΔX=0.02 ΔZ=0.01	ΔX=-0.03 ΔZ=0.05 R=0.05	ΔX=-0.16 ΔZ=-0.21 R=0.19	
35	38		2X						X			X		2X	X		0		ΔX=-0.03 ΔY=-0.03 ΔV=0.0009	0			0		ΔX=-0.03 ΔY=-0.03 ΔV=0.0009	0		
36	39	X	2X						X	X		2X		4X	X		0		ΔX=-0.24 ΔY=-0.18 ΔV=0.0009	0			0		ΔX=-0.24 ΔY=-0.18 ΔV=0.0009	0		
37	40								5X				2X	4X	X	X		0	ΔX=0.11 ΔY=0.09 ΔZ=-0.12 Δ_V=0.0004	ΔX=0.01 ΔY=-0.01 ΔZ=0.01	ΔX=0.09 ΔY=0.1			0	ΔX=0.11 ΔY=0.09 ΔZ=-0.12 Δ_V=0.0004	ΔX=0.01 ΔY=0.01 ΔZ=0.01	ΔX=0.09 ΔY=0.1	
38	41	X							4X				3X	4X	X	X		0	ΔX=0.11 ΔY=0.09 ΔZ=-0.12 Δ_V=0.0004	ΔY=0.01	ΔX=0.09 ΔY=0.1			0	ΔX=0.11 ΔY=0.09 ΔZ=-0.12 Δ_V=0.0004	ΔY=0.01	ΔX=0.09 ΔY=0.1	

V. Systematization and Learning of Results

		Geometric Primitives										Transactions					CATIA vs GeoModel (VP1)						CATIA vs Geant4					
							GeoModel																					
	Ex. №	Cube	Tube	Pyr	Trap.	Cone	PolyC.	PolyG.	Arbitr.	Sym.	Dsym	M	R	Subt.	M	R	M	R	Subtr.	M	R	Conf	M	R	Subt	M	R	Conf
39	55	X			X							2X	2X	2X	X	X	0	0	ΔX=0.08 ΔY=0.01	ΔY=0.02	ΔX=-0.01 ΔY=0.02	-	0	0	ΔX=0.08 ΔY=0.01	ΔY=0.02	ΔX=-0.01 ΔY=0.01	-
40	56	2X										3X		3X	X	X	0		ΔX=0.03 ΔY=0.02	0	ΔX=0.01	-	0		ΔX=0.03 ΔY=0.02	0	0	-
41	57		2X									2X	2X	X	X	X	0	0	ΔX=0.04 ΔY=0.02 ΔV=0.002	ΔX=0.01	ΔX=0.02 ΔY=0.03 R=0.01		0	0	ΔX=0.04 R=0.02 ΔV=0.002	ΔX=0.01 ΔY=0.01 ΔZ=0.01	ΔX=0.02 ΔY=0.03 R=0.05	-
42	58	2X	X									X		2X	2X	X	0		ΔX=0.03 ΔY=0.02	ΔY=-0.02 R=0.01	ΔX=0.02		0		ΔX=0.03 ΔY=0.2 R=0.02	ΔY=-0.01 R=0.02	ΔX=0.07 ΔY=-0.03 R=0.05	-
43	59	2X	X									X		2X	2X	X	0		ΔX=0.03 ΔY=0.02 Δ_V=0.0005 R=0.01	0	ΔY=-0.02		0		ΔX=0.03 ΔY=0.21 Δ_V=0.0001 R=0.17	0	ΔY=0.23 R=0.05	-
44	60	X									2X	X	X	2X	2X	2X	0	0	ΔX=0.15 ΔY=-0.22 ΔZ=-0.06	ΔX=0.01 ΔZ=-0.02	ΔX=-0.09 ΔY=0.07		0	0	ΔX=0.15 ΔY=-0.16 ΔZ=0.08	ΔX=0.26 ΔY=0.03 ΔZ=-0.02	ΔX=-0.07 ΔY=-0.04	-
45	61								3X			X	X	2X	2X	2X	0	0	ΔX=0.15 ΔY=-0.22 ΔZ=-0.06	ΔX=0.01 ΔZ=-0.02	ΔX=-0.09 ΔY=0.07		0	0	ΔX=0.15 ΔY=-0.16 ΔZ=0.08	ΔX=0.26 ΔY=0.03 ΔZ=-0.02	ΔX=-0.07 ΔY=-0.04	-
46	63	2X												X	X	X	0		ΔY=-0.09 ΔZ=0.06	ΔZ=0.01	ΔX=0.03 ΔY=0.01	-	0		ΔY=-0.09 ΔZ=0.06	ΔY=-0.01 ΔZ=0.01	ΔX=0.03 ΔY=0.02	-
47	69	X	X									X		X	X		0		ΔX=-0.06 ΔY=-0.05	0		-	0		ΔX=-0.06 ΔY=-0.05	0		-
48	72	X			X							3X	3X	2X	X	X	0	0	ΔX=0.08 ΔY=0.01	ΔY=0.02	ΔX=-0.01 ΔY=0.02	0	0	0	ΔX=0.08 ΔY=0.01	ΔY=0.02	ΔX=-0.01 ΔY=0.01	0
49	74	4X			2X							6X	6X	5X	2X	2X	0	0	ΔX=0.08 ΔY=0.01	ΔY=0.02	ΔX=-0.01 ΔY=0.02	-	0	0	ΔX=0.08 ΔY=0.01	ΔY=0.02	ΔX=-0.01 ΔY=0.01	-
50	75	2X	X									2X		X		X	0		ΔX=-1.34 ΔZ=0.94 Δ_V=0.175		ΔX=-0.47 ΔZ=0.33	Clash= 1.28	0		ΔX=-1.44 ΔZ=-0.9 Δ_V=0.044		ΔZ=-0.09	Clash= 0.91
51	77	X	2X									X	X	X	X	X	0		ΔX=-1.71 ΔZ=-1.25 Δ_V=34.45	0	0	-	0	0	ΔX=-1.75 ΔZ=-1.25 R=0.05 ΔV=34.45	0		-

Postulate #01

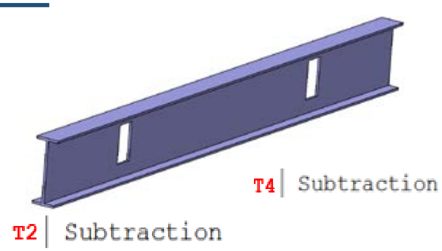
- For all type of detector geometries dimensional, form and positioning faults are caused by *Boolean* operations



Postulate #02

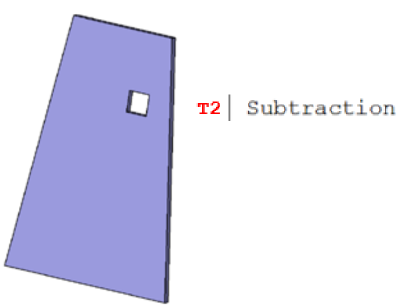
- All internal surfaces received by *Boolean* subtraction of parametrical primitives from Box brings 0 faults

- Test Example #09



	Arbitrary
	Arbitrary
T1	Move
T2	Subtraction
T3	Move
T4	Subtraction
T5	Move (Z)
T6	Rotation

- Test Example #15



	Pyramid
	Cube
T1	Move
T2	Subtraction
T3	Move
T4	Rotation

V. Systematization and Learning of Results

Postulate #03

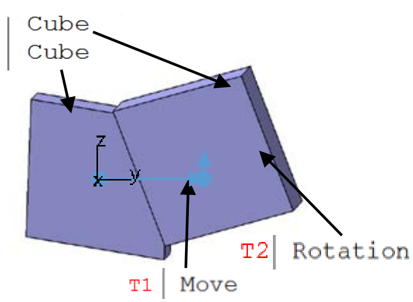
- *Boolean* operations are correlate with *Move* and *Rotate* transactions executing after the *Boolean.* All *Move/Rotate* transactions before *Boolean* are fine

		Geometric Primitives										Transactions					CATIA vs GeoModel (VP1)						CATIA vs Geant4					
							GeoModel																					
	Ex. №	Cube	Tube	Pyr	Trap.	Cone	PolyC.	PolyG.	Arbitr.	Sym.	Dsym	M	R	Subt.	M	R	M	R	Subtr.	M	R	Conf	M	R	Subt	M	R	Conf
1	1			3X								5X	4X	5X	X	X	0	0	ΔX=0.25 ΔY=-0.15 Δ_V=0.0014	ΔX=-0.02 ΔY=0.01	ΔX=0.07 ΔY=-0.18		0	0	ΔX=0.25 ΔY=-0.15 Δ_V=0.0014	ΔX=-0.02 ΔY=0.01	ΔX=0.06 ΔY=-0.17	
2	2	2X										2X	X	2X	X	X	0	0	ΔY=0.01 ΔZ=-0.02	0	ΔX=0.01		0	0	ΔY=0.01 ΔZ=-0.02	ΔZ=0.03	ΔX=-0.01 ΔY=-0.02	
3	4	X							X					X	X	X			ΔX=-0.03 ΔY=-0.02	0	ΔX=0.02 ΔY=-0.02 ΔZ=-0.02				ΔX=-0.03 ΔY=-0.02	0	ΔX=0.02 ΔY=-0.02	
4	6	2X										X		X	X	X	0		ΔX=-0.23 ΔZ=-0.13 ΔV=0.0002	0	ΔX=0.03 ΔY=0.1 ΔZ=0.01		0		ΔX=-0.23 ΔZ=-0.13 ΔV=0.0002	ΔZ=0.03	ΔX=0.03 ΔY=0.1 ΔZ=0.01	
5	7	X							X					2X	X	X			ΔX=-0.07 ΔY=-0.05	ΔX=0.01 ΔY=0.05	ΔX=-0.02 ΔY=0.09				ΔX=-0.07 ΔY=-0.05	ΔX=0.01 ΔY=0.05	ΔX=0.04 ΔY=0.09	
6	8	2X										X	X	X	X	X	0	0	ΔZ=-0.01	0	0		0	0	ΔZ=-0.01	0	0	
7	9								2X			2X		2X	X	X	0		0	0	ΔX=-0.01		0		0	0	0	
8	10	3X										4X		4X	X	X	0		ΔX=0.03 ΔY=0.03	ΔX=0.03 ΔY=0.03	ΔX=-0.04 ΔY=-0.02		0		ΔX=0.03 ΔY=0.03	ΔX=0.03 ΔY=0.03	ΔX=-0.04 ΔY=-0.02	
9	11	2X												X	X	X			ΔY=-0.09 ΔZ=-0.06	0	ΔX=0.03 ΔY=0.01				ΔY=-0.09 ΔZ=-0.06	ΔY=-0.01 ΔZ=-0.01	ΔX=0.03 ΔY=0.02	
10	12								2X					X	X	X			ΔX=-0.09 ΔY=-0.06	ΔY=-0.02	ΔX=0.03 ΔY=0.01				ΔX=-0.09 ΔY=-0.06	ΔY=-0.03	ΔX=0.03 ΔY=0.02	
11	13	X	X							X		X		2X	X	X	0		ΔX=0.01 Δ_V=0.0002	ΔX=-0.03 ΔY=-0.02	ΔX=-0.01 ΔY=0.02		0		ΔX=0.01 Δ_V=0.0002	ΔX=0.03 ΔY=-0.03	ΔX=-0.01 ΔY=0.03	
12	14	X	X						X			2X		2X	X	X	0		ΔX=-0.03 ΔY=-0.02 Δ_V=0.0002	0	ΔX=-0.01 ΔY=0.02		0		ΔX=-0.03 ΔY=-0.02 Δ_V=0.0002	0	ΔX=-0.01 ΔY=0.03	

Postulate #04

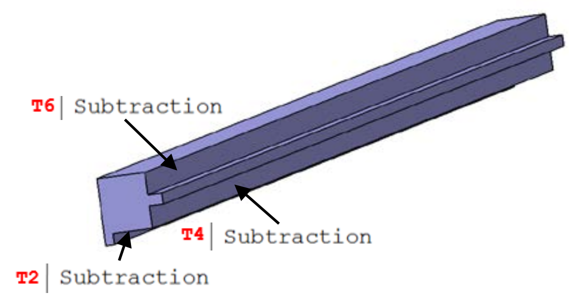
- For all external surfaces created by subtraction of parametrical primitives from Box, *Boolean* operation don't correlated with *Move/Rotation* transactions

- Test Example #08



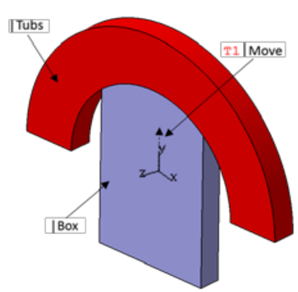
Cube
Cube
T1 Move
T2 Rotation
T3 Subtraction
T4 Move
T5 Rotation

- Test Example #56



Box
Box
T1 Move
T2 Subtraction
T3 Move
T4 Subtraction
T5 Move
T6 Subtraction
T7 Move
T8 Rotation

- Test Example #77



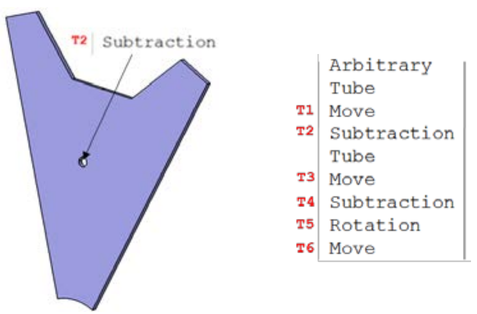
Box
Tubs
T1 Move
T2 Subtraction
T3 Move
T4 Rotation
Tubs
T5 Rotation

V. Systematization and Learning of Results

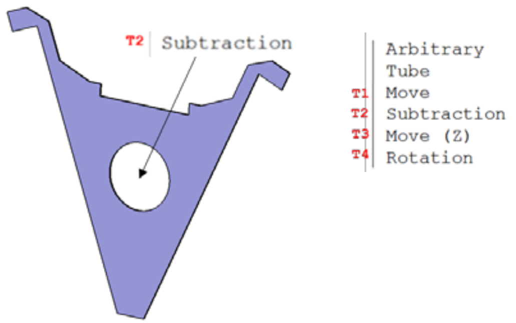
Postulate #05

- For some internal surfaces created by subtraction of parametrical primitives from Polygon methods, *Boolean* operation don’t correlated with *Move* transactions

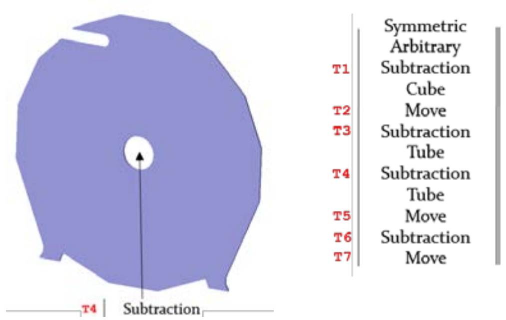
- Test Example #19, #20



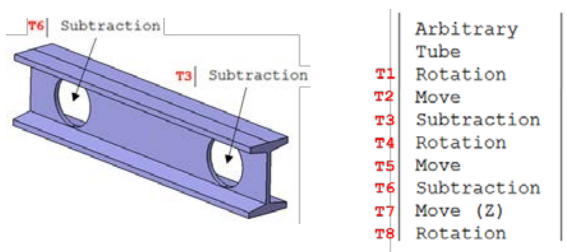
- Test Example #22



- Test Example #38, #39



- Test Example #34, #35

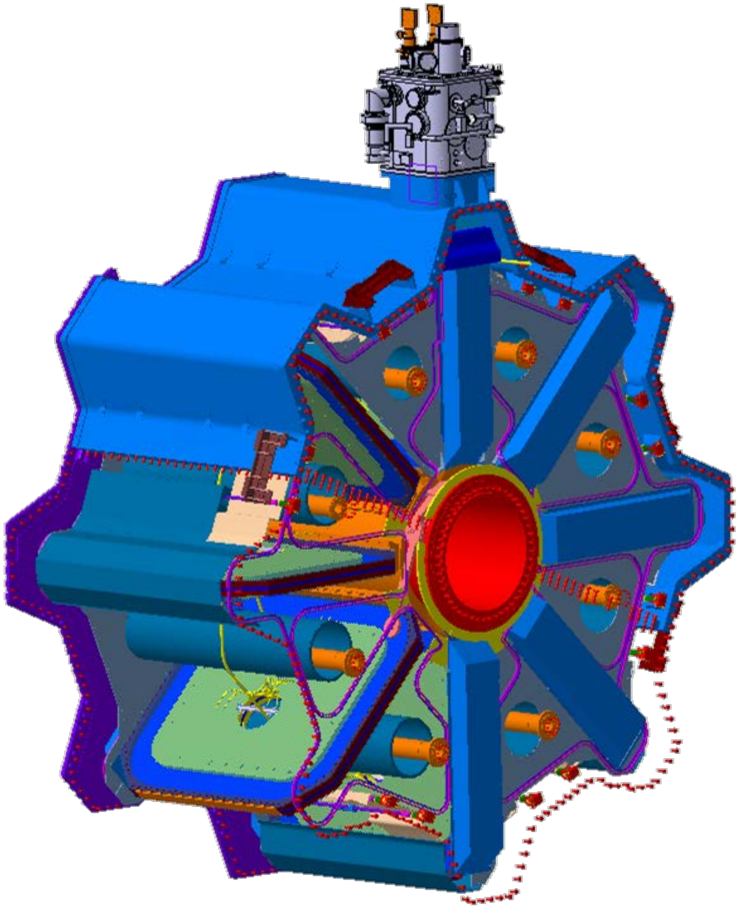


Checking Hypothesis 02:

Investigation of as-built geometry descriptions with geometry descriptions of simulation

ATLAS End-CAP Toroid Study

- ATLAS End-CAP toroid Magnet Assembly is the heaviest component of Detector. Weight is 280t

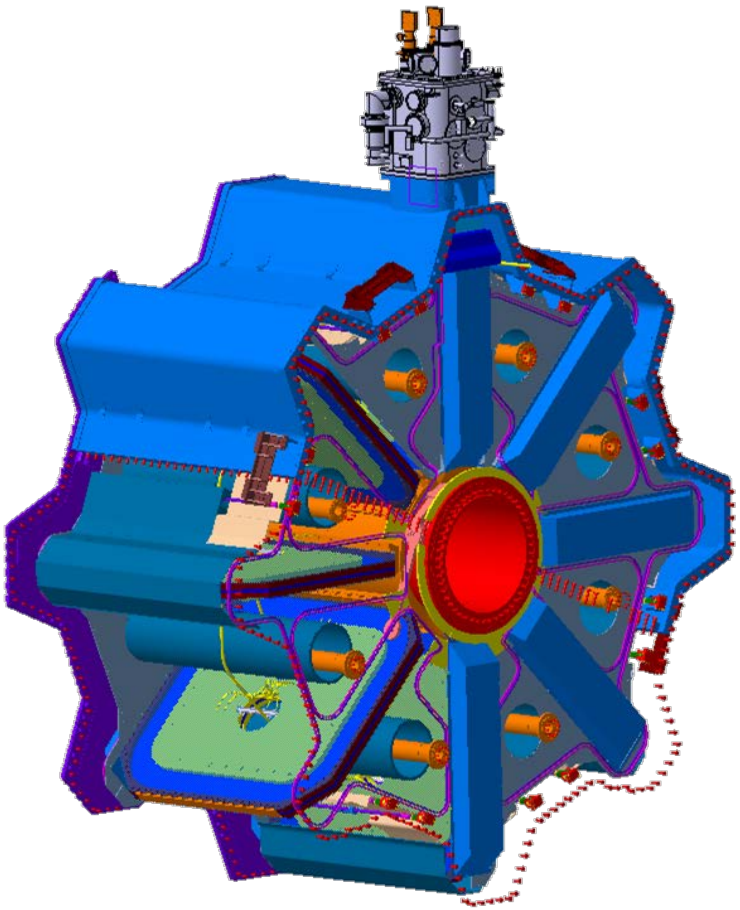


ATLAS End-CAP Toroid Study

Source geometry has been taken from SmarTeam Engineering Database:

Path : ATLAS CURRENT/Detector System/Magnets ATLAS/Toroid Magnets ATLAS/Barrel Toroid Magnet ATLAS/End-cap Toroid Magnet
Model: **ST0268528 ECT assembly side C (id: CAD000628534)**

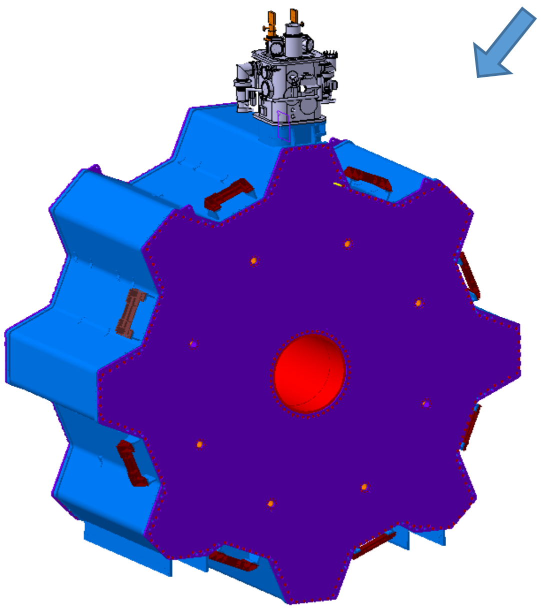
Missing parts have been created from CDD Drawings (902 drawings):

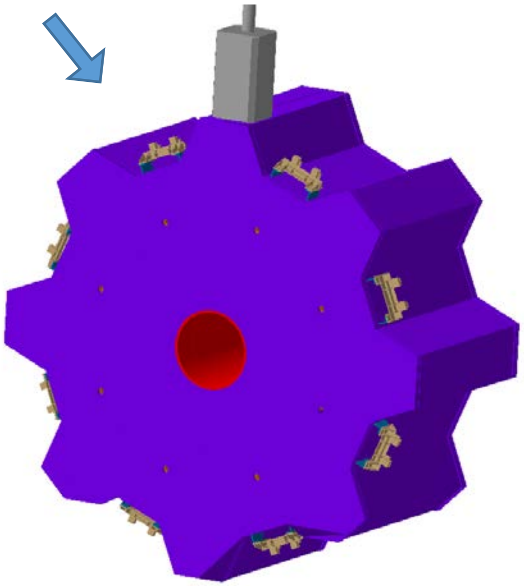


Group	No.	Part	*Drawings Added*
Vacuum vessel	1	Cover	*90*
	2	Shield	*219*
	3	Tie Rods	*64*
	4	Bore Tube	*4*
	5	Turret	*268*
Cold Mass	6	Coil	*4*
	7	Keystone box	*27*
	8	Services	*135*
	9	Supports	*13*
	10	Joke	*12*
	11	Tower	*30*

ATLAS End-CAP Toroid Study

		CATIA	XML	Difference	%
1	Cold Mass	116740 kgs	123012 kgs	+6’272 kgs	5.4 %
2	Thermal Shielding	15988 kgs	15957 kgs	-31 kgs	0.2 %
3	Cover	57966 kgs	57185 kgs	-781 kgs	1.3 %
4	Bore Tube	13433 kgs	10208 kgs	-3’225 kgs	24.0 %
5	Yoke	1820 kgs	1338 kgs	-483 kgs	26.5 %
6	Stay Tube	2028 kgs	2214 kgs	+186 kgs	9.2 %
7	JTV Shielding	4161 kgs	4510 kgs	+349 kgs	8.4 %
8	Turret	2476 kgs	1512 kgs	-964 kgs	38.9 %
9	Tie Rod	3077 kgs	1268 kgs	-1’809 kgs	58.8 %
10	Bolts/	2965 kgs		-2’965 kgs	100.0 %
11	Services	869 kgs		-869 kgs	100.0 %

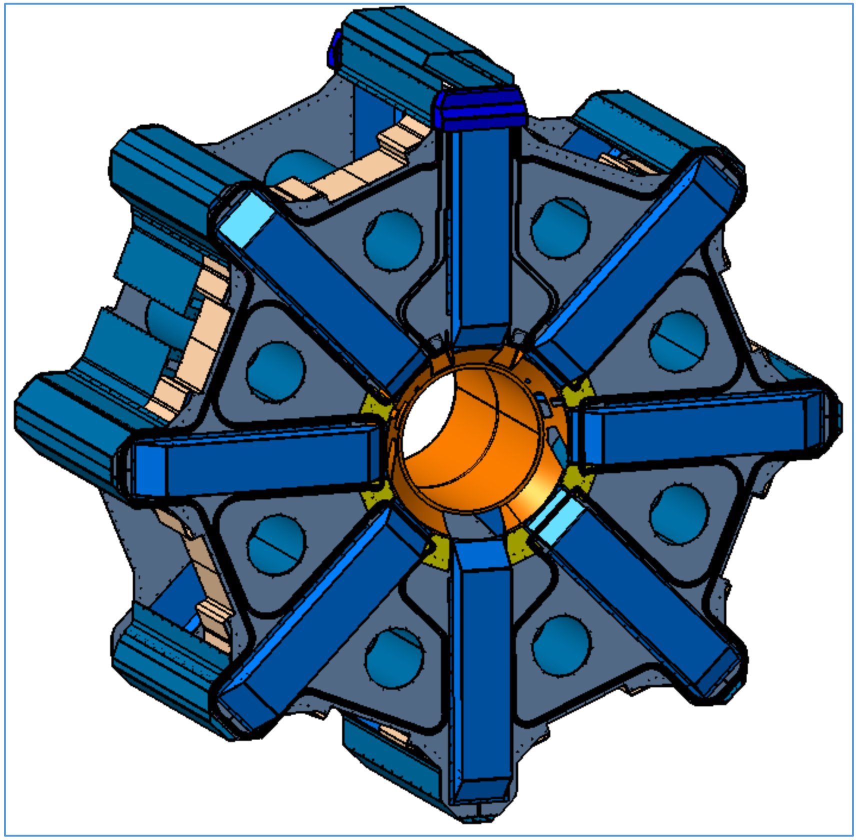




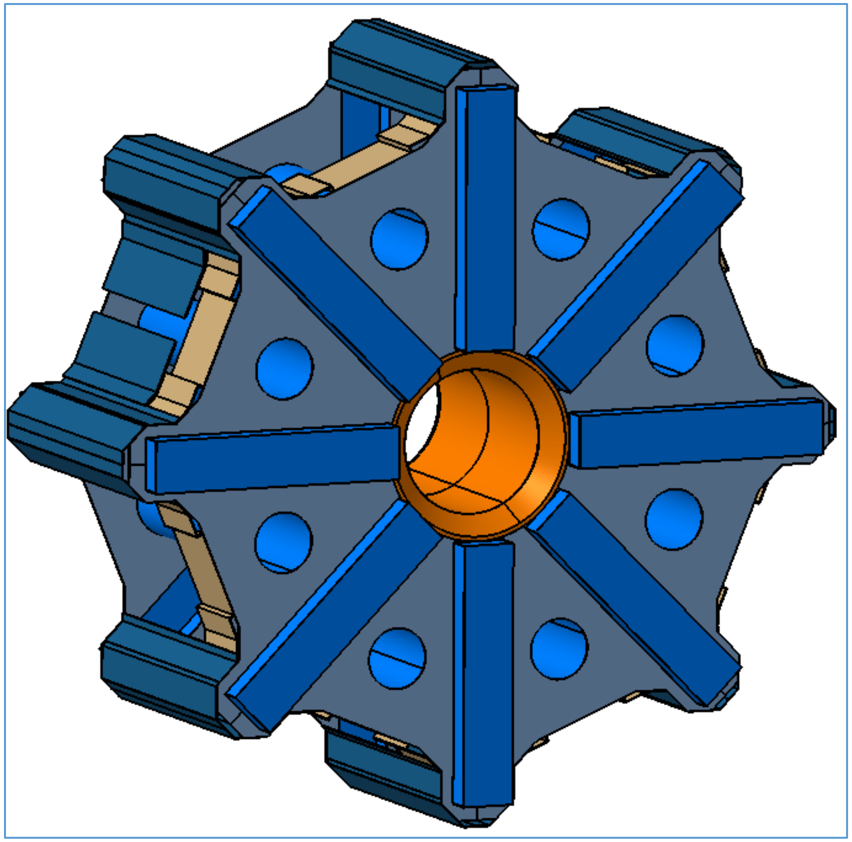
Simplification/Thermal Shielding Assembly

	Detailed	Simplified		Detailed	Simplified		Material	
	Volume/ m³	Volume/ m³	Difference/ m³	Mass/ kgs	Mass/ kgs	Difference/ kgs		Density
Thermal Silding	6,057	6,056	0,001	16`353,9	16`351,2	2,7	Aluminum	2700

Detailed model



Simplifield model



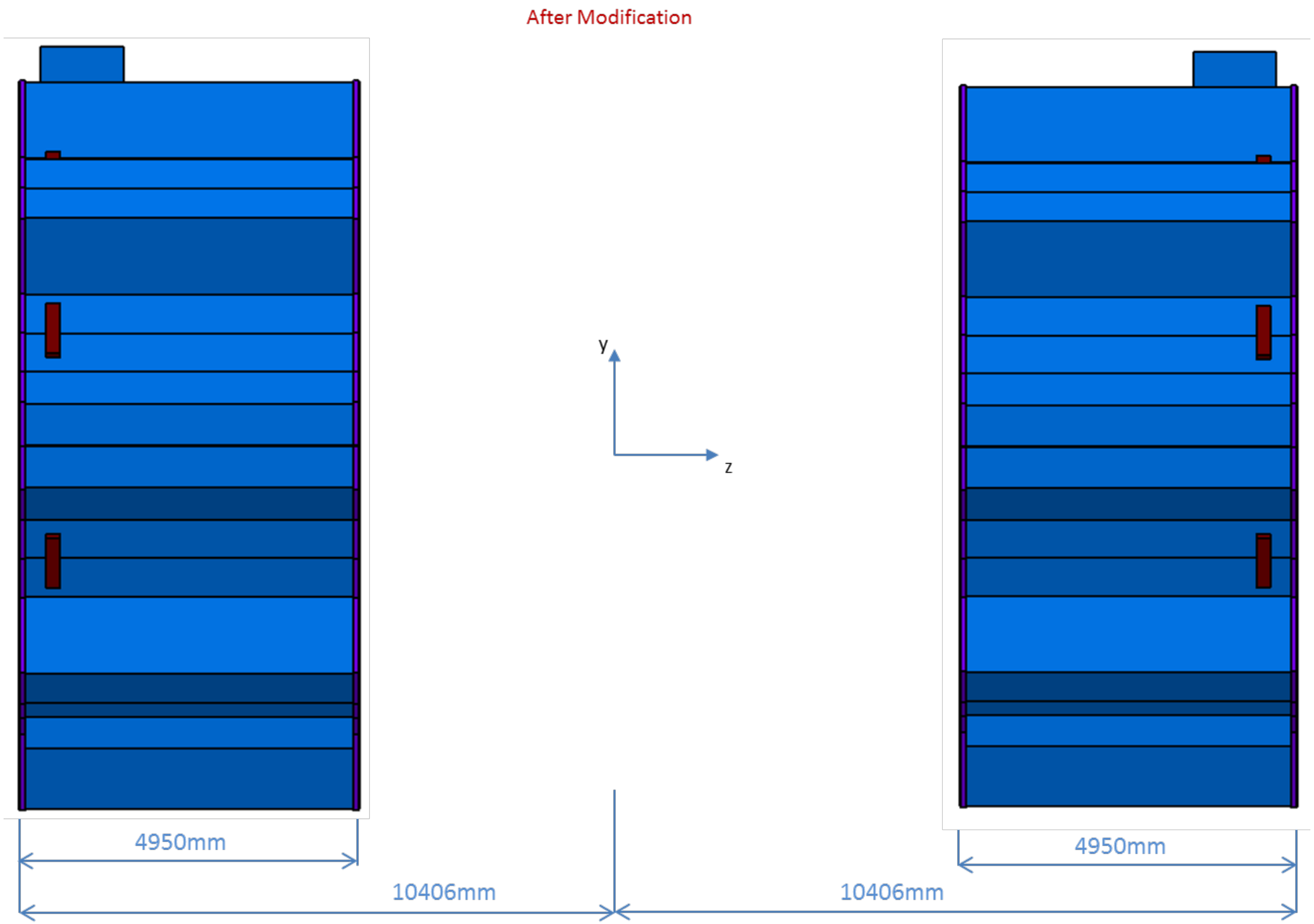
ATLAS End-CAP Toroid Study / Simplification

- Results of Simplification of End-CAT Toroid Assemblies

	Detailed	Simplified		Detailed	Simplified		Material	
	Volume/ m³	Volume/ m³	Difference/ m³	Mass/ kgs	Mass/ kgs	Difference/ kgs		Density
Cold Mass	43,24	43,23	0,01	116`748	116`721	27	Aluminum	2700
Thermal Silding	6,057	6,056	0,001	16`353	16`351	2	Aluminum	2700
Cover	20,8	20,804	-0,004	56`160	56`170,8	-10,8	Aluminum	2700
Brackets	0,22	0,2201	-0,0001	1760	1760,8	-0,8	Steel	8000
BoreTube	1,679	1,678	0,001	13`432	13`424	8	Steel	8000
Yoke	0,231	0,231	0	1848	1848	0	Steel	8000
Stay Tube	0,751	0,751	0	2027,7	2027,7	0	Aluminum	2700
JTV Shilding	1,65	1,649	0,001	4158	4155,48	2,52	Polyboron	2520
Tie Rod	0,393	0,393	0	3144	3144	0	Steel	8000
Bolts/	0,371	0,371	0	2968	2968	0	Steel	8000
Services	0,06	0,06	0	480	480	0	Steel	8000

ATLAS End-CAP Toroid Study / Conflicts Checking

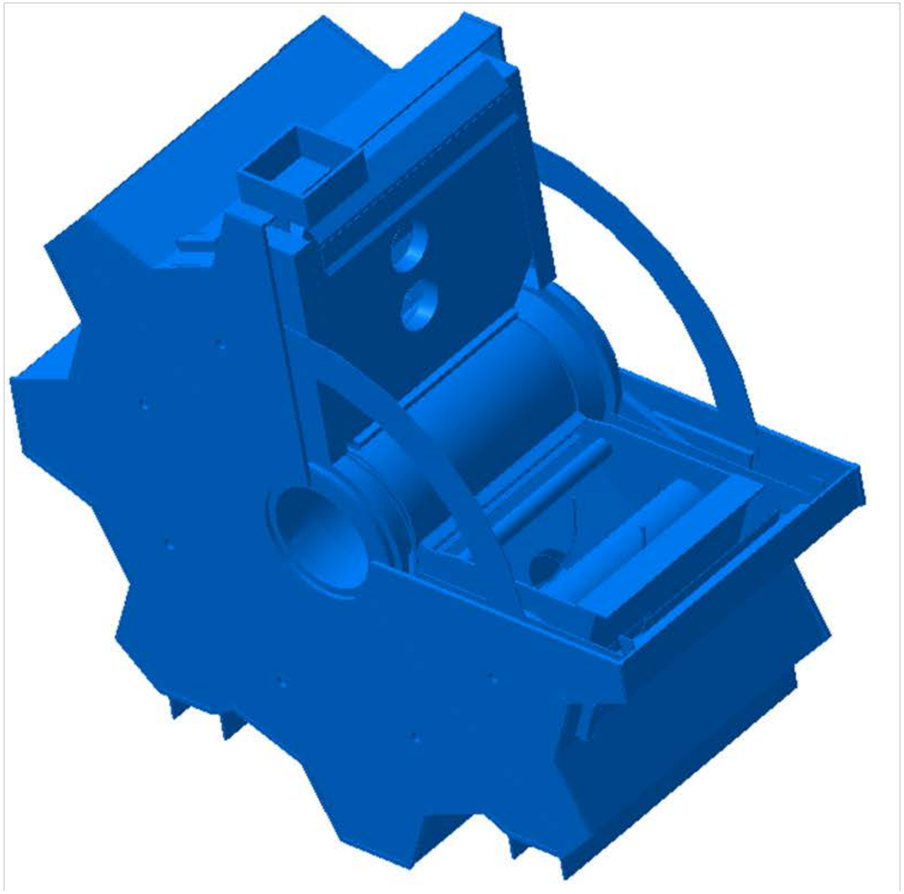
- ECT Cover *as-built* model



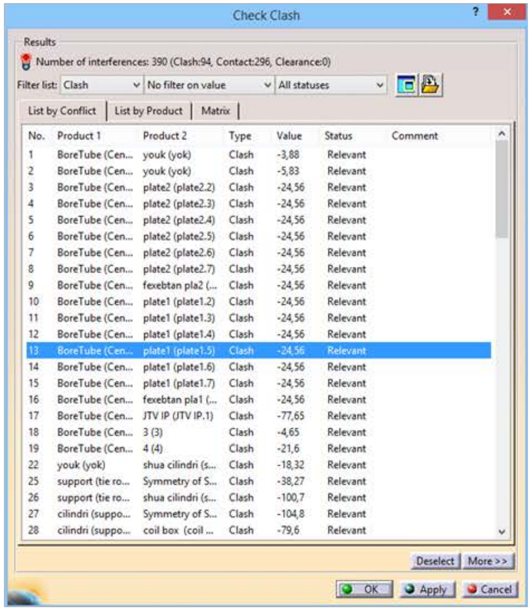
ATLAS End-CAP Toroid Study / Conflicts Checking

- Internal Conflicts of ECT

ECT After Modification



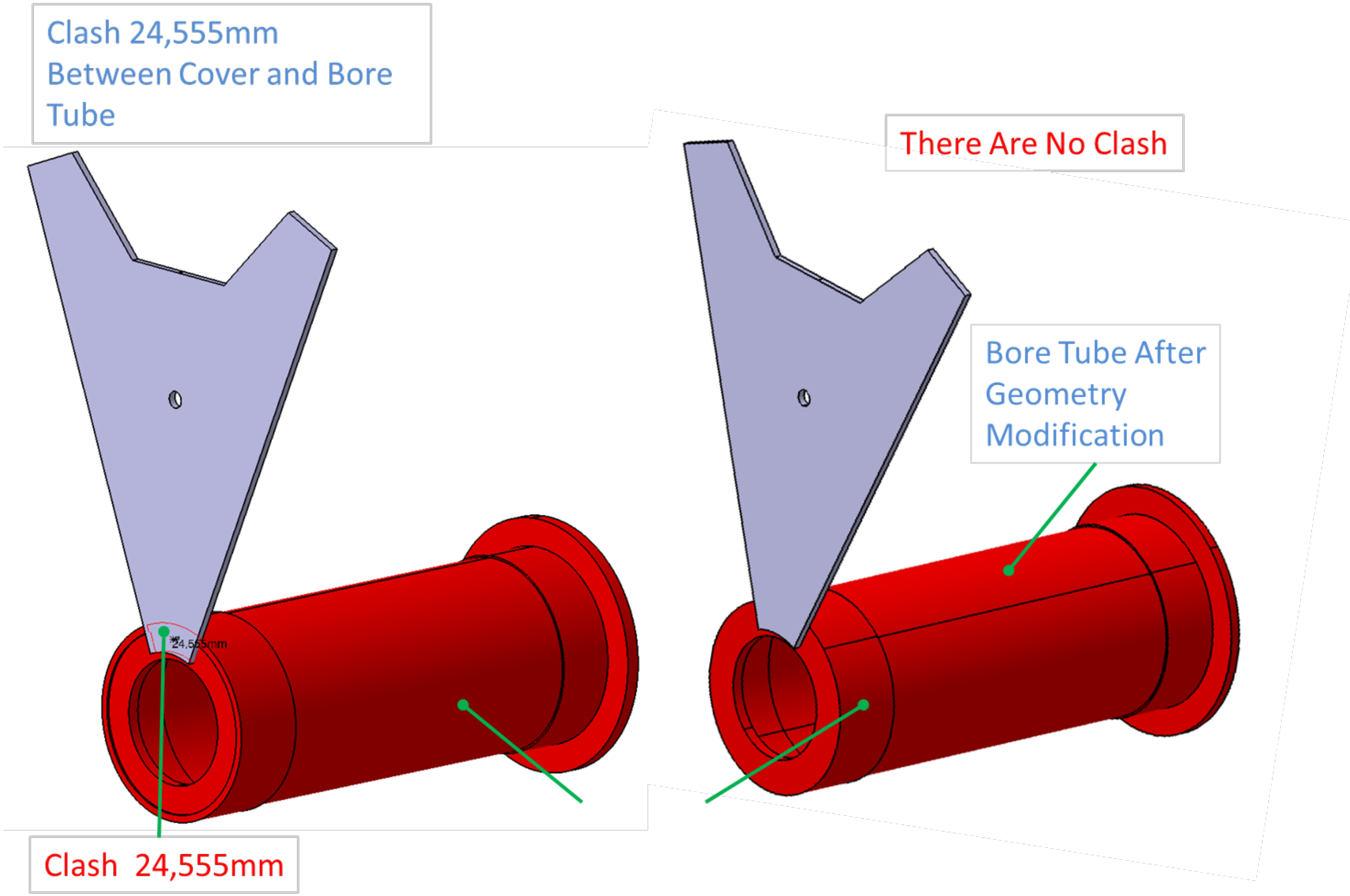
There Was Internal Conflicts



No.	Product 1	Product 2	Type	Value	Status	Comment
1	BoreTube (Cen...	youk (yok)	Clash	-3,88	Relevant	
2	BoreTube (Cen...	youk (yok)	Clash	-5,83	Relevant	
3	BoreTube (Cen...	plate2 (plate2.2)	Clash	-24,56	Relevant	
4	BoreTube (Cen...	plate2 (plate2.3)	Clash	-24,56	Relevant	
5	BoreTube (Cen...	plate2 (plate2.4)	Clash	-24,56	Relevant	
6	BoreTube (Cen...	plate2 (plate2.5)	Clash	-24,56	Relevant	
7	BoreTube (Cen...	plate2 (plate2.6)	Clash	-24,56	Relevant	
8	BoreTube (Cen...	plate2 (plate2.7)	Clash	-24,56	Relevant	
9	BoreTube (Cen...	fexebtan pla2 (...	Clash	-24,56	Relevant	
10	BoreTube (Cen...	plate1 (plate1.2)	Clash	-24,56	Relevant	
11	BoreTube (Cen...	plate1 (plate1.3)	Clash	-24,56	Relevant	
12	BoreTube (Cen...	plate1 (plate1.4)	Clash	-24,56	Relevant	
13	BoreTube (Cen...	plate1 (plate1.5)	Clash	-24,56	Relevant	
14	BoreTube (Cen...	plate1 (plate1.6)	Clash	-24,56	Relevant	
15	BoreTube (Cen...	plate1 (plate1.7)	Clash	-24,56	Relevant	
16	BoreTube (Cen...	fexebtan pla1 (...	Clash	-24,56	Relevant	
17	BoreTube (Cen...	JTV IP (JTV IP.1)	Clash	-77,65	Relevant	
18	BoreTube (Cen...	3 (3)	Clash	-4,65	Relevant	
19	BoreTube (Cen...	4 (4)	Clash	-21,6	Relevant	
22	youk (yok)	shua cilindri (s...	Clash	-18,32	Relevant	
25	support (tie ro...	Symmetry of S...	Clash	-38,27	Relevant	
26	support (tie ro...	shua cilindri (s...	Clash	-100,7	Relevant	
27	cilindri (suppo...	Symmetry of S...	Clash	-104,8	Relevant	
28	cilindri (suppo...	coil box (coil ...	Clash	-79,6	Relevant	

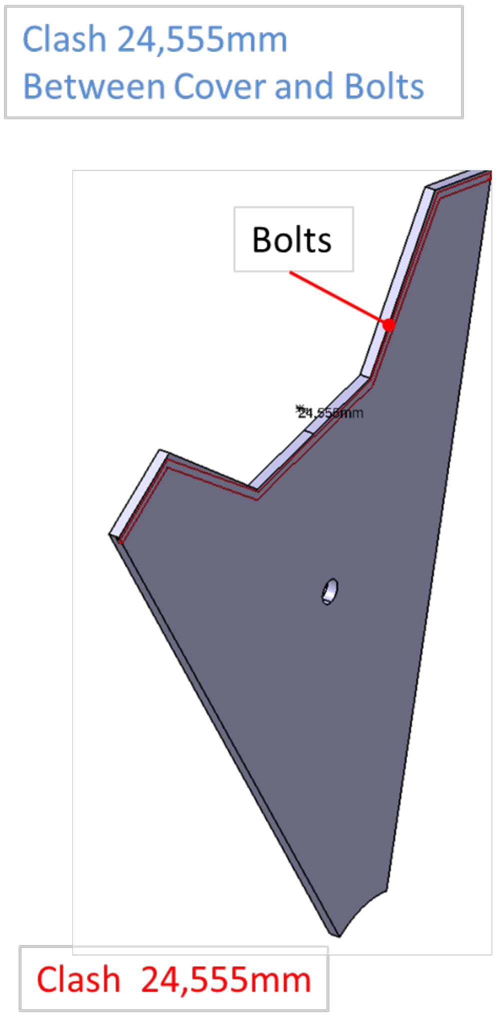
ATLAS End-CAP Toroid Study / Conflicts Checking

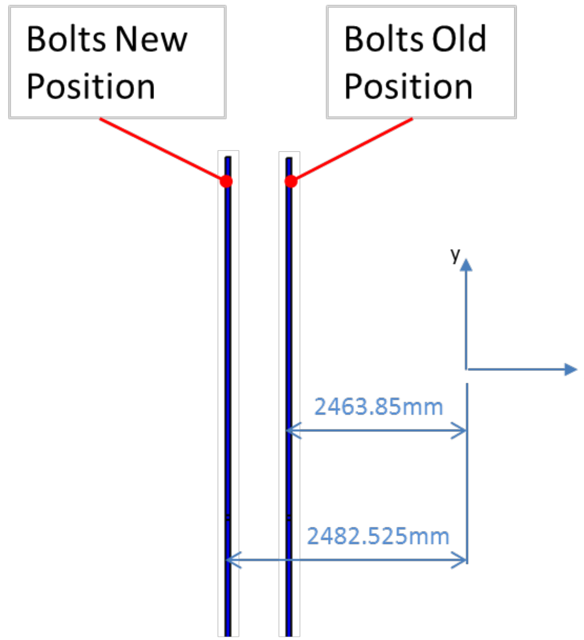
- Internal Conflicts of ECT

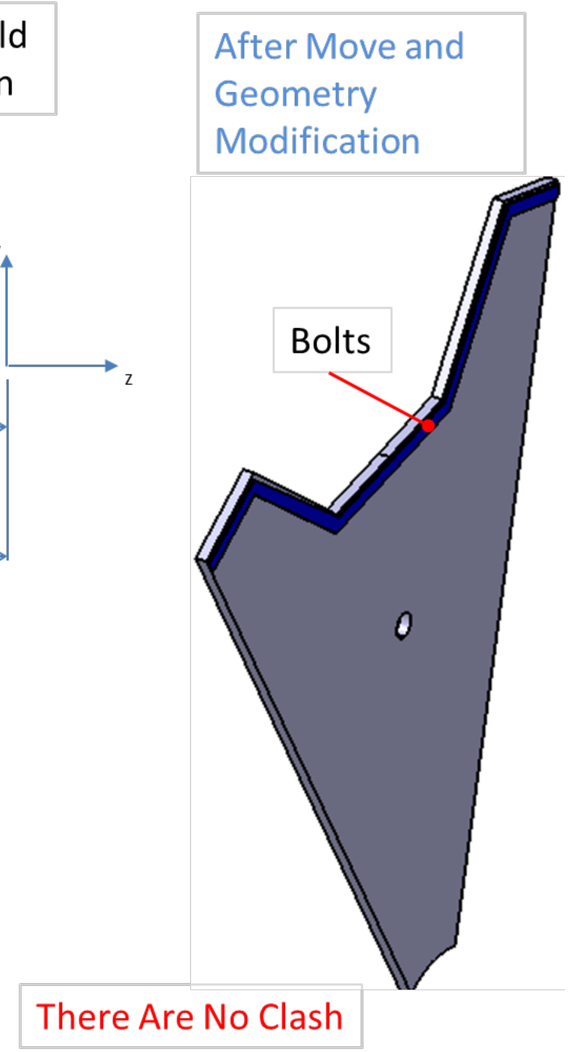


ATLAS End-CAP Toroid Study / Conflicts Checking

- Internal Conflicts of ECT

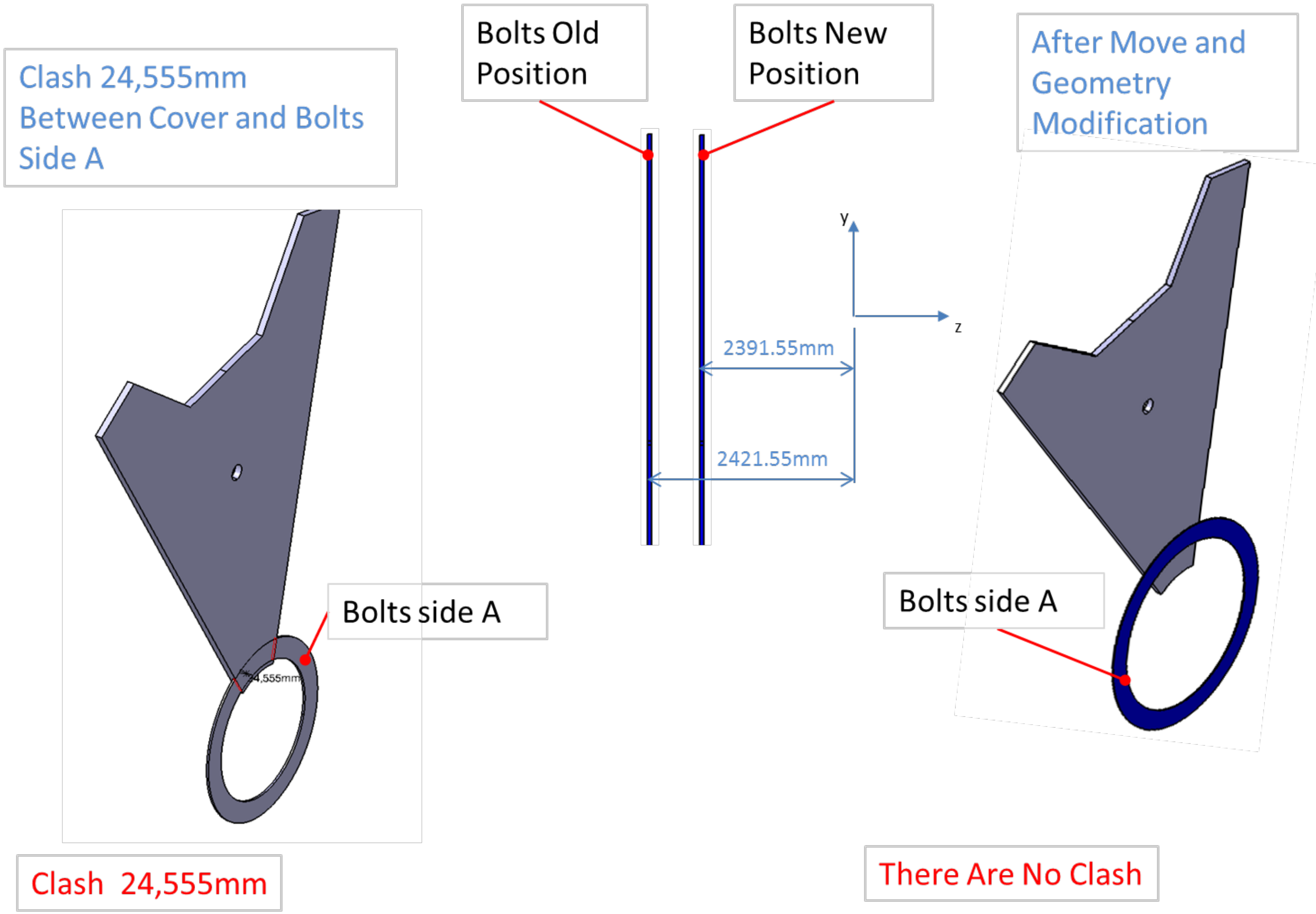






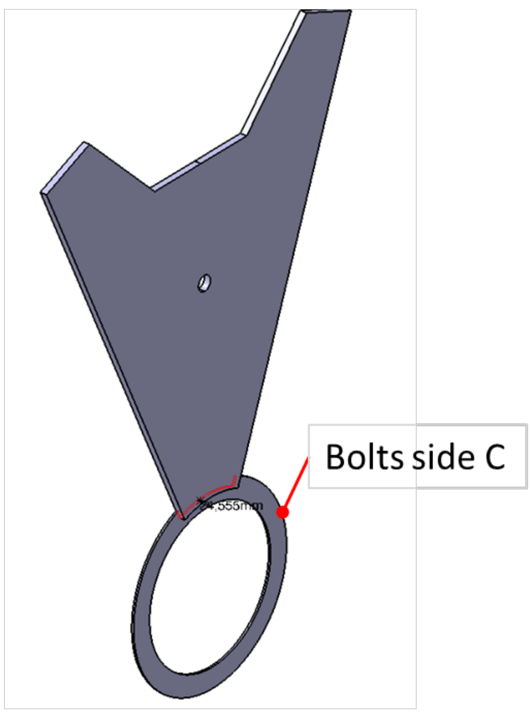
ATLAS End-CAP Toroid Study / Conflicts Checking

- Internal Conflicts of ECT

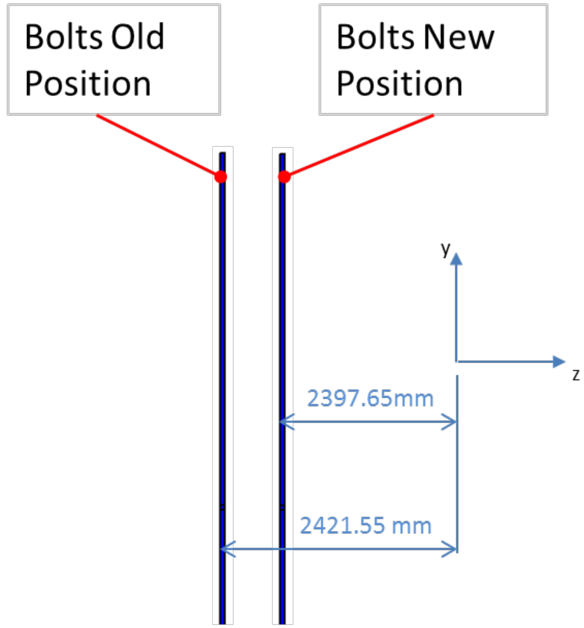


- Internal Conflicts of ECT

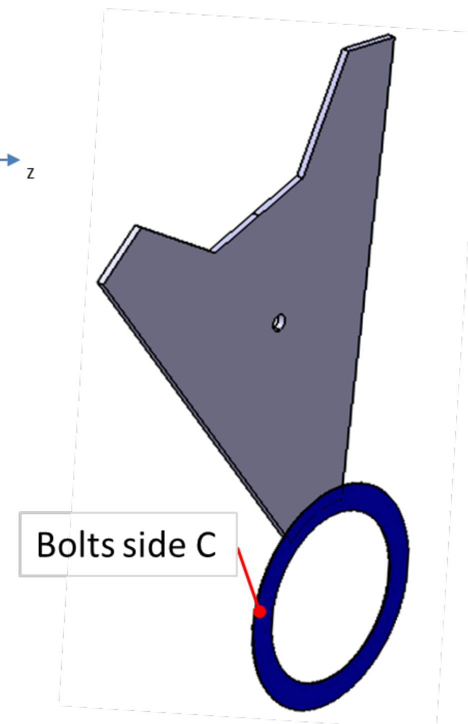
Clash 24,555mm Between Cover and Bolts Side C



Clash 24,555mm



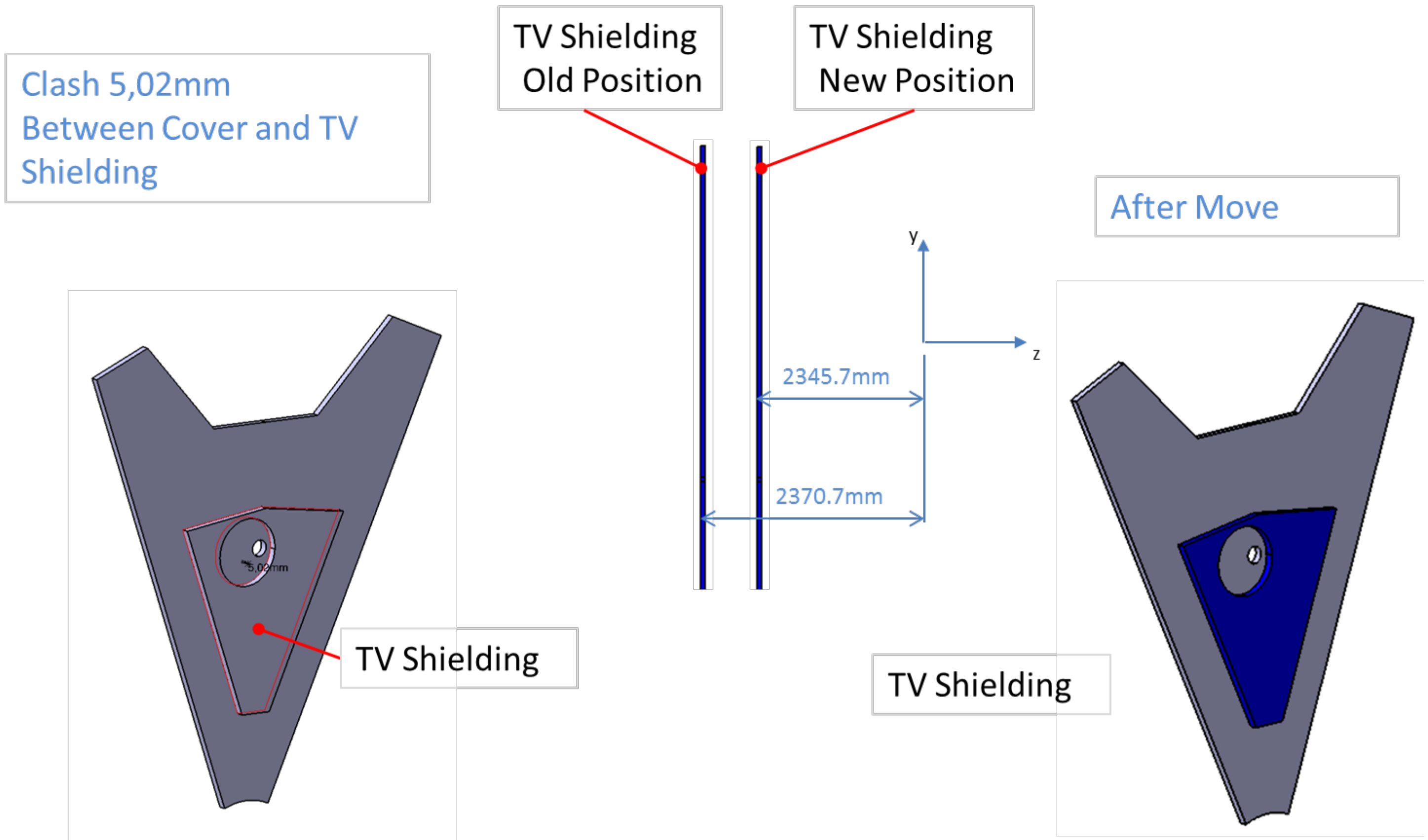
After Move and Geometry Modification



There Are No Clash

ATLAS End-CAP Toroid Study / Conflicts Checking

- Internal Conflicts of ECT



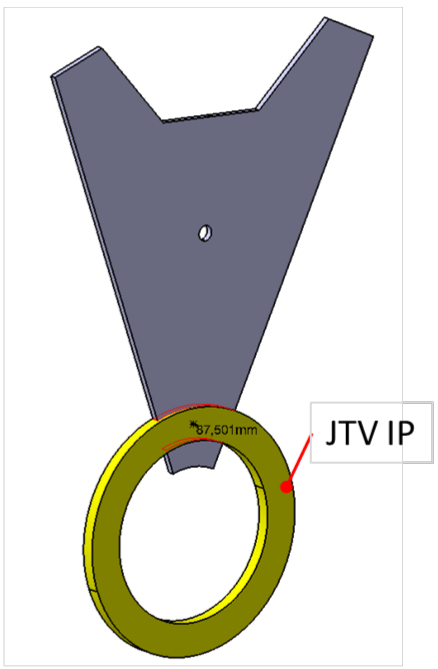
Clash 5,02mm

There Are No Clash

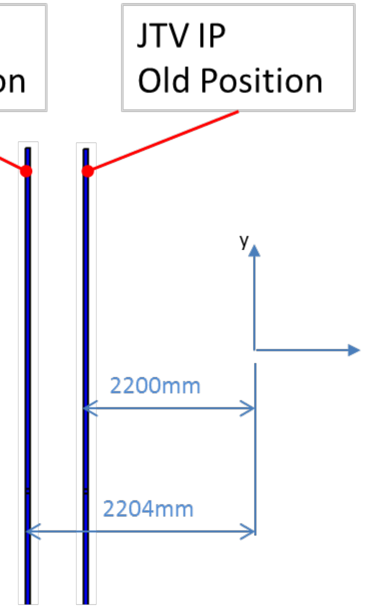
ATLAS End-CAP Toroid Study / Conflicts Checking

- Internal Conflicts of ECT

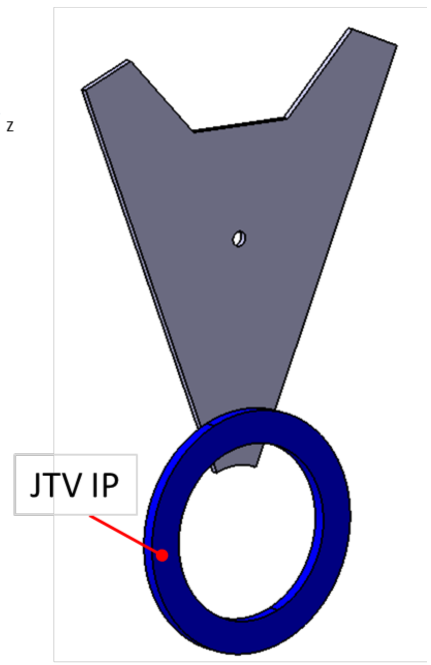
Clash 87,501mm
Between Cover and JTV IP



Clash 87,501mm



After Move



There Are No Clash

ATLAS End-CAP Toroid Study / Conflicts Checking

- ## Internal Conflicts of ECT

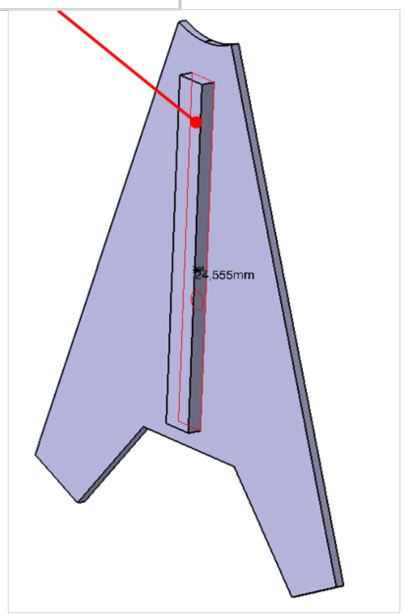
Clash 24,555mm
Between Cover and JTV IP

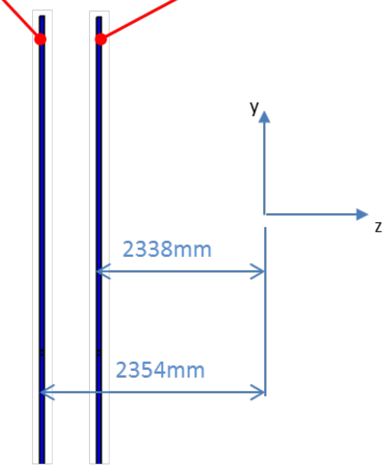
Cover Connection Box
Old Position

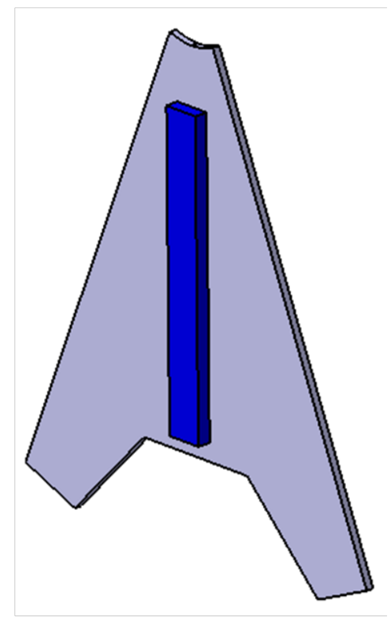
Cover Connection Box
New Position

After Move and
Geometry
Modification

Cover Connection Box





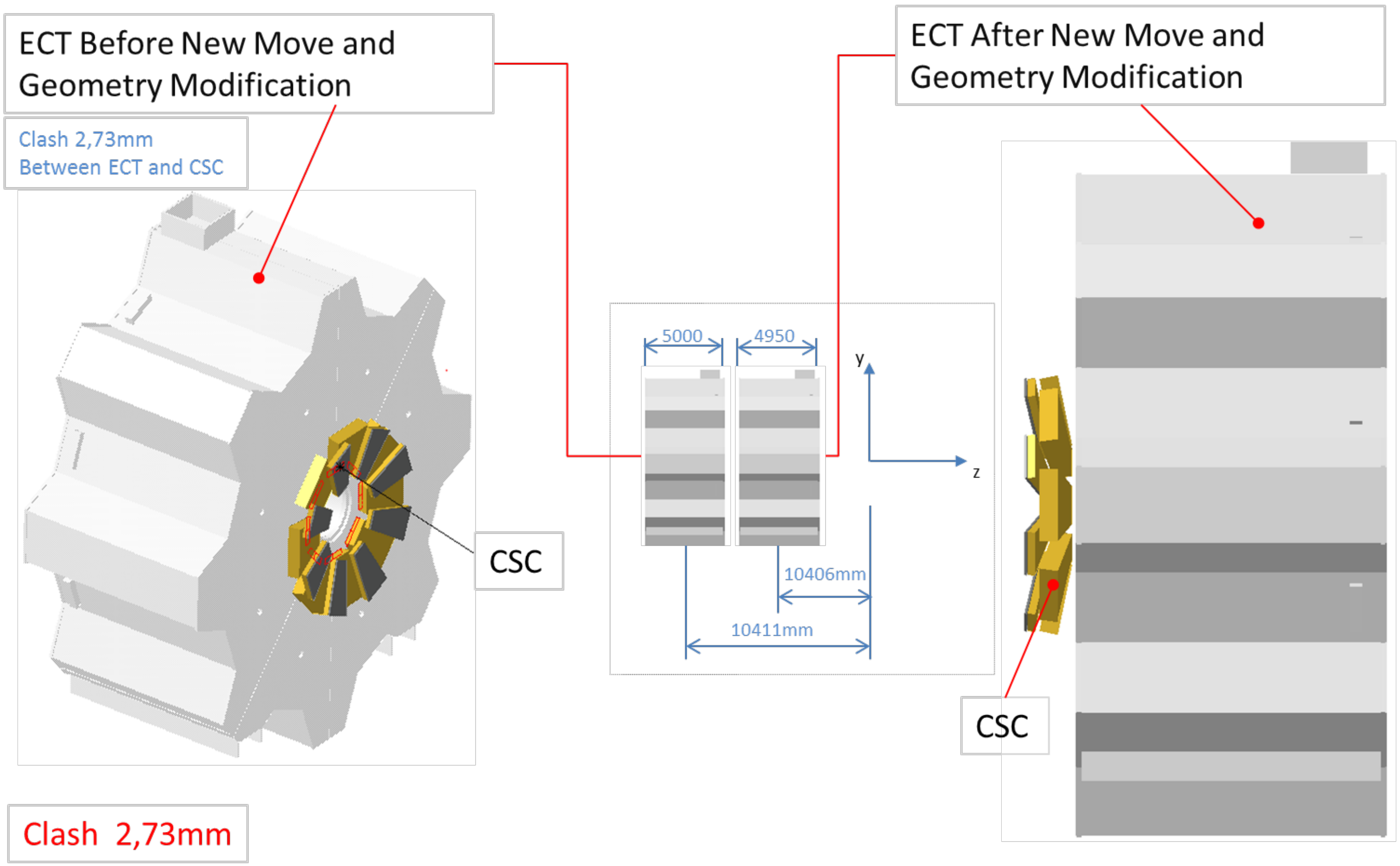


Clash 24,555mm

There Are No Clash

ATLAS End-CAP Toroid Study / Conflicts Checking

- External Conflicts of ECT



There Are No Integration Conflicts

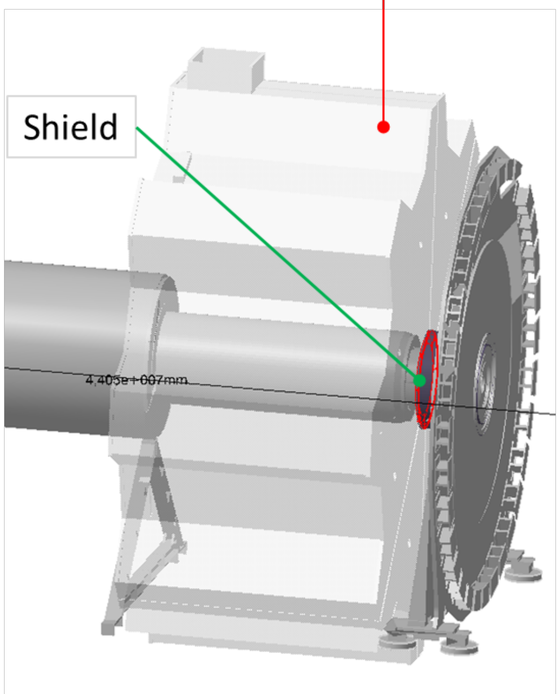
ATLAS End-CAP Toroid Study / Conflicts Checking

- ## External Conflicts of ECT

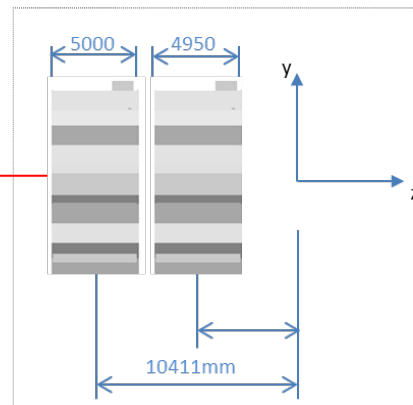
ECT Before New Move and Geometry Modification

Clash 2,73mm
Between ECT and Shield

Shield

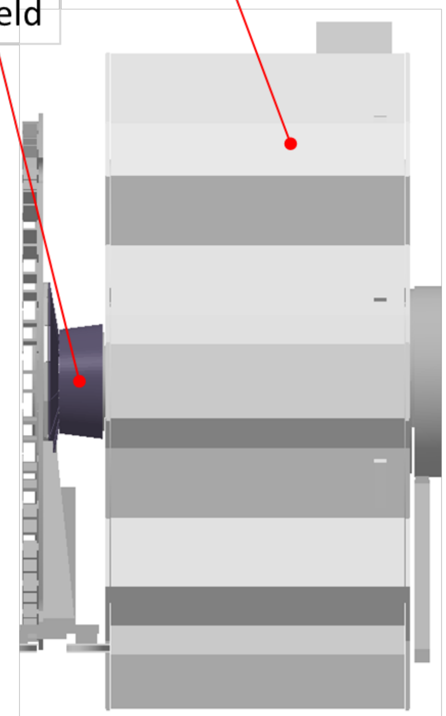


Clash 4,4mm



ECT After New Move and Geometry Modification

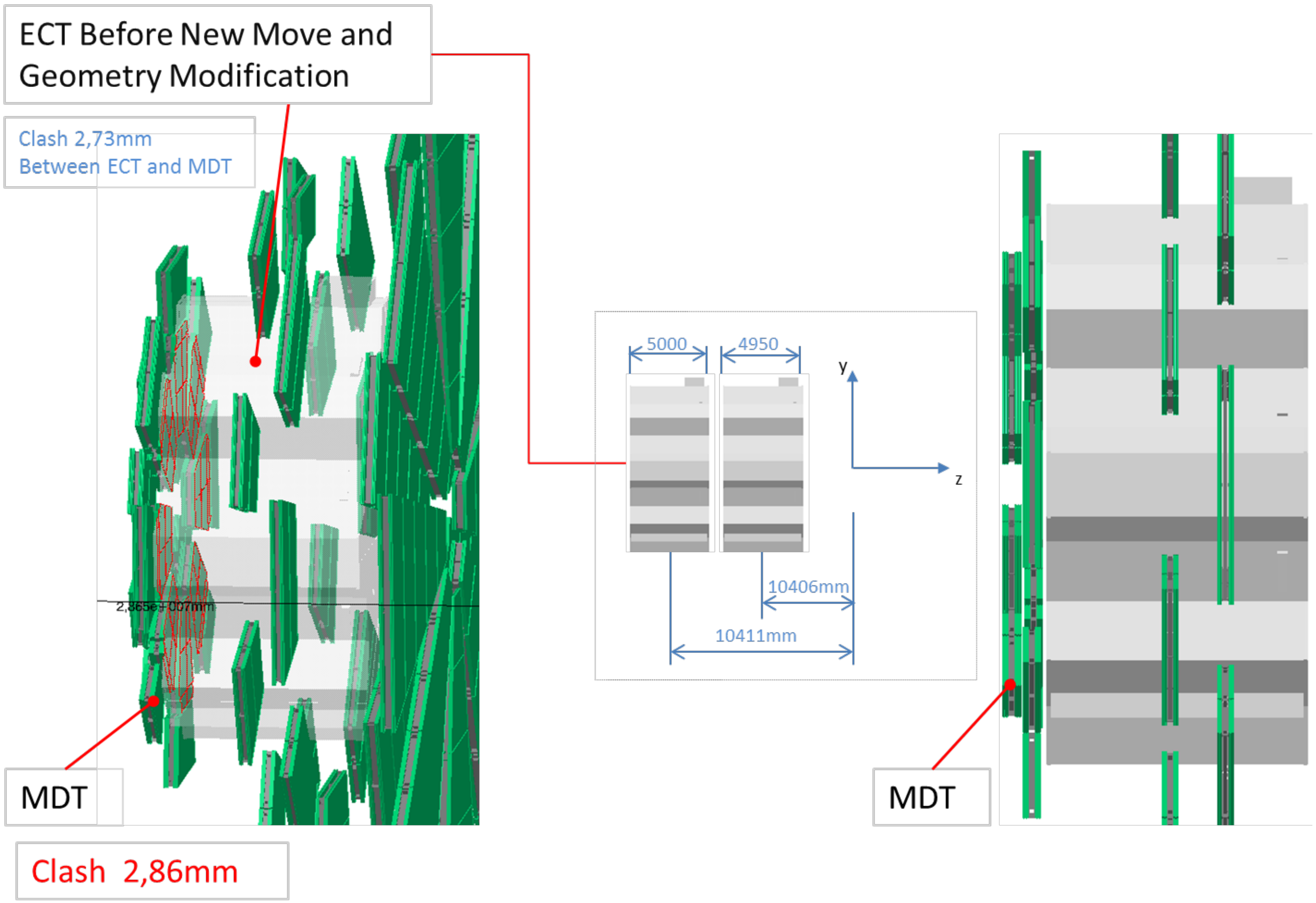
Shield



There Are No Integration Conflicts

ATLAS End-CAP Toroid Study / Conflicts Checking

- ## External Conflicts of ECT



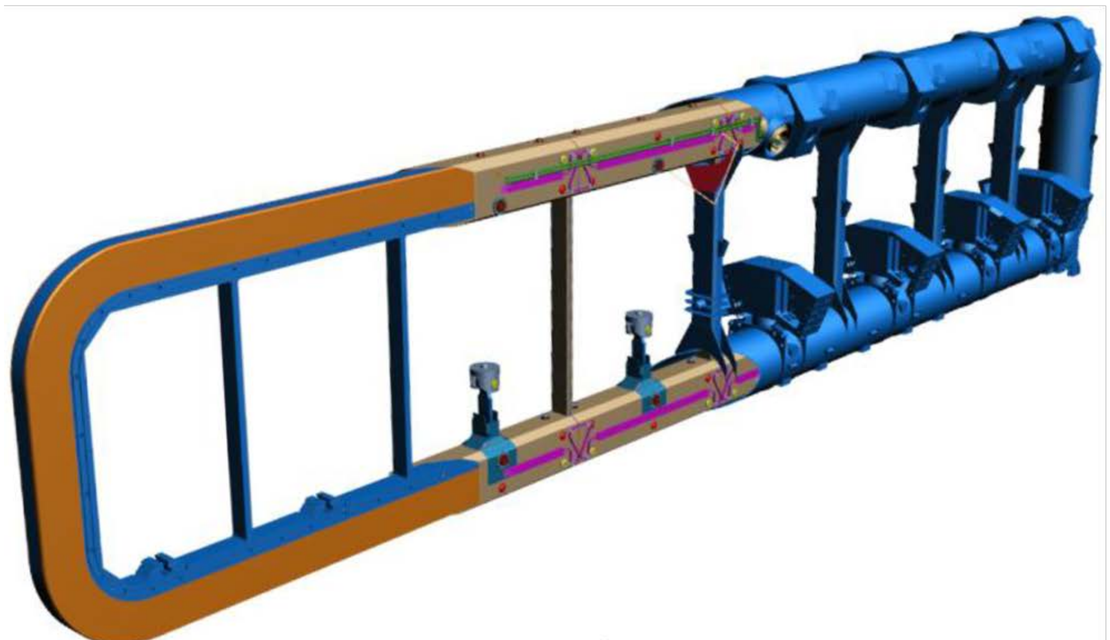
ATLAS End-CAP Toroid Study

Conclusions of End-CAP Toroid Study

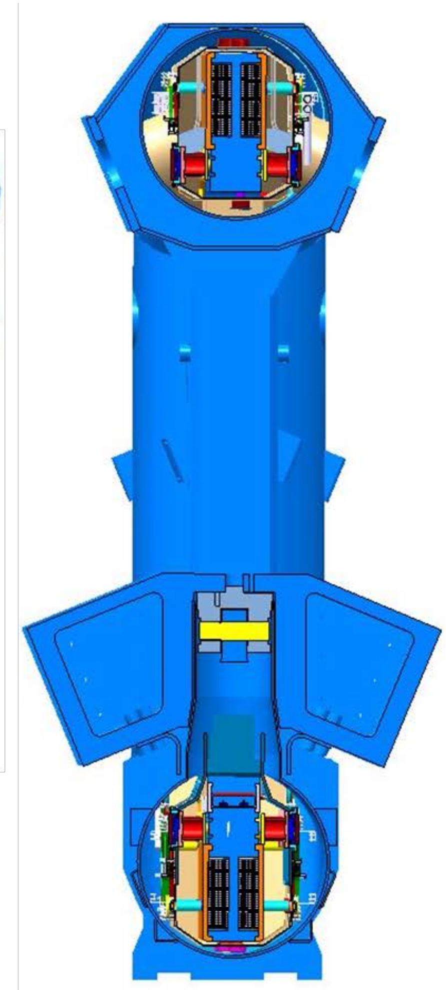
1. Compare analyse of CATIA vs XML shows >20% difference in volume and weight for majority of components
2. The grouping of volumes in the two geometry systems may differ somewhat, but the distribution of mass in the detector still shows significant differences
3. Most big discrepancies were detected for BoreTube assembly – 3 tonnes; TieRod assembly – 2 tonnes and Turret assembly – 960 kg
4. Conflicts analyses discover substantial integration conflicts for internal assembly of ECT as well external conflicts with surrounded components of detector

ATLAS Coil Study

- ATLAS detector have 8 identical Coils



Total	24.75	92348
	Volume (m^3)	Weight (kg)



ATLAS Coil Study

- Source geometry has been taken from SmarTeam Engineering Database:

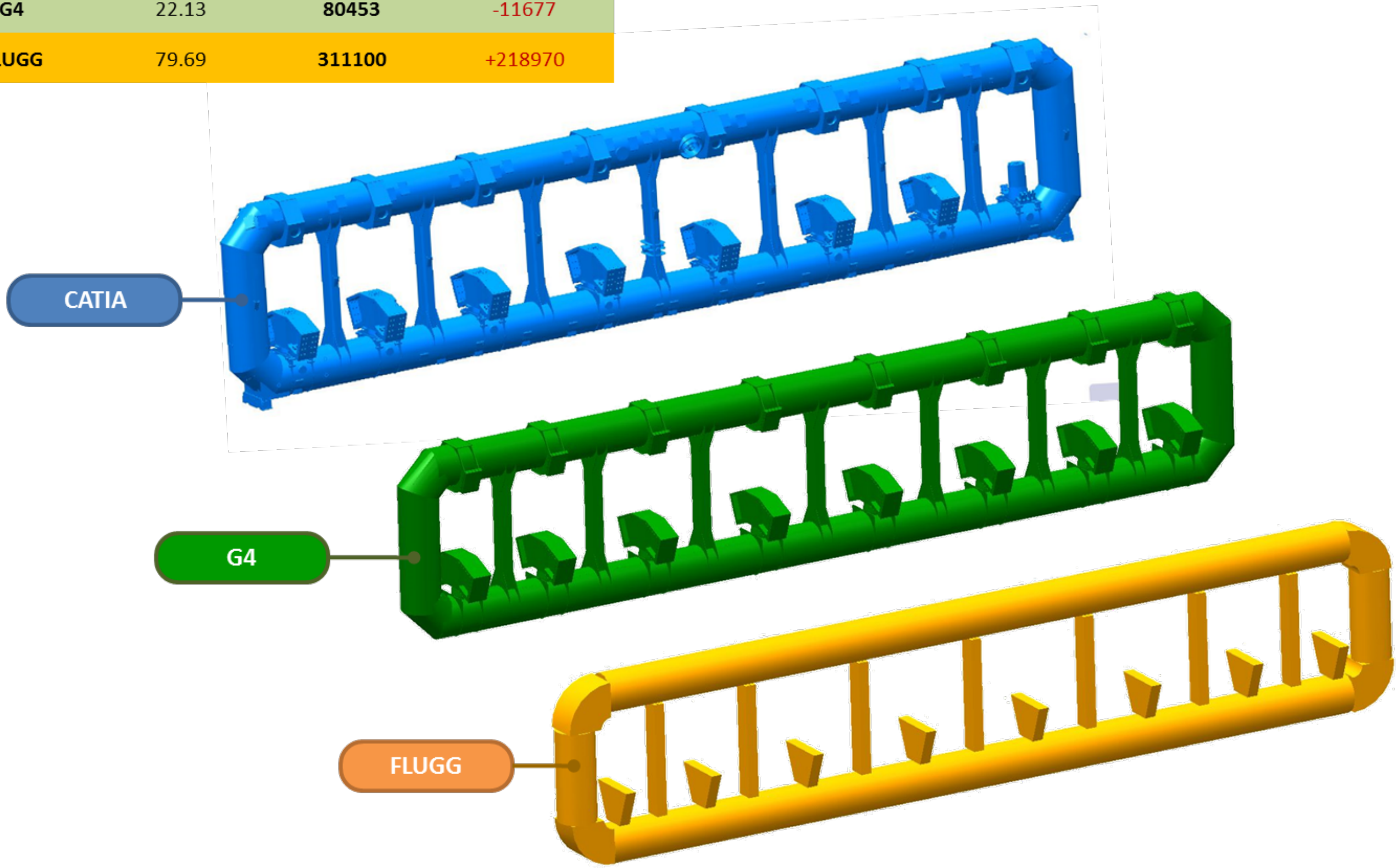
  Path : ATLAS2009/Detector System/Magnets ATLAS/Toroid Magnets ATLAS/Barrel Toroid Magnet ATLAS/TB coils
  Model: **ST0301587 TB COIL SEC2 (id: CAD000323373**)
  Date : 01/11/2011

- 225 manufacturing drawings have been founded on CDD and missing parts was added to primary Smarteam geometry

ATLAS Coil Study

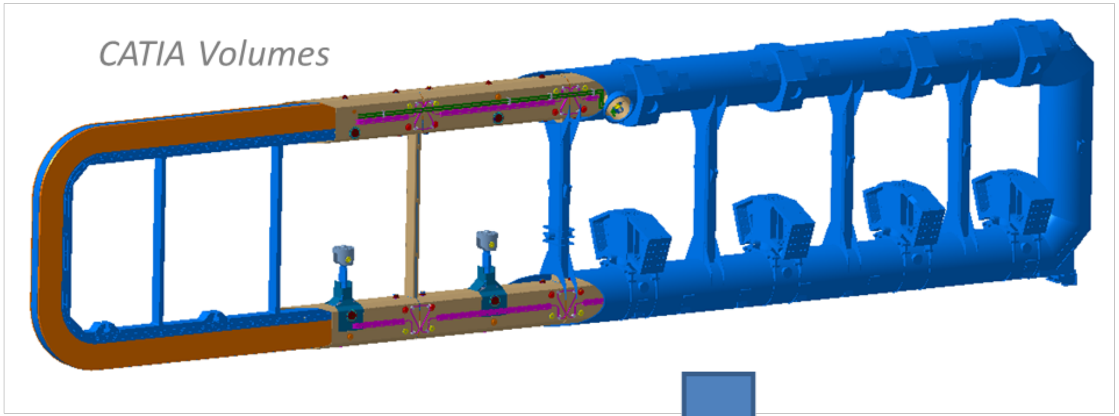
- Compare Analyses

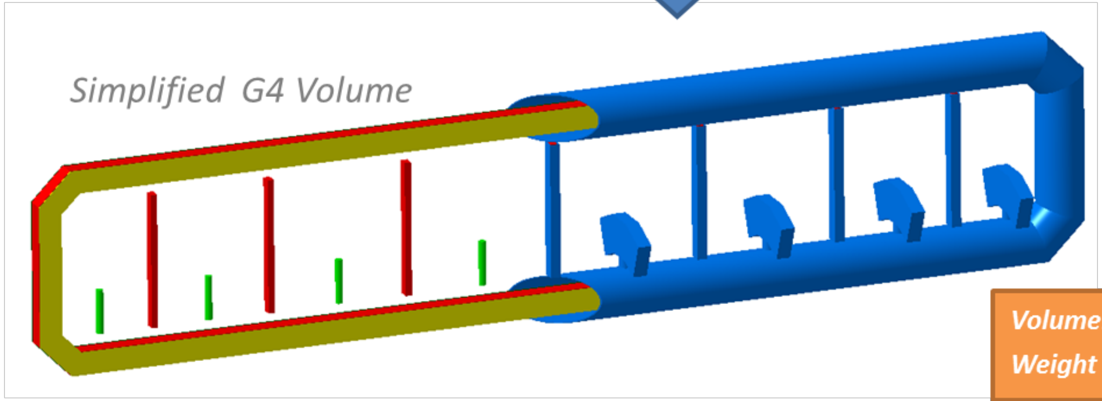
Model	Volume (m3)	Weight (kg)	Difference (kg)
CATIA	24.75	**92130**	
G4	22.13	**80453**	-11677
FLUGG	79.69	**311100**	+218970



ATLAS Coil Study

- Simplification of Assembly



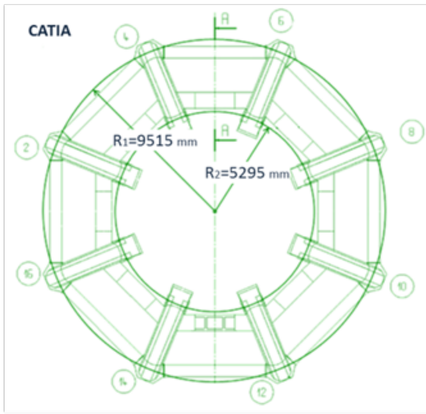


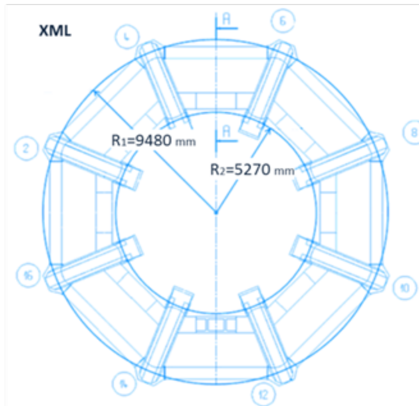
Volume: 24.7 m3 Weight : 92031kg		Difference: Volume: 0.05 m3 Weight : 99kg
Volume: 24.75 m3 Weight : 92130kg		

ATLAS Coil Study

- Integration Conflicts Analyses

  - COIL's + Warm Structure Displacement

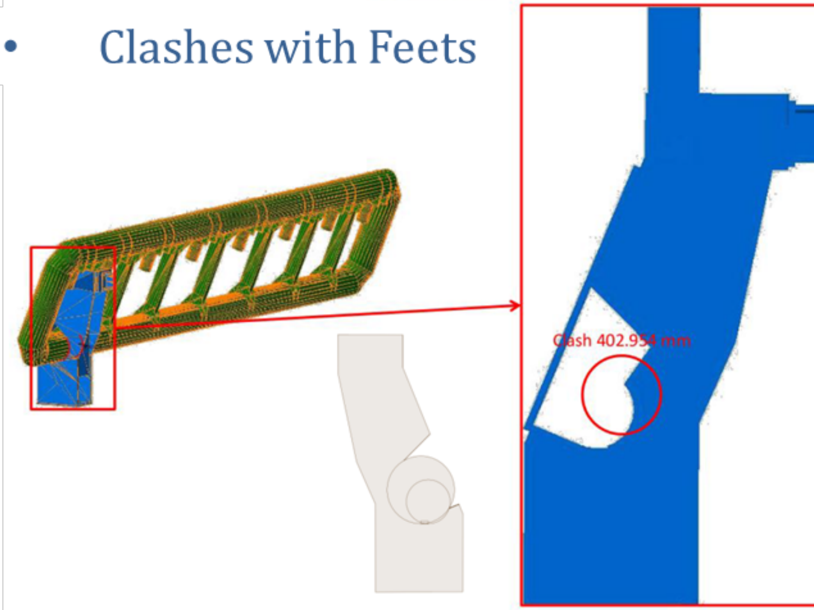




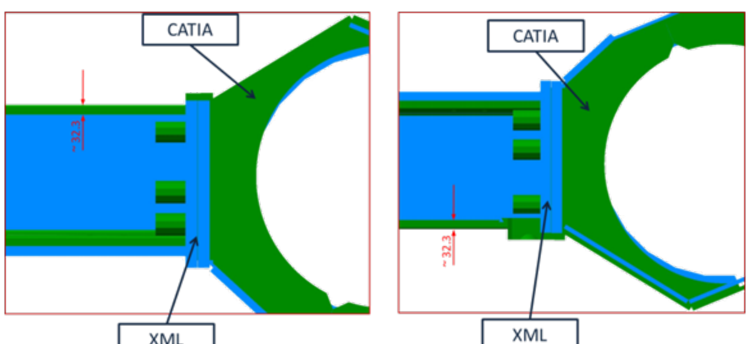
$\Delta_{R1} = R1|_{CATIA} - R1|_{XML}$ = 9515 mm – 9480 mm = 35 mm

$\Delta_{R1} = R2|_{CATIA} - R2|_{XML}$ = 5295 mm – 5270 mm = 25 mm

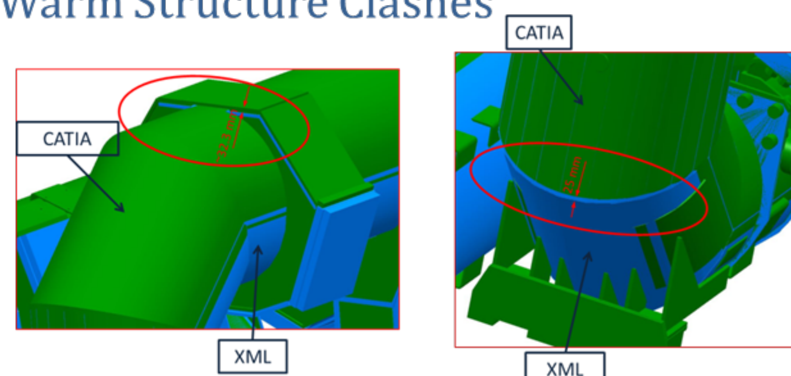
  - Clashes with Feets



  - Warm Structure Clashes



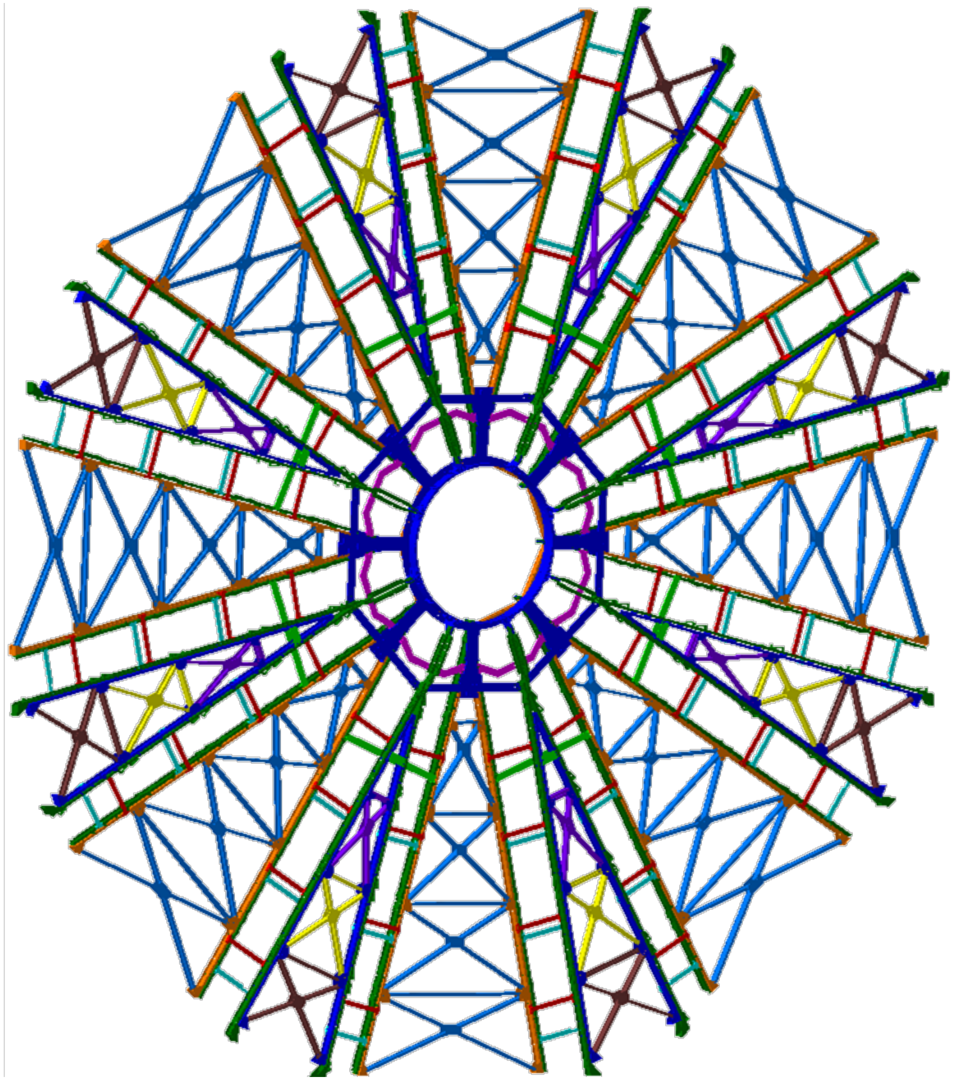
  - Warm Structure Clashes



Conclusions of Coil Study

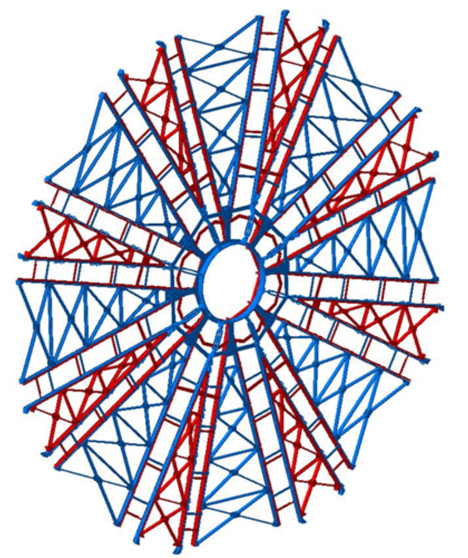
1. Compare analyse shows big differences in volume and weight between CATIA and XML descriptions
2. 11.6 tonnes missed materials were discovered for GEANT-4 geometry descriptions
3. 219 tonnes added materials were discovered for FLUGG geometry descriptions
4. Conflicts analyses discover substantial integration conflicts for internal assembly of Coil as well external conflicts with feet's of detector.
5. 35mm dispositioning of Coil has been discovered

MDT Supports Study



MDT Supports Study

- Calculation of Total Volume and Weight



Big Sector Wheel

5'822 kg $|_{\text{Total Weight}}$ = 1419kgs $|_{\text{Vol.1}}$ + 918kgs $|_{\text{Vol.2}}$ + 339kgs $|_{\text{Vol.3}}$ +
+773.5kgs $|_{\text{Vol.4.1,4.2}}$ + 708.5kgs $|_{\text{Vol.5}}$ + 1216kgs $|_{\text{Vol.6.1-6.8}}$
+448kgs $|_{\text{Bolts\&Nuts}}$

2.0464 m^3 $|_{\text{Total Volume}}$ = 0.0657 m^3 $|_{\text{Vol.1}}$ + 0.0425 m^3 $|_{\text{Vol.2}}$ + 0.0157 m^3 $|_{\text{Vol.3}}$
+0.0358 m^3 $|_{\text{Vol.4.1,4.2}}$ + 0.0328 m^3 $|_{\text{Vol.5}}$ + 0.0563 m^3 $|_{\text{Vol.6.1-6.8}}$
+ 0.056 m^3 $|_{\text{Bolts\&Nuts}}$

Small Sector Wheel

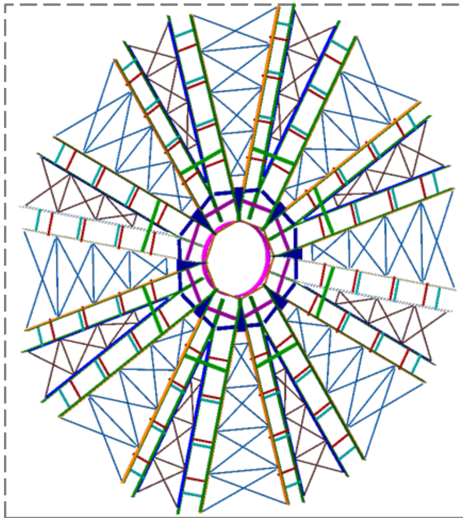
4'710 kg $|_{\text{Total Weight}}$ = 1438.56 kgs $|_{\text{Vol.1}}$ + 1051.92 kgs $|_{\text{Vol.2}}$ + 397.44 kgs $|_{\text{Vol.3}}$
+ 306.72 kgs $|_{\text{Vol.4}}$ + 248.4 kgs $|_{\text{Vol.5}}$ + 216 kgs $|_{\text{Vol.6}}$
+ 239.76 kgs $|_{\text{Vol.7}}$ + 162 kgs $|_{\text{Vol.8}}$ + 125.28 kgs $|_{\text{Vol.9}}$
+ 524 kgs $|_{\text{Bolts\&Nuts}}$

1.6159 m^3 $|_{\text{Total Volume}}$ = 0.5328 m^3 $|_{\text{Vol.1}}$ + 0.3896 m^3 $|_{\text{Vol.2}}$ + 0.1472 m^3 $|_{\text{Vol.3}}$
+ 0.1136 m^3 $|_{\text{Vol.4}}$ + 0.092 m^3 $|_{\text{Vol.5}}$ + 0.08 m^3 $|_{\text{Vol.6}}$
+ 0.0888 m^3 $|_{\text{Vol.7}}$ + 0.06 m^3 $|_{\text{Vol.8}}$ + 0.0464 m^3 $|_{\text{Vol.9}}$
+ 0.0655 m^3 $|_{\text{Bolts\&Nuts}}$

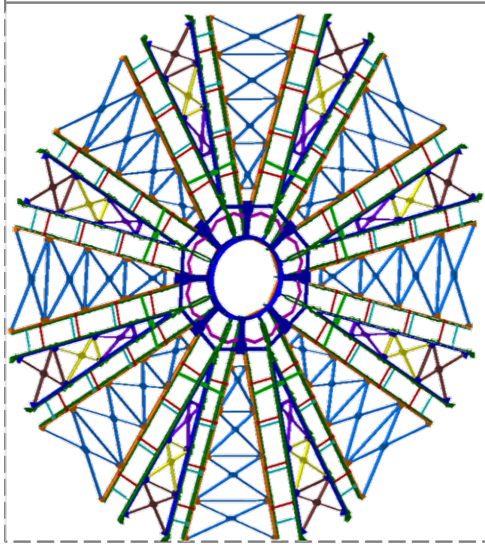
BW MDT All Sector Total	**3.6723** Volume (m^3)	**10'532** Weight (kgs)

MDT Supports Study

- Simplification of Large and Small Sectors



Simplified Volumes



Detailed Volumes

Total Volume: 3.5548 m3
Total Weight: 9598.24 kg

Total Volume: 3.5408 m3
Total Weight: 9560 kg

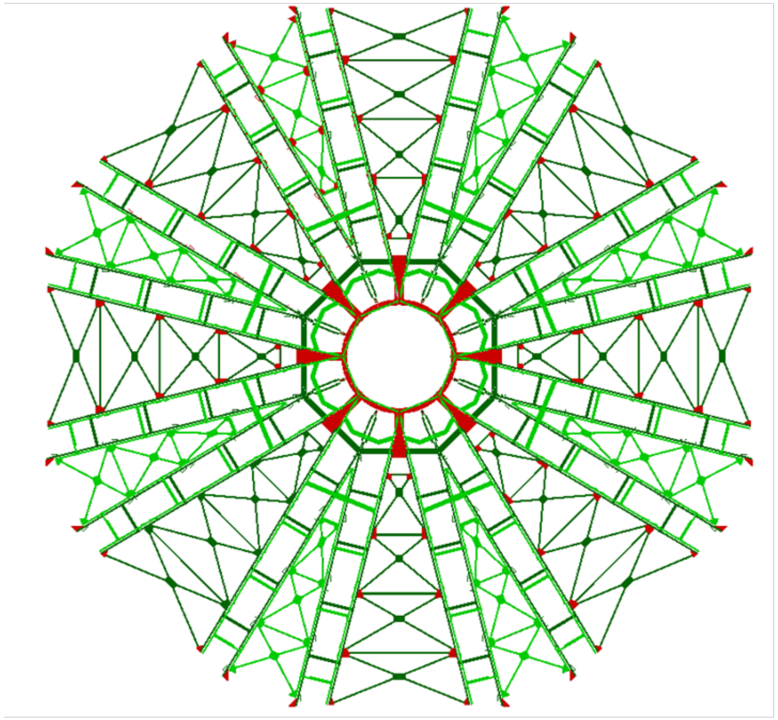
Difference:
Total Volume: 0.014 m3
Total Weight: 37.8 kg

MDT Supports Study

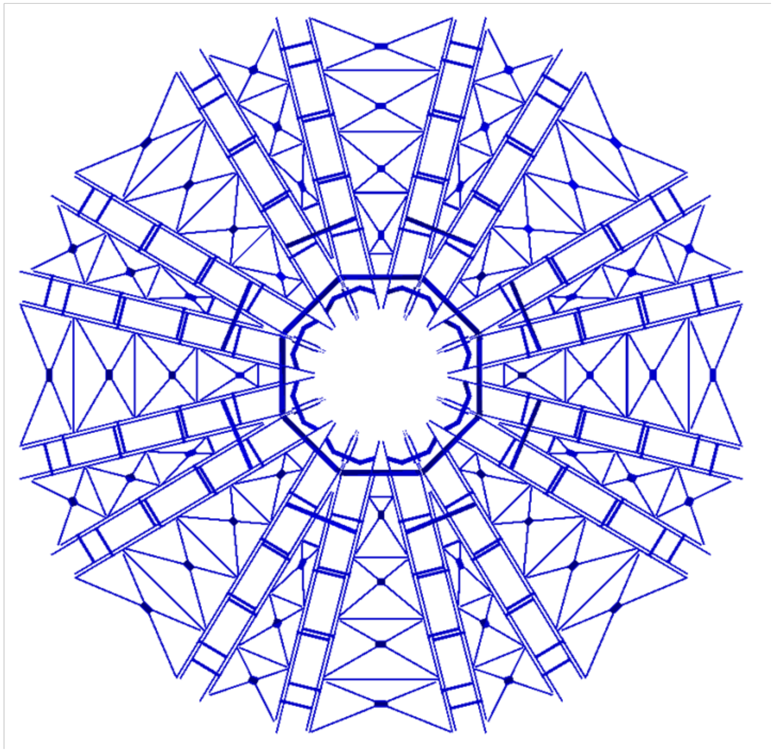
- Integration Conflicts Analyses

Model	Material	Density (kg/m3)	Volume (m^3)	Weight (kgs)	Missing (kgs)
CATIA	Aluminum/Stainless Steel	2700 / 8000	3.6723	**10’532**	
PERSINT/XML	Aluminum	2700	2.3184	**6’260**	**-4’272**

CATIA Model

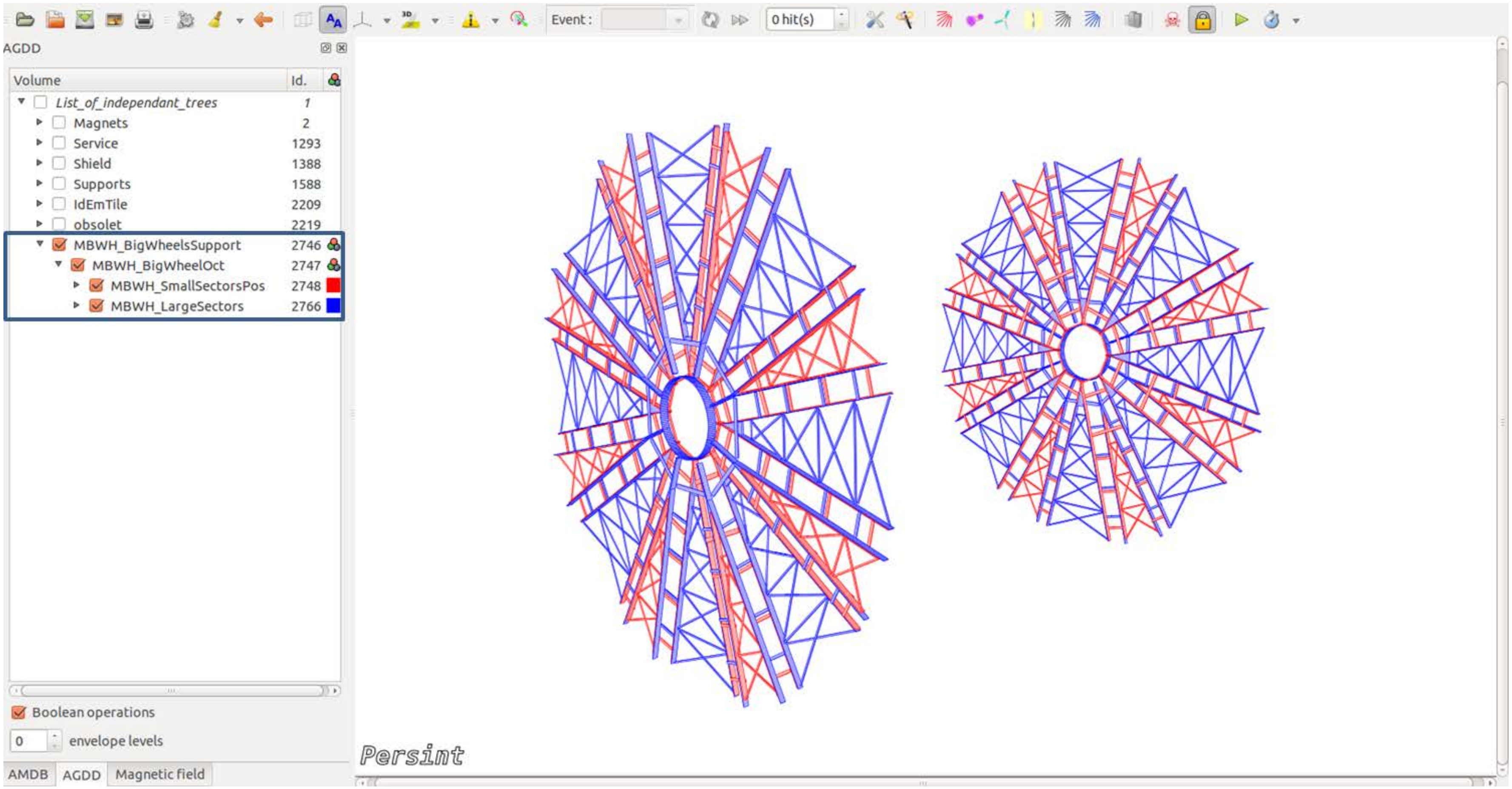


GEANT-4 Model



MDT Supports Study

- Integration Conflicts Analyses



No Integration Conflicts

Conclusions of MDT Support Study

1. Compare analyse shows big differences in volume and weight between CATIA and XML descriptions
2. 4.2 tonnes missed materials were discovered for GEANT-4 geometry descriptions
3. There are no Integration Conflicts

Final Conclusions

General Conclusions

- Hypothesis #01 has been approved: Simulation software infrastructure added geometry inaccuracies

1. For all type of detector geometries dimensional, form and positioning faults are caused by *Boolean* operations
2. All internal surfaces received by *Boolean* subtraction of parametrical primitives from *Box* brings 0 faults
3. *Boolean* operation correlated with *Move/Rotation* transactions in GEANT. Once *Boolean* operation is implemented transactions generating geometry displacements of support points of geometry created by *Boolean* procedures
4. For all external surfaces created by subtraction of parametrical primitives from *Box*, *Boolean* operation don't correlated with *Move/Rotation* transactions

General Conclusions

5. For some internal surfaces created by subtraction of parametrical primitives from *Polygon* methods, *Boolean* operation don't correlated with *Move* transactions

6. A*rbitrary* Polygon method is most reliable way to simulate detector geometry in simulation software infrastructure

7. B*oolean* operation cause clashes (~1.28mm) inside geometry which is "visible" for large size volumes and not visible for smaller because of limitations of CATIA tool using for analyses

8. Increasing of dimensional values of geometry are exponentially increase values of inaccuracies added by *Boolean* operations

General Conclusions

- Hypothesis #02 has been approved: Geometry descriptions in simulation are not consistent with as-built geometry descriptions. As a result it may cause discrepancies between real and simulated data.

1. Compare analyses of ECT, Coils and MDT Supports show inconsistence with as-built geometry in terms of volumes, weight, positioning and existence of integration conflicts
2. Compare analyse of ECT shows >20% difference in volume and weight for majority of components
3. ECT Conflicts analyses discover substantial integration conflicts for internal assembly and external conflicts with surrounded components of detector as well
4. For Coil Assembly 11.6 tonnes missed materials were discovered for GEANT-4 and 219 tonnes added materials were discovered for FLUGG geometry descriptions

General Conclusions

5. Coil’s Conflicts analyses discover substantial integration conflicts for internal assembly and external conflicts with feet's of detector as well
6. Coil’s dispositioning on 35mm has been discovered
7. For MDT Supports 4.2 tonnes missed materials were discovered for GEANT-4 geometry descriptions

- Comments are welcome

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Thanks for your attention!