Development of Geometrical Descriptions of Magnet System of ATLAS Detector for the Simulation and Reconstruction Software Packages

Master's Degree DISSERTATION

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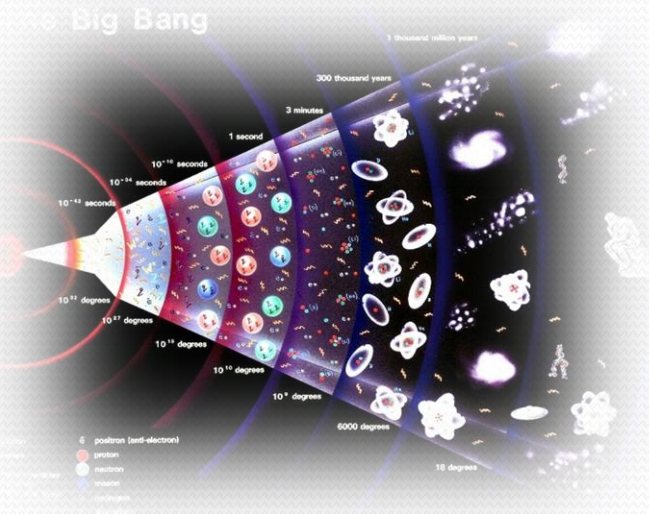
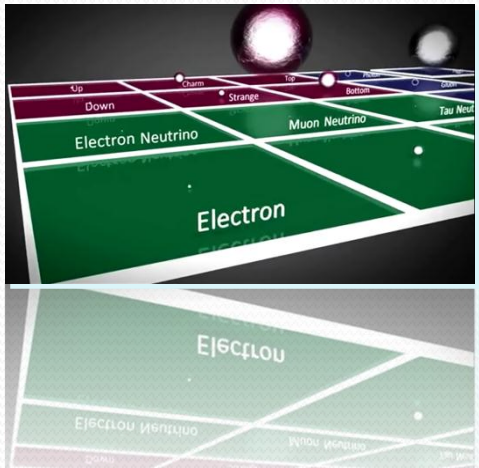
TECHNICAL UNIVERSITY OF GEORGIA

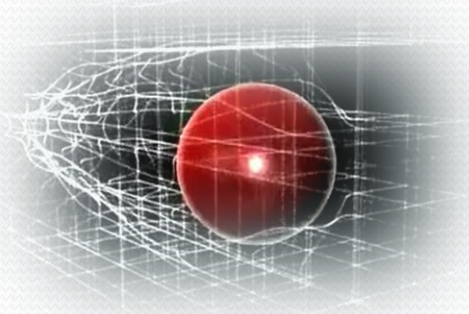
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH, CERN

High Energy Physics Research

- Investigation of Big Bang
- How matter was created
- Are there any extra dimensions
- Microscopic black holes

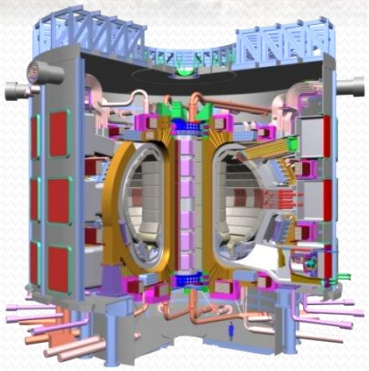




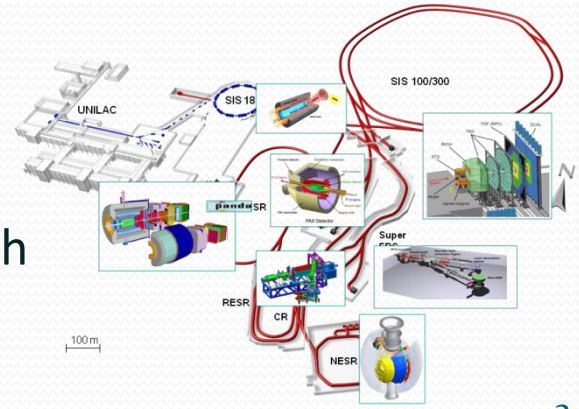


High Energy Physics Research

- LHC – Large Hadronic Collider, Geneva, Switzerland
- 10’000 Science and Engineers
- 100 Countries

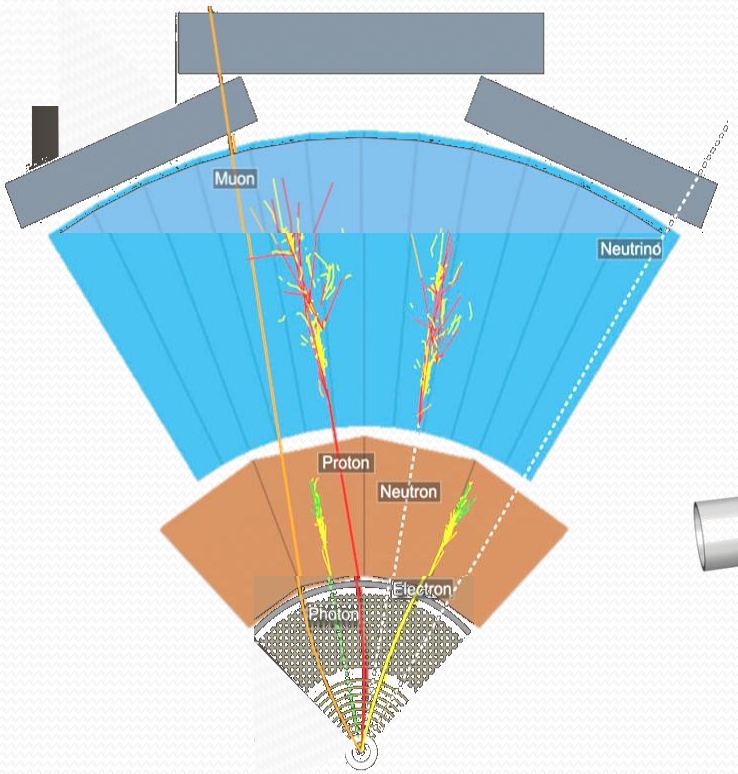


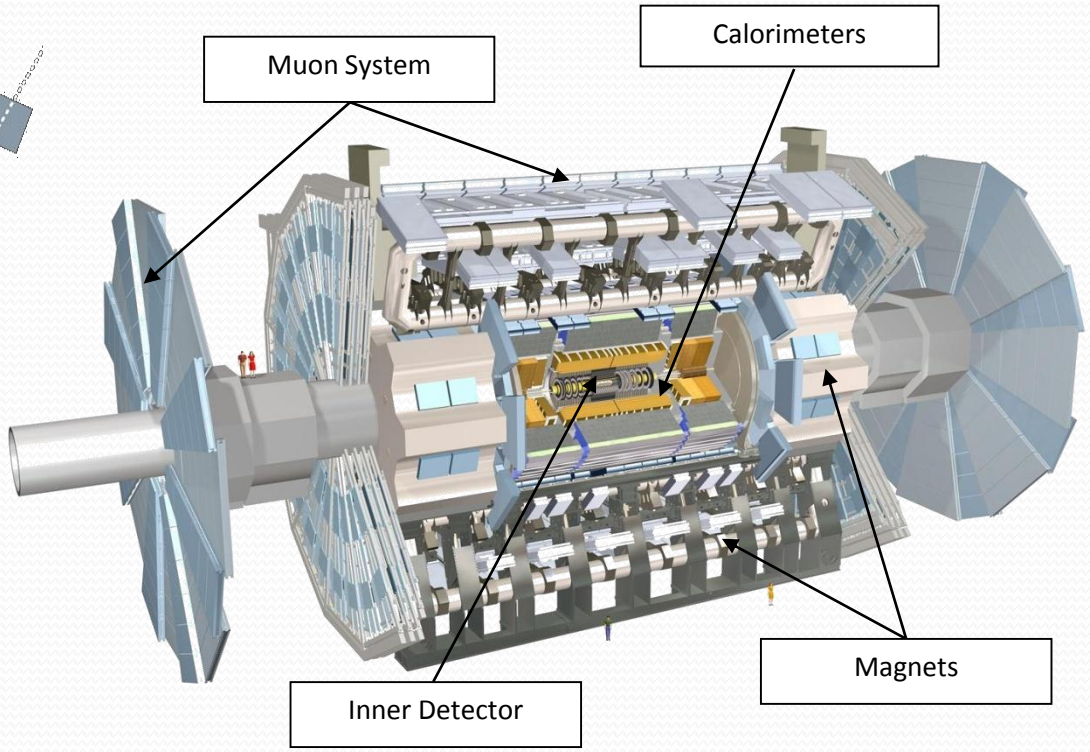
- ITER – International Thermonuclear Experimental Reactor, Cadareche, France
- 33 Countries



- FAIR – Facility for Antiproton and Ion Research Darmstadt, Germany
- 11 Countries

ATLAS Detector Description

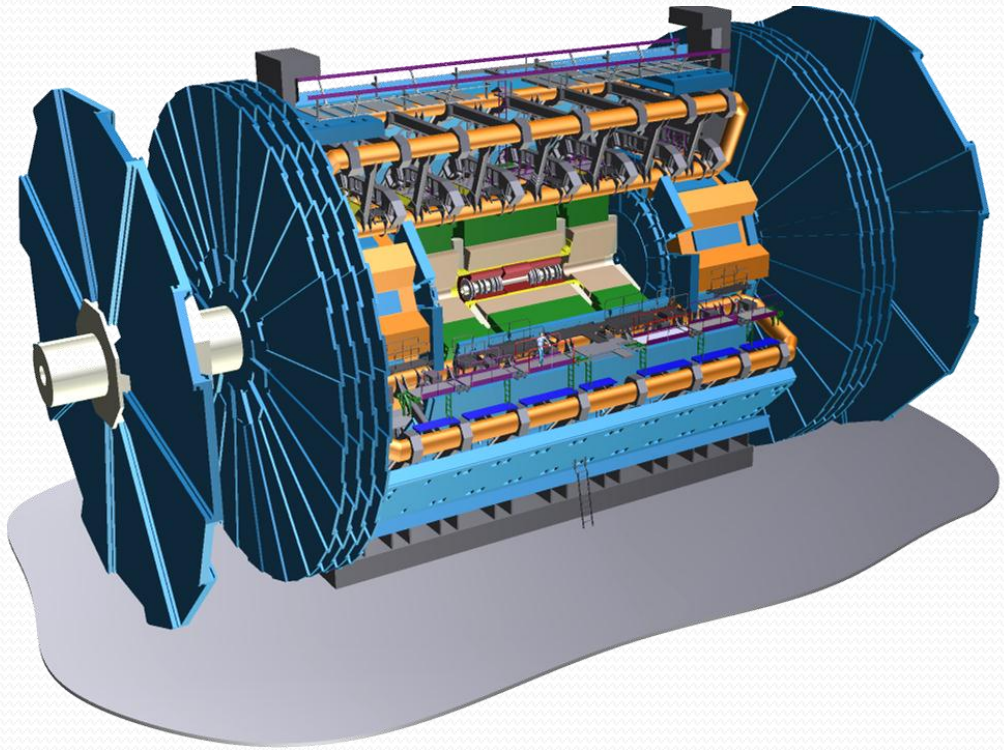




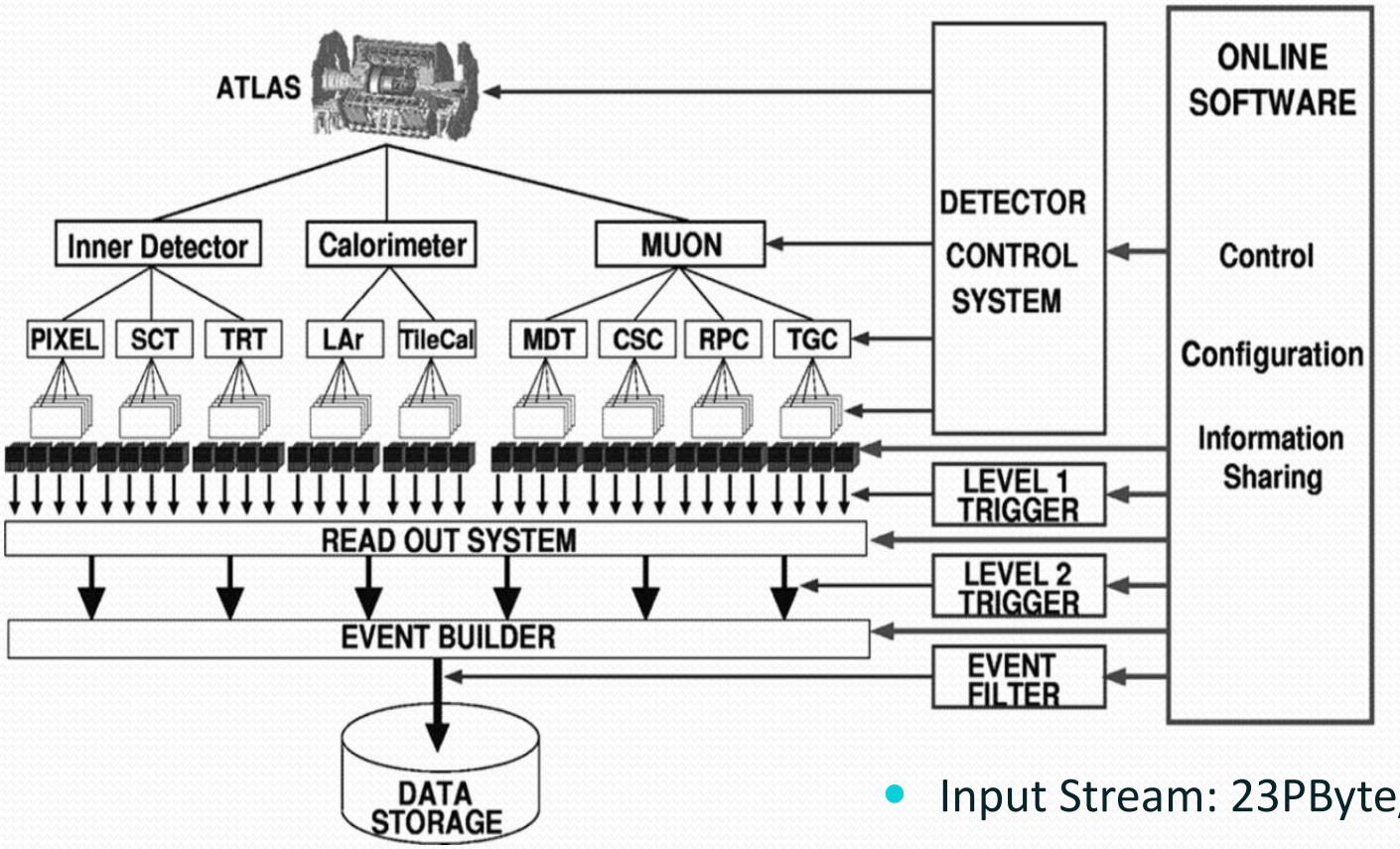
ATLAS Computing

5 Main Directions:

- Data Acquisition
- Data Storage
- Reconstruction
- Simulation
- Data Distribution

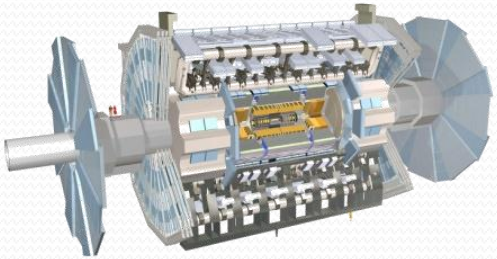


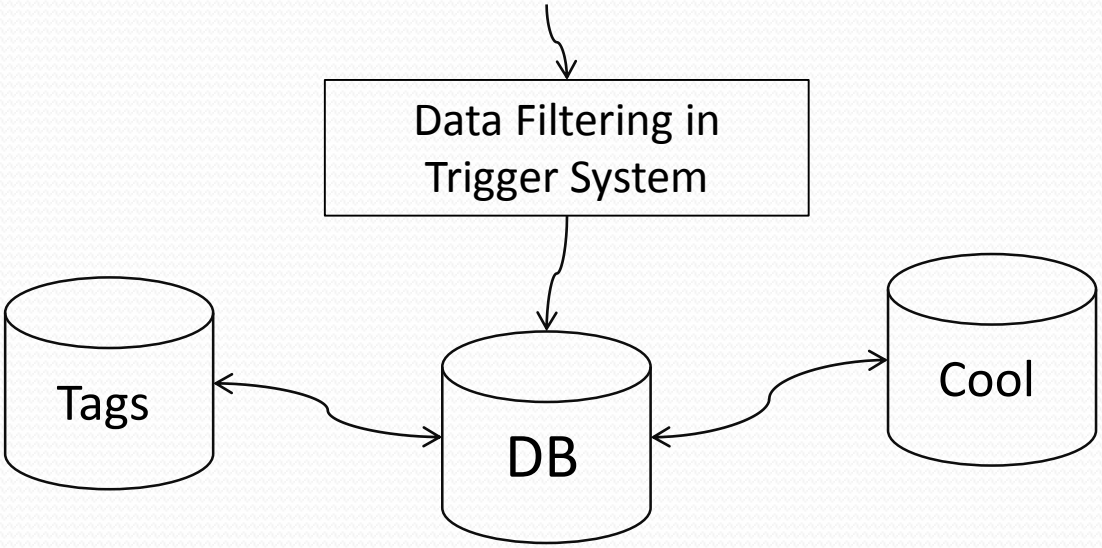
ATLAS Computing/Data Acquisition



- Input Stream: 23PByte/Sec
- Output Stream: 100MByte/Sec

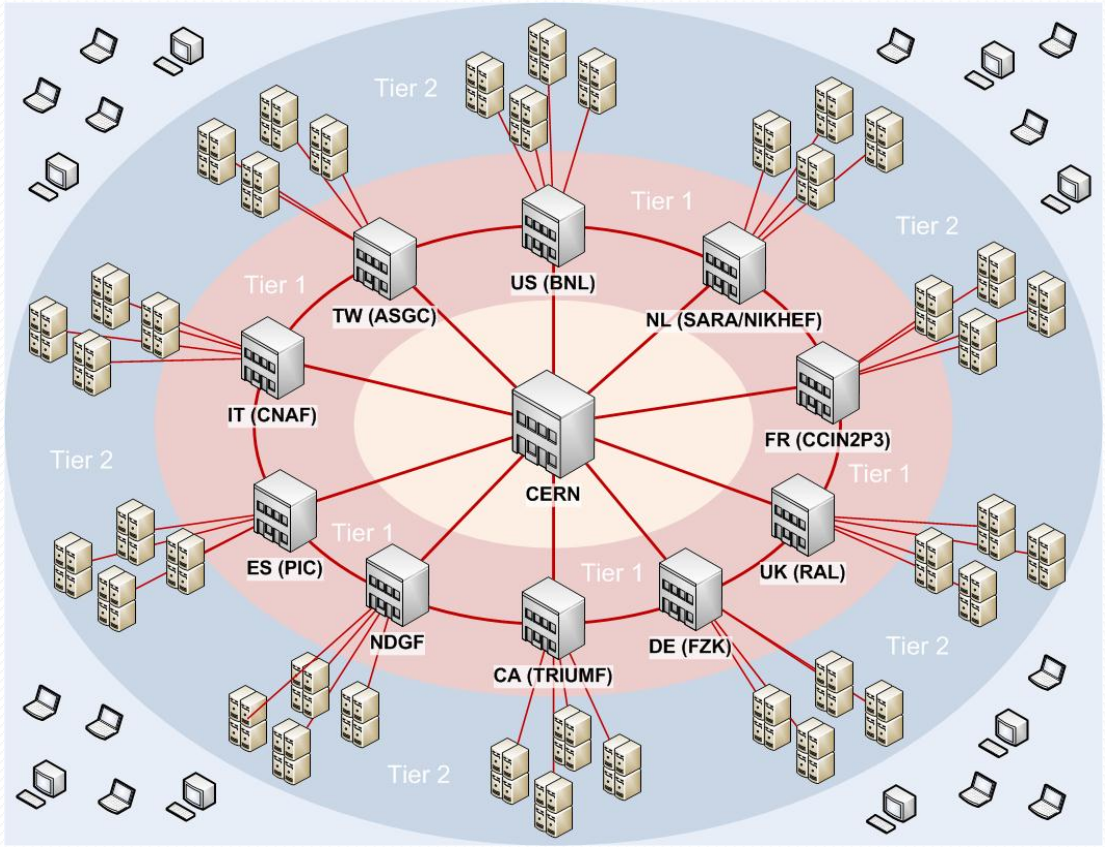
ATLAS Computing/Data Storage



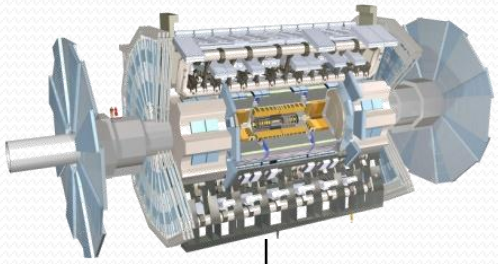


ATLAS Computing/Data Distribution

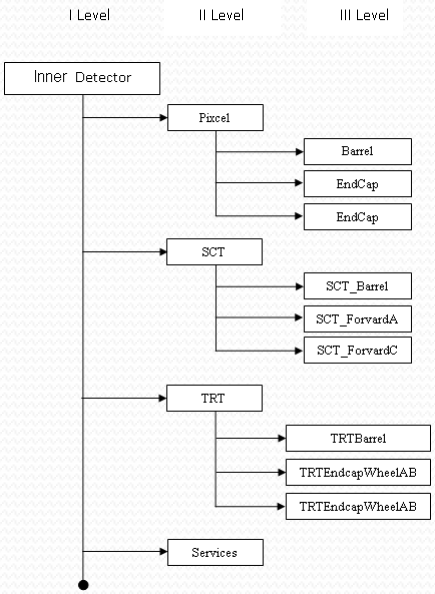
GRID

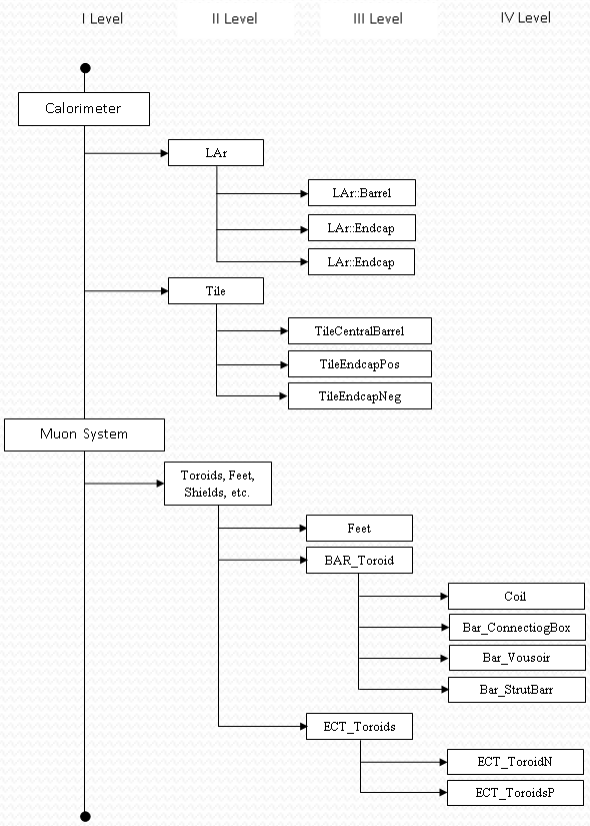


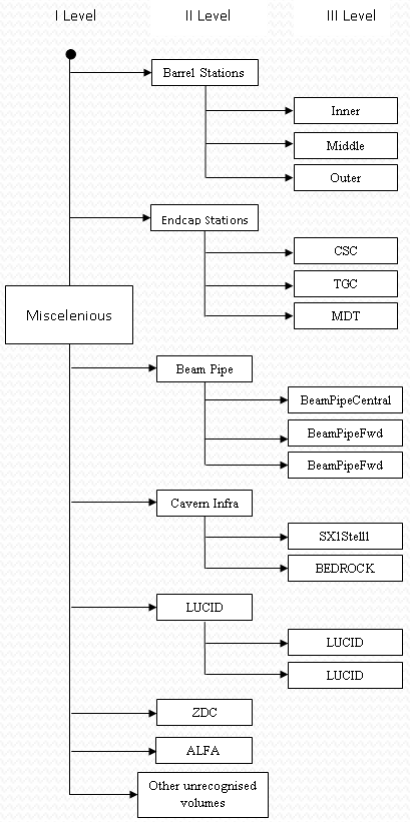
Reconstruction and Simulation



Detector Structure in Geant4/C++



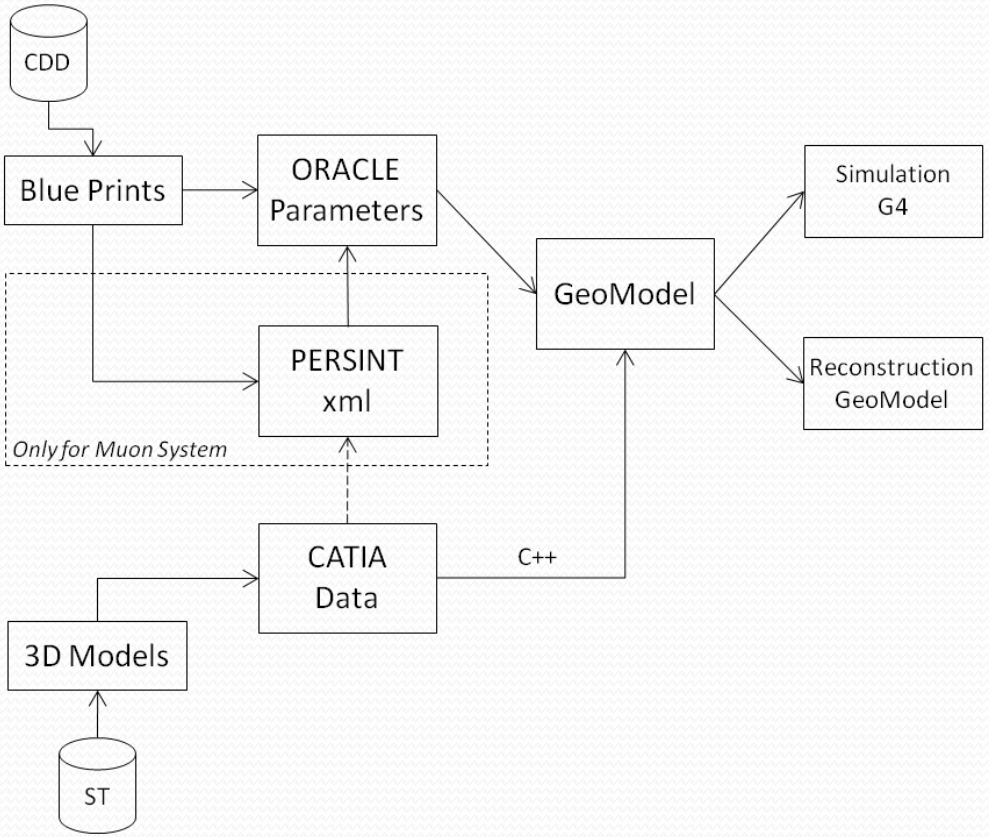




Geant4/C++ Models Preparation

New Method Forsee:

- Extraction of Models from Smarteam Engineering Database
- Import of Geant4/C++ models in CATIA
- Compare Analysis
- Modification of Component Geometry
- Geant4/C++ conflicts checking



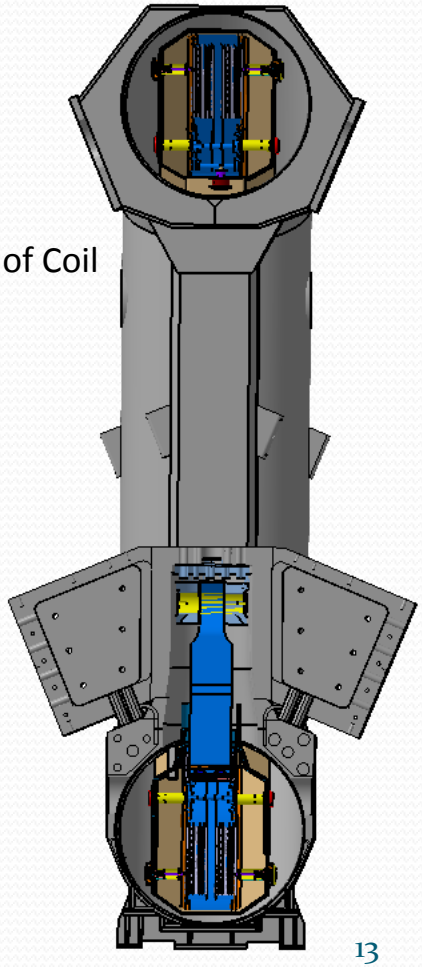
Research Map of Dissertation

1. Reproduction of Coils Engineering Model in CATIA
2. Segmentation and Definition of Mass Properties
3. Compare Analysis of Engineering and GEANT4/C++ Models
4. Simplification of Geometry
5. Generation of Geant4/C++ Codes

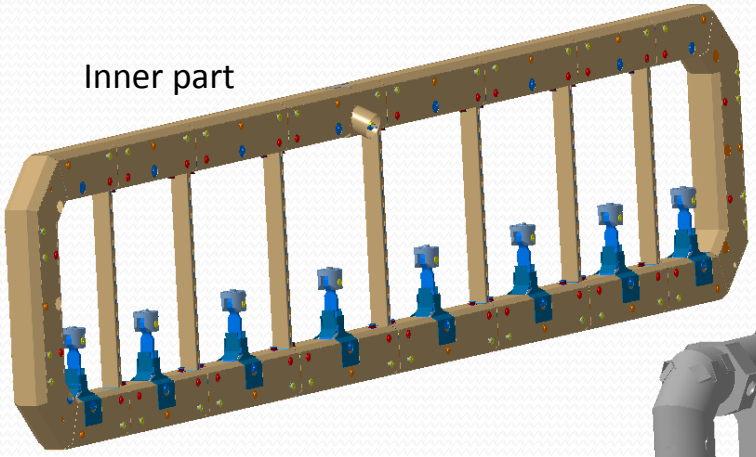
Model Reproduction in CATIA

1. Engineering Model of Coil has been extracted from SmarTEAM database
2. After, model was reproduced in CATIA by adding data from 225 CDD Drawings

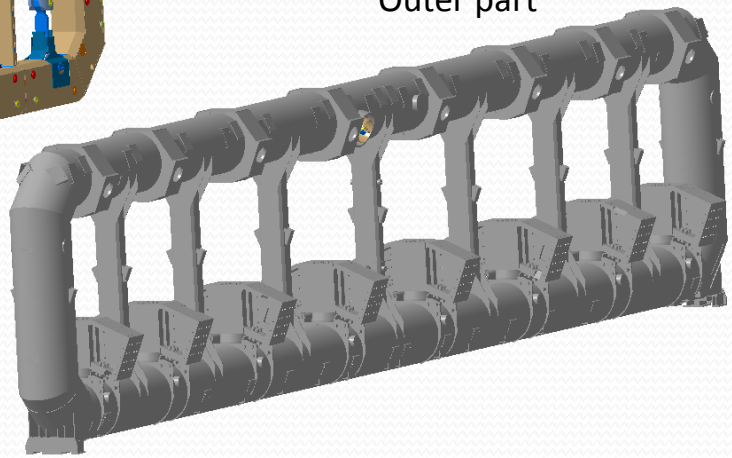
Section of Coil



Inner part



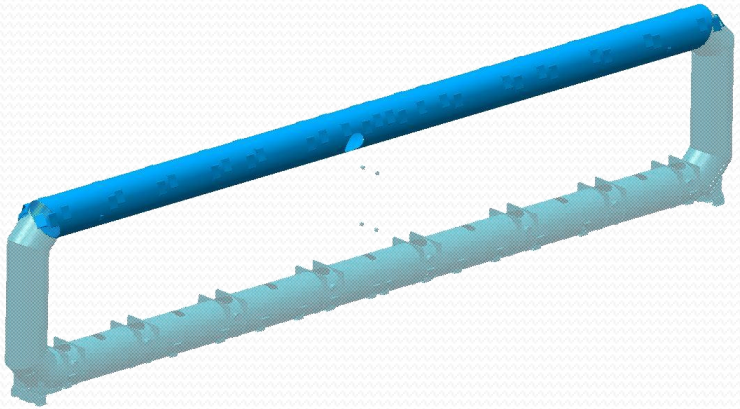
Outer part



Segmentation and Definition of Mass

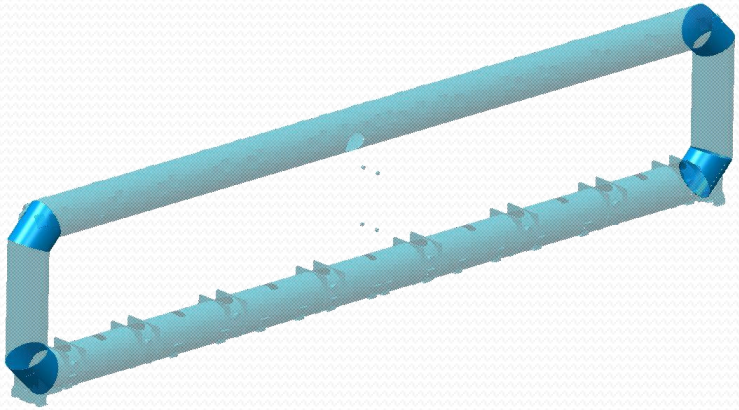
Vol.1. Cryostat Top

Volume 1	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	1	Cryostat Top	Assembly	Stainless Steel 304L	8000	1.26	1.26	10 088
							Total Mass (kg): **10 088**	



Vol.2, 4, 6, 8. Cryostat Corner

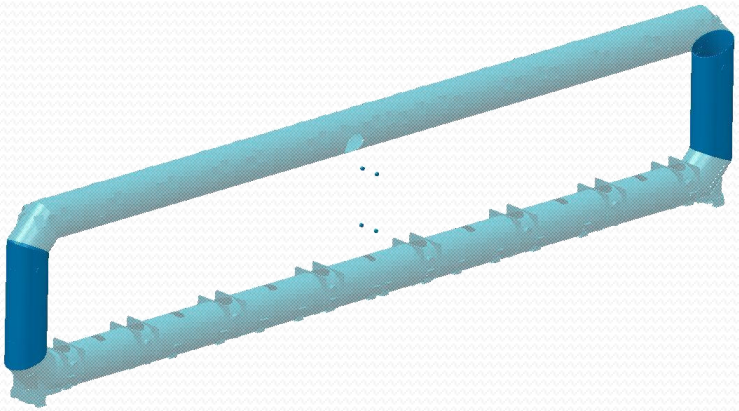
Volume 2,4,6,8	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	4	Cryostat Corner	Assembly	Stainless Steel 304L	8000	0.04	0.16	1 344
							Total Mass (kg): **1 344**	



Segmentation and Definition of Mass

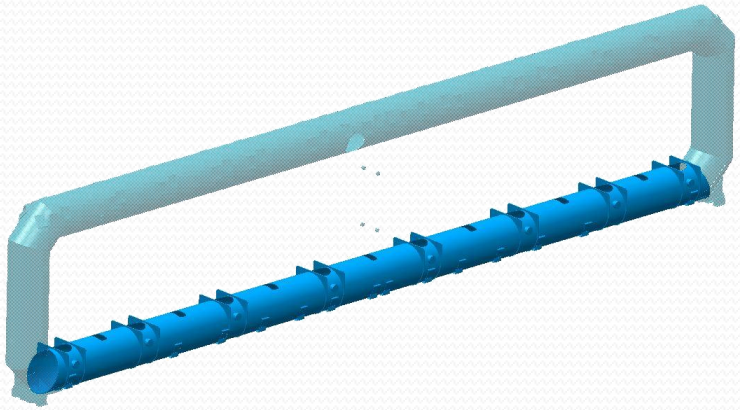
Vol.3, 7. Cryostat Short

Volume 3,7	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	2	Cryostat Short	Assembly	Stainless Steel 304L	8000	0.16	0.34	2 704
							Total Mass (kg): **2 704**	



Vol.5. Cryostat Bottom

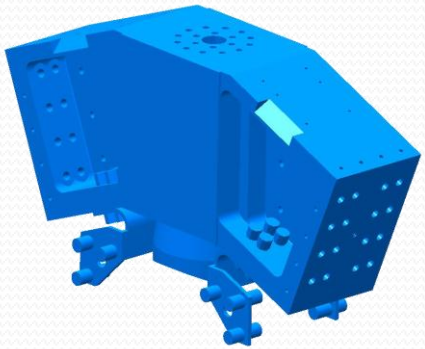
Volume 5	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	1	Cryostat bottom	Assembly	Stainless Steel 304L	8000	1.42	1.42	11 368
							Total Mass (kg): **11 368**	



Segmentation and Definition of Mass

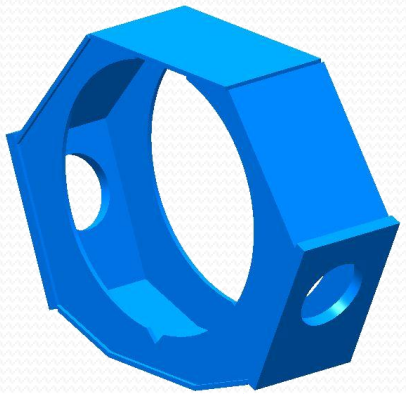
Vol.9. Voussoirs

Volume 9	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	8	Voussoirs	Assembly	Aluminum/Stainless Steel 304L	2650	0.55	4.42	12 344
							Total Mass (kg): **12 344**	



Vol.10. Steffeners

Volume 10	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	8	Steffener	Assembly	Stainless Steel 304L	8000	0.08	0.67	5 336
							Total Mass (kg): **5 336**	



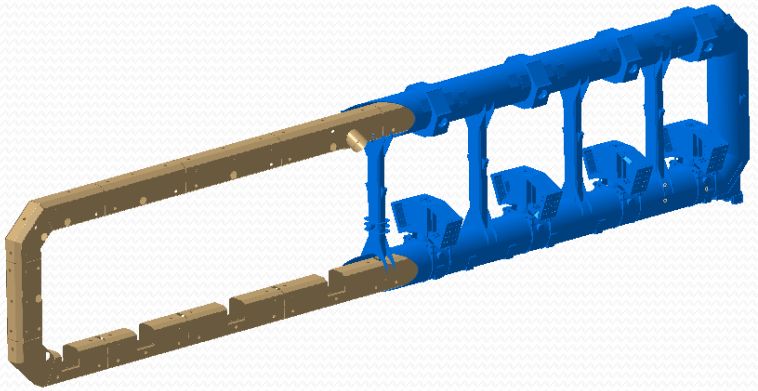
Segmentation and Definition of Mass

Vol.11. Ribs

Volume 11	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	7	Rib	Assembly	Stainless Steel 304L	8000	0.09	0.6	4 824
							Total Mass (kg): **4 824**	

Vol.12. Thermal Shielding

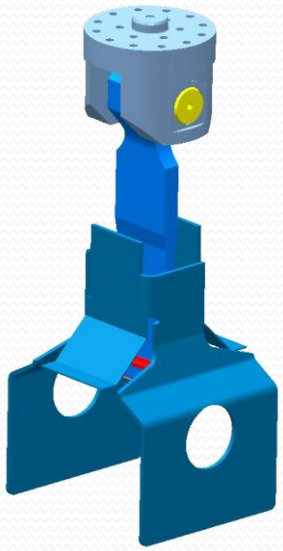
Volume 12	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	1	Thermal Shielding	Part	Aluminum 3003.H22	2740	0.74	0.74	2 020
							Total Mass (kg): **2 020**	



Segmentation and Definition of Mass

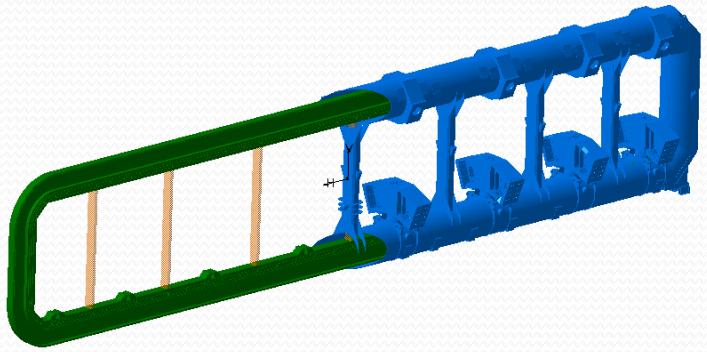
Vol.13. Tie Rod

	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
Volume 13	8	Tie rod	Part	Titan TA5E-ELI	4480	0.016	0.1280	573.44
	8	Lug (Tie rod)	Part	Stainless Steel Z3 CN18-10	8000	0.028	0.2240	1792.0
	8	Shouldered axis (Tie rod)	Part	Titan TA5E-ELI	4480	0.005	0.0400	179.2
	8	Small bar support (Tie rod)	Part	Stainless Steel Z3 CN18-10	8000	0.0002946	0.0024	18.9
	16	Piston (Tie rod)	Part	Stainless Steel Z3 CN18-10	8000	0.00007062	0.0011	9.0
	16	Convex bar (Tie rod)	Part	Stainless Steel Z3 CND 17-12 Az	8000	0.00008187	0.0013	10.5
	16	Concave bar (Tie rod)	Part	Stainless Steel Z3 CND 17-12 Az	8000	0.0001569	0.0025	20.1
	8	Tie-Rod Therm. Plate	Part	Al uminum 1050 H22	2705	0.015	0.12	324.6
						Total:	**0.52**	**2 928**



Vol.14. Casing

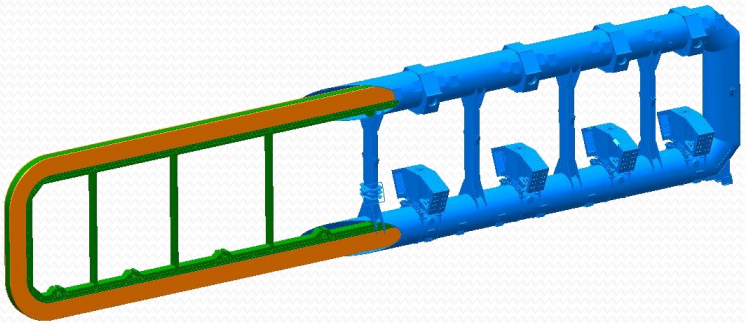
	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
Volume 14	1	casing	Part	Aluminum 5083	2650	6.959	6.959	18440.82
	86		Part	Aluminum 7075 T73	2810	0.00022	0.0189	53.1
	16		Part	Aluminum 5083	2650	0.0002	0.032	84.8
						Total :	**7**	**18 579**



Segmentation and Definition of Mass

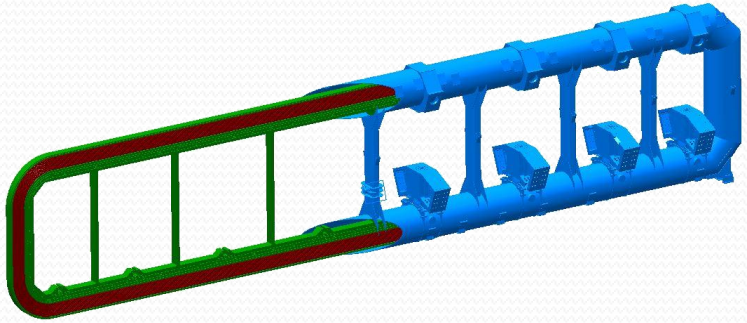
Vol.15. Casing Part

Volume 15	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	1	casing part	Part	Aluminum 5083 h112	2660	1.87	1.87	4 964
							Total Mass (kg): **4 963**	



Vol.16. Coils

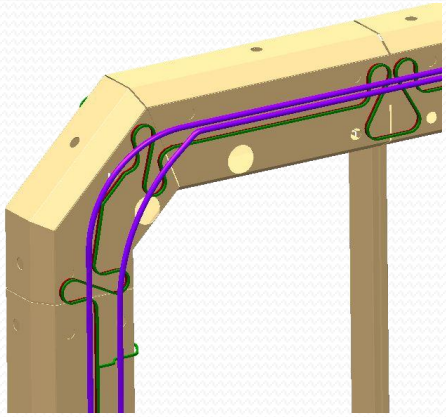
Volume 16	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	1	Coils	Part	Aluminum	2700	4.37	4.37	11 573
							Total Mass (kg): **11 573**	



Segmentation and Definition of Mass

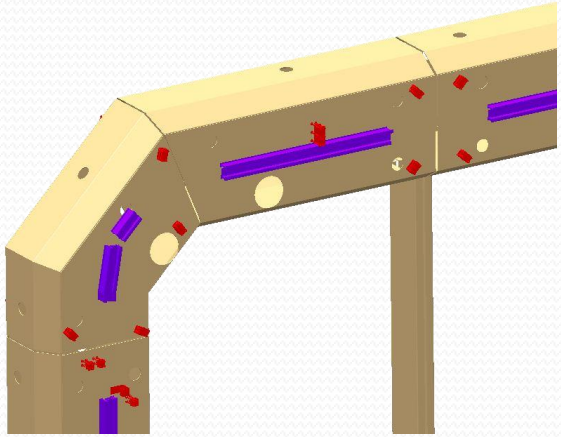
Vol.17. Services

	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
Volume17	1	Pipes	Part	Aluminum 1050	2705	0.0640	0.0640	173.1
	1	Part5	Part	Stainless Steel 304L	8000	0.0040	0.0040	32.0
	1	Part2	Part	Stainless Steel 304L	8000	0.0040	0.0040	32.0
	1	atltbyr_0036	Part	Stainless Steel 304L	8000	0.0006	0.0006	4.6
	2	atltbyr_0035	Part	Stainless Steel 304L	8000	0.0003	0.0005	4.1
	1	atltbyr_0034	Part	Stainless Steel 304L	8000	0.0005	0.0005	4.1
	1	atltbyr_0033	Part	Stainless Steel 304L	8000	0.0004	0.0004	3.2
						Total :	**0.07**	**253**



Vol.18. Service Support

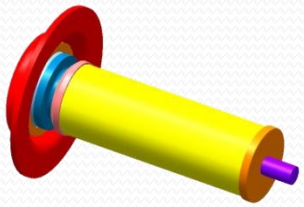
	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
Volume18	139	S3	Part	Multiple*		0.000085	0.01	31.72
	81	Parts	Part	Multiple*		0.00018	0.01479	22.1
	1	Pipes	Part	Aluminum 1050	2705	0.179	0.179	484.2
						Total	**0.2**	**538.0**

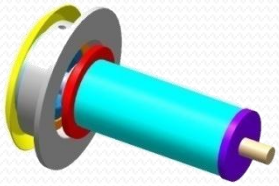


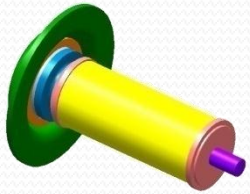
Segmentation and Definition of Mass

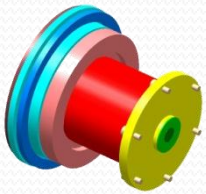
Vol.19. Fasteners

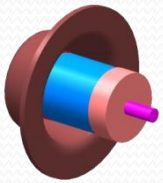
	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
Volume 19	108	Support A1.1	Part	Aluminum 5083 F	2660	0.0001048	0.0113184	30.1
	108	Support A1.5	Part	Stainless Steel 304L	8000	0.00004723	0.00510084	40.8
	108	Support A1.6	Part	Stainless Steel 304L	8000	0.00006412	0.00692496	55.4
	100	Support A1.8	Part	Stainless steel AISI 304 L	8000	0.00002734	0.002734	21.9
	52	Support C1.2	Part	Aluminum 5083 F	2660	0.0001228	0.0063856	17.0
	58	Support C1.7	Part	Stainless Steel 304L/316L	8000	0.0000223	0.0012934	10.3
	58	Support C1.8	Part	Stainless Steel 304L/316L	8000	0.00002888	0.00167504	13.4
	28	Support D1.1	Part	Stainless Steel 304L/316L	8000	0.00005369	0.00150332	12.0
	28	Support D1.5	Part	Aluminum 2024 T3	2780	0.0001857	0.0051996	14.5
	44	E EST_2	Part	Stainless Steel AISI 304 L	8000	0.0004261	0.0187484	150.0
	44	E EST_3	Part	PERMAGLAS TE630	1850	0.0005058	0.0222552	41.2
	44	E EST_4	Part	Aluminum	2700	0.0007714	0.0339416	91.6
	44	E EST_5	Part	Aluminum	2700	0.0005786	0.0254584	68.7
	44	E EST_6	Part	Aluminum	2700	0.0006777	0.0298188	80.5
	44	E EST_7	Part	Aluminum	2700	0.0001206	0.0053064	14.3
	44	E EST_9	Part	Aluminum	2700	0.0005685	0.025014	67.5
	72	Support F1.1	Part	Stainless Steel 304L/316L	8000	0.00008567	0.00616824	49.3
	72	Support F1.3	Part	Aluminum 2024 T3	2780	0.0001163	0.0083736	23.3
	72	Support F1.5	Part	Stainless Steel 304L/316L	8000	0.00003998	0.00287856	23.0
	72	Support F1.6	Part	Stainless Steel 304L/316L	8000	0.00009161	0.00659592	52.8
	72	Support F1.8	Part	Stainless Steel AISI 304L	8000	0.00002725	0.001962	15.7
	72	Support F1.13	Part	PERMAGLAS TE630	1850	0.00007735	0.0055692	10.3
	all	other parts					0.0591	213.4
							Total Mass (kg):	1117.1

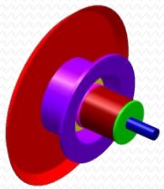












Segmentation and Definition of Mass

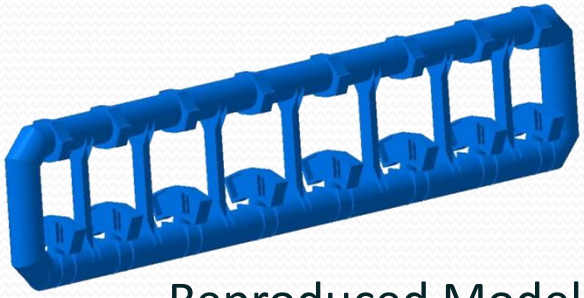
Vol.20. Ribs of Thermal Shielding

Volume 20	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	7	Ribs of Thermal Shielding	Part	Aluminum 3003.H22	2740	0.0144	0.101	276
							Total Mass (kg): **276**	

Vol.21. Ribs of Casing

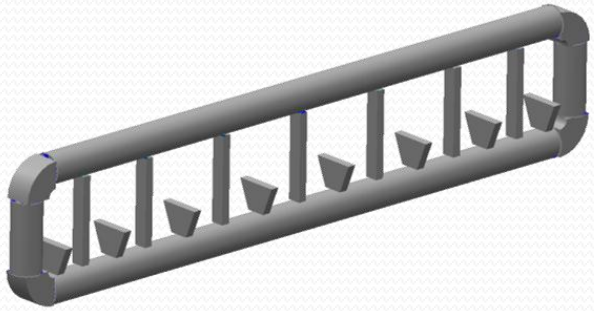
Volume 21	Number of Items	Part Name		Material	Density (kgs/m³)	Volume (m³)	Total Volume (m³)	Total Mass (kgs)
	7	Ribs of Coil casing	Part	Aluminum 5083	2650	0.1	0.7	1 873
							Total Mass (kg): **1 873**	

Compare Analysis

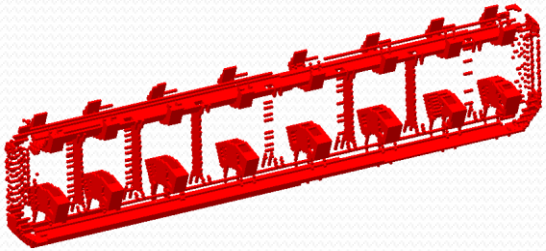


Reproduced Model

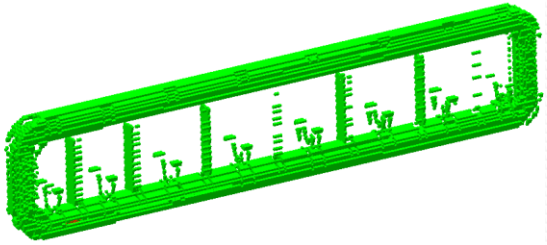
VS



Geant4/C++ Model



Δ_1 = Geant4/C++ - CATIA



Δ_2 = CATIA – Geant4/C++

$\Delta_v = \Delta_{v1} + \Delta_{v2} + \Delta_{v3} + \Delta_{v4} + \Delta_{v5} + \Delta_{v6} + \Delta_{v7} + \Delta_{v8} = 0.124\ m^3 - 0.001\ m^3 + 0.176\ m^3 + 0.198\ m^3 - 0.157\ m^3 + 0.088\ m^3 + 0.149\ m^3 + 2.327\ m^3 = 2.9\ m^3$

$\Delta_v = \Delta_{m1} + \Delta_{m2} + \Delta_{m3} + \Delta_{m4} + \Delta_{m5} + \Delta_{m6} + \Delta_{m7} + \Delta_{m8} = 1138\ kg + 14\ kg + 158\ kg + 1738\ kg - 911\ kg + 778\ kg + 1248\ kg + 7517.9\ kg = 11\ 680.9\ kg$

Simplification of Geometry

2 Standard Phases of Synthesis:

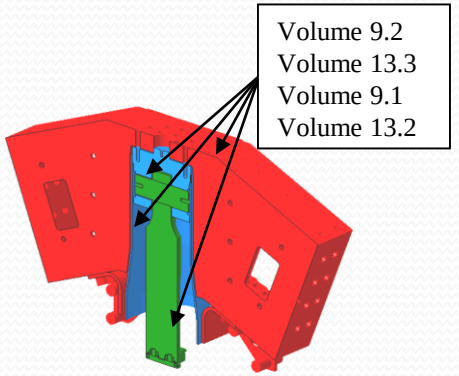
- Grouping of components with same materials and density
- Unify groups with kindred materials and density

Simplification of Voussoirs

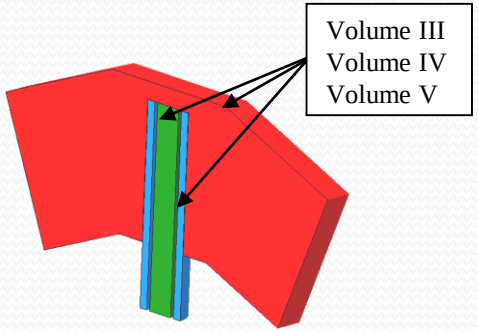
	Name	Material	Density	Volume	Weight	
Volume 9	Vossuoir	Aluminium	2650	0.537	1423	Volume 9.1
	Vossuoir	SSTEEL	8000	0.015	120	Volume 9.2
Volume 13	Tie rod	TA5E-ELI	4480	0.016	72	Volume 13.2
	Lug	Z3 CN18-10	8000	0.028	224	
	Shouldered axis	TA5E-ELI	4480	0.005	22	
	Small bar support	Z3 CN18-10	8000	0.0003	2	Volume 13.3
	Piston	Z3 CN18-10	8000	0.0001	1	
	Convex bar	Z3 CND 17-12 Az	8000	0.0001	1	
	Concave bar	Z3 CND 17-12 Az	8000	0.0002	1	
	Tie-Rod Therm. Plate	Al 1050 H22	2705	0.015	41	Volume 13.1

Discrepancies in Volume = 0.05 m^3

in Mass = 15Kg



1st Phase

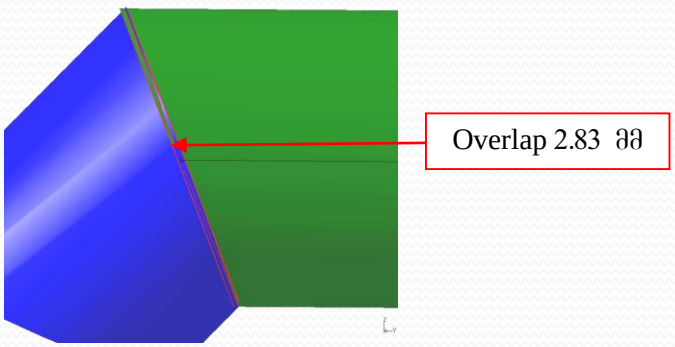


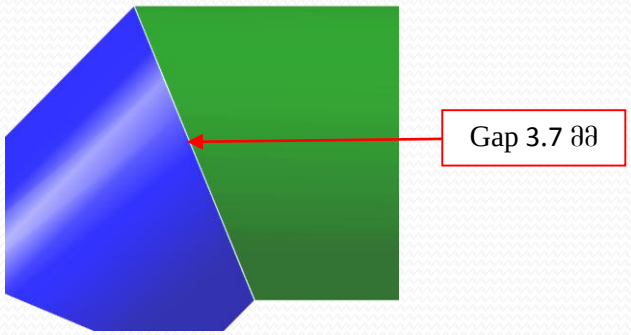
2nd Phase

Generation of Geant4/C++ Codes

Geant4/C++ causes:

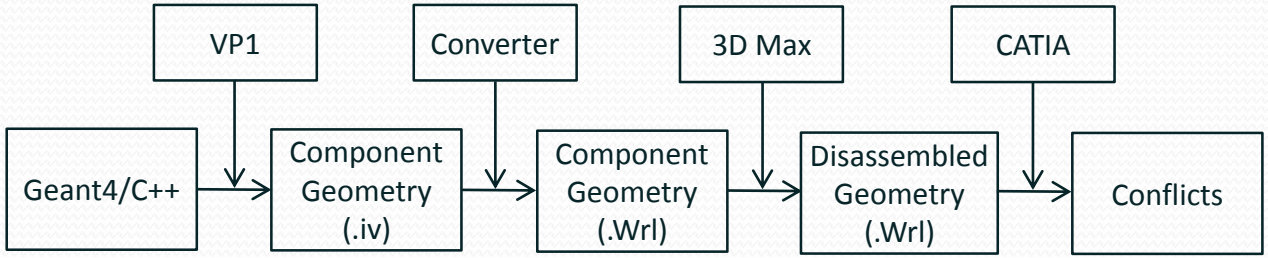
- Necessity for additional detalization of Geometry
- Programming in Z0 position
- Necessity in additional geometrical transactions for final positioning
- Creation of Overlaps and Gaps

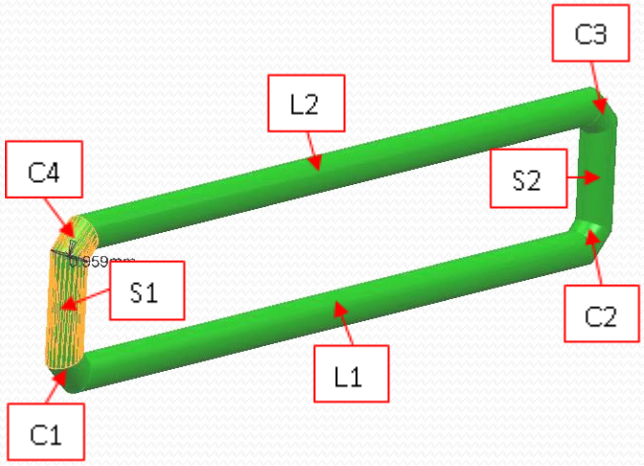




Generation of Geant4/C++ Codes

- Method for Geant4/C++ conflicts detection and evaluation in CATIA

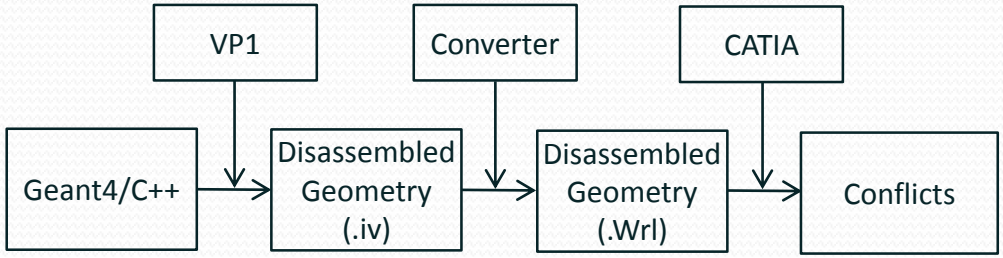


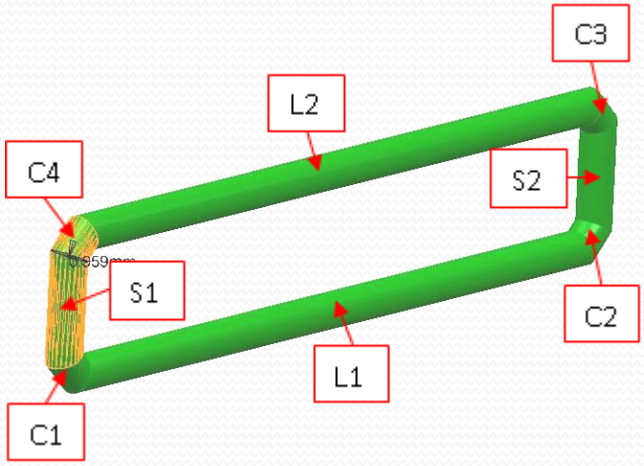


No.	Product 1	Product 2	Type	Value
1	C1 (C1.1)	L1 (L1.1)	Clash	-4.62
2	C1 (C1.1)	S1 (S1.1)	Clash	-1.41
3	C2 (C2.1)	L1 (L1.1)	Clash	-3.38
4	C2 (C2.1)	S2 (S2.1)	Clash	-0.96
5	C3 (C3.1)	L2 (L2.1)	Clash	-3.03
6	C3 (C3.1)	S2 (S2.1)	Clash	-0.58
7	C4 (C4.1)	L2 (L2.1)	Clash	-3.99
8	C4 (C4.1)	S1 (S1.1)	Clash	-0.49

Generation of Geant4/C++ Codes

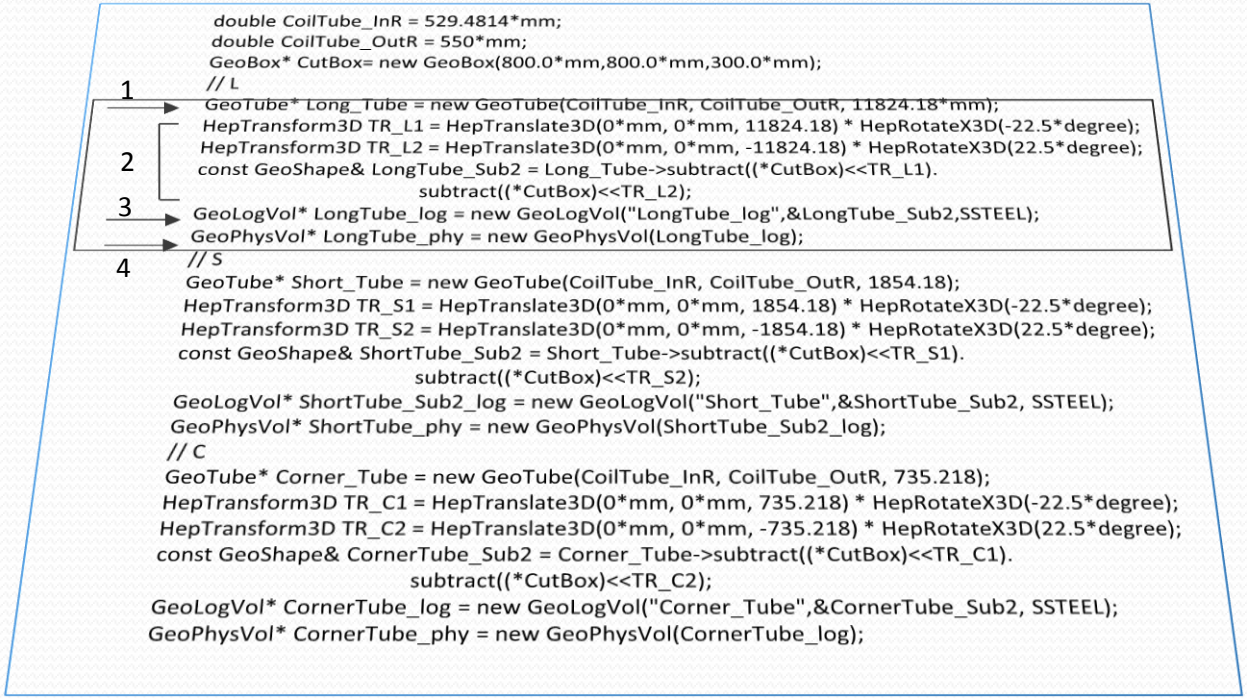
- Method for Geant4/C++ conflicts detection and evaluation in CATIA





Overlap		Volume I (mm)							
Components		*Sector 2*	*Sector 4*	*Sector 6*	*Sector 8*	*Sector 10*	*Sector12*	*Sector 14*	*Sector 16*
C3	*L2*	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
C3	*S2*	0	0	0	0	0	0	0	0
C4	*L2*	0.04	0.03	0.03	0.03	0.03	0	0.03	0.03
C4	*S1*	0	0	0	0	0.03	0	0	0
C1	*L1*	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
C1	*S1*	0	0	0	0	0	0	0	0
C2	*L1*	0	0	0	0	0	0	0	0
C2	*S2*	0	0	0	0	0	0	0	0

Generation of Geant4/C++ Codes



```
double CoilTube_InR = 529.4814*mm;
double CoilTube_OutR = 550*mm;
GeoBox* CutBox= new GeoBox(800.0*mm,800.0*mm,300.0*mm);
// L
GeoTube* Long_Tube = new GeoTube(CoilTube_InR, CoilTube_OutR, 11824.18*mm);
HepTransform3D TR_L1 = HepTranslate3D(0*mm, 0*mm, 11824.18) * HepRotateX3D(-22.5*degree);
HepTransform3D TR_L2 = HepTranslate3D(0*mm, 0*mm, -11824.18) * HepRotateX3D(22.5*degree);
const GeoShape& LongTube_Sub2 = Long_Tube->subtract((*CutBox)<<TR_L1).
                                subtract((*CutBox)<<TR_L2);
GeoLogVol* LongTube_log = new GeoLogVol("LongTube_log",&LongTube_Sub2,SSTEEL);
GeoPhysVol* LongTube_phy = new GeoPhysVol(LongTube_log);
// S
GeoTube* Short_Tube = new GeoTube(CoilTube_InR, CoilTube_OutR, 1854.18);
HepTransform3D TR_S1 = HepTranslate3D(0*mm, 0*mm, 1854.18) * HepRotateX3D(-22.5*degree);
HepTransform3D TR_S2 = HepTranslate3D(0*mm, 0*mm, -1854.18) * HepRotateX3D(22.5*degree);
const GeoShape& ShortTube_Sub2 = Short_Tube->subtract((*CutBox)<<TR_S1).
                                 subtract((*CutBox)<<TR_S2);
GeoLogVol* ShortTube_Sub2_log = new GeoLogVol("Short_Tube",&ShortTube_Sub2, SSTEEL);
GeoPhysVol* ShortTube_phy = new GeoPhysVol(ShortTube_Sub2_log);
// C
GeoTube* Corner_Tube = new GeoTube(CoilTube_InR, CoilTube_OutR, 735.218);
HepTransform3D TR_C1 = HepTranslate3D(0*mm, 0*mm, 735.218) * HepRotateX3D(-22.5*degree);
HepTransform3D TR_C2 = HepTranslate3D(0*mm, 0*mm, -735.218) * HepRotateX3D(22.5*degree);
const GeoShape& CornerTube_Sub2 = Corner_Tube->subtract((*CutBox)<<TR_C1).
                                  subtract((*CutBox)<<TR_C2);
GeoLogVol* CornerTube_log = new GeoLogVol("Corner_Tube",&CornerTube_Sub2, SSTEEL);
GeoPhysVol* CornerTube_phy = new GeoPhysVol(CornerTube_log);
```


- According to Given Structure it was generated Geant4/C++ code for the full Coil
- Code consists of 235 programming strings

Conclusions

1. Creation of precise descriptions of ATLAS detector components on the base of engineering data is actual task for the Reconstruction and Simulation
2. Implementation of CATIA provides efficient way for the comparison of Geant4/C++ descriptions with Engineering models
3. Compare analysis should be done by CATIA DMU algorithms
4. Geometry export from Geant4/C++ to CATIA should be done on the base of facet representation of geometry (*.wrl* file)
5. New method of visualisation and calculation of Geant4/C++ overlaps and Gaps on the base of CATIA, was developed
6. For the ATLAS detector Coils – New models reproduction, Compare analysis, Simplification and Geant4/C++ code generation have been done

Thank you for Attention