The Micromegas Vertex Tracker geometry for GEMC

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This report describes the MVT geometry as entered into the CLAS12 simulation package GEMC. It summarizes all the inputs so that they can easily be checked. Attention is paid to the approximations which were made. It contains updates and corrections with respect to the draft report released Nov. 30, 2016.

The MVT is composed of a 6-layer barrel (BMT) and a 6-disk forward detector (FMT). An initial version of the BMT geometry was implemented by Sebastien Procureur (2012, active zones only). Initial versions of the FMT were implemented by Frédéric Georges (2015, an internal report in French describes this work). The present version builds on these. In addition, it takes into account final sizes for the built detectors and it incorporates all structure elements (save for some screws and holes) and elements such as cables and connectors which could be on the pathway of particles. Some simplifying approximations were implemented in the description of such elements. These will be mentioned hereafter.

Missing: i) a portion of FMT cables at the downstream end of the BMT mother volume (from z = 292.3 to 298.3 mm), ii) FMT gas tubes at the same downstream end of the BMT mother volume and within the FMT volume, iii) FMT gas connectors on the FMT disks. Note that the description of the FMT cables is discontinuous.

All numbers below are for the GEMC simulation. Some may differ slightly from the real dimensions or positions. This is especially true when using effective thicknesses for mesh, cables, connectors,.... Also several numbers refer to absolute positions and do not appear as such in the programs.

At this stage, there is no provision for global positioning errors (e.g. shifts in z relative to the nominal positions). Several parameters would have to be changed for such shifts.

Files used: fmt.pl, bmt.pl, micromegas__parameters_new.txt, materials.pl, micromegas.pl .

Acknowledgements: many thanks to David Attié, Stephan Aune and Rémi Granelli for some explanations on various drawings, to Franck Sabatié for setting up my environment with Linux and GEMC, to Maurizio Ungaro for some checks on the GEMC output and to Maxime Defurne for small adjustments in a few positions.

Forward Micromegas Tracker (FMT)

Mother volume (made of air): z_{min} = 298.3 mm, z_{max} = 373 mm, φ_{min} = 0°, φ_{max} = 360°, R_{min} = 22 mm, R_{max} = 250 mm. z_{min} corresponds to the most downstream part of BMT, its closing plate and the attachments for the FMT on the BMT-FMT peek interface.

All volumes in the FMT tables below are cylinders or cylindrical sectors ("Tube" for Geant).

Active zones

For the 6 annular disks, **φ_{min} = 0°, φ_{max} = 360°, R_{min} = 39 mm, R_{max} = 195 mm** if one considers the radial extension of the drift space (between inner peek ring and outer Al ring), or **R_{min} = 48 mm, R_{max} = 185 mm** if one considers the strips extension diminished by the inner photoresist ring. The signal strips extension is **R_{min} = 42 mm, R_{max} = 185 mm** (Maxime uses R_{min} = 42.575 mm, R_{max} = 185.4 mm in the tracking).

The interdisk distance is nominally 11.9 mm, except between D3 and D4 13.9 mm. The table below gives the z position of the most upstream element of a detector (z_o = FMT_zpos_layerk in parameter file). The **active zone** (drift space, neglecting 64 μm of photoresist above the mesh, gas2 in fmt.pl) is **between z_o + 2.697 mm and z_o + 7.697 mm** for all disks.

Disk	z_o (mm)
1	300.3
2	312.2
3	324.1
4	338.0
5	349.9
6	361.8

For each detector disk

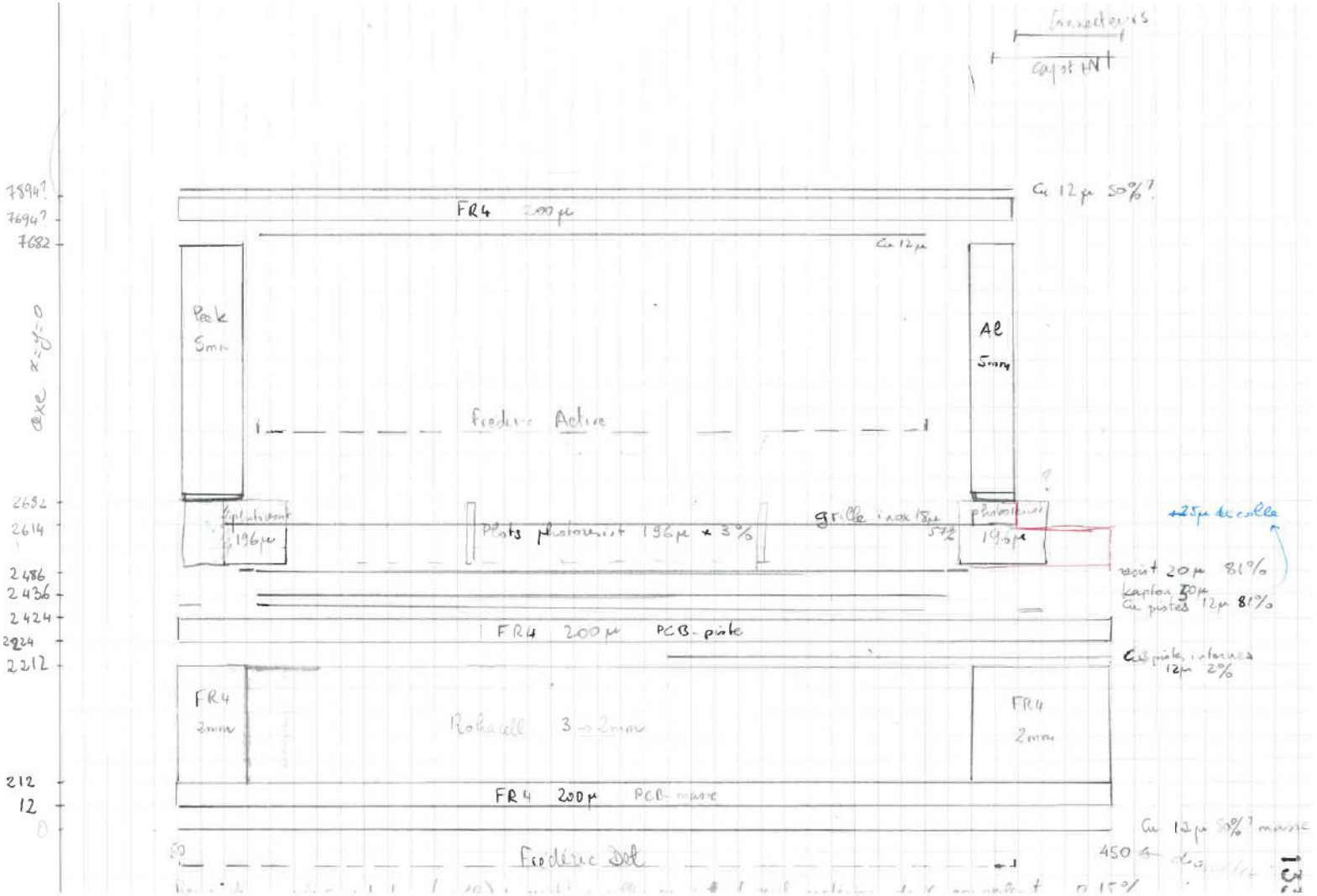
The z positions in the table below are given relative to the above z_o. When not covering the full range, the azimuthal angles are given for the first sub-element in D1, all others being deduced by the indicated rotation. In fmt.pl, the (initial) azimuthal angles are coded for a position of D1 where connectors are placed symmetrically with respect to the y-axis, and then rotated to the nominal position via the parameter FMT_overall_disks_rotation in micromegas__parameters_new.txt. Here, they are given directly in their nominal position (for D1). In addition each disk is deduced from the previous one by a 60° rotation. I was not able to check that the present values of the rotation parameters (FMT_overall_disks_rotation = 60° and FMT_overall_spacers_rotation = 0°) correspond to the actual setup. Likewise the angular position of the inner screws (3.6° for the first one) was not confirmed. Units: mm, degrees.

Element	Sub-element	Description	$[z_{min}, z_{max}]$ (relative to z_o)	$[R_{min}, R_{max}]$	$[\varphi_{min}, \varphi_{max}]$ (for D1)
Ground		Cu 12 µm modeled by a uniform 5 µm layer to account for 41% filling fraction	[0, 0.005]	[25, 225]	[0, 360]
PCB-ground		FR4 200 µm	[0.005, 0.205]	[25, 225]	
Inner FR4 ring		FR4 2 mm	[0.205, 2.205]	[25, 40]	
Rohacell		Rohacell 4 mm compressed in 2 mm	[0.205, 2.205]	[40, 195]	
Outer FR4 ring		FR4 2 mm	[0.205, 2.205]	[195, 225]	
PCB-detector		FR4 200 µm	[2.205, 2.405]	[25, 225]	
Strips		Cu 12 µm – filling fraction 81% absorbed in the definition of the material	[2.405, 2.417]	[42, 185]	
Kapton		Kapton 50 µm	[2.417, 2.467]	[42, 185]	
Glue 25 µm neglected					
Resistive strips		Resistive paste 20 µm – filling fraction 81% absorbed in	[2.467, 2.487]	[42, 185]	

		the definition of the material			
Inner Photoresist		Photoresist 128 µm	[2.487, 2.615]	[25, 48]	
Gas1 (amplification)		Neon/Ethane/CF4 128 µm	[2.487, 2.615]	[48, 193]	
Photoresist pillars in amplification gap and in 64 µm above the mesh completely negligible (in average)					
Outer Photoresist		Photoresist 128 µm	[2.487, 2.615]	[193, 225]	
Mesh 45/18		Inox 18 µm - effective thickness = 0.45 * 18 µm absorbed in the definition of the material	[2.615, 2.633]	[39, 204]	
Inner Photoresist		Photoresist 64 µm	[2.633, 2.697]	[25, 48]	
Gas omitted (hence air by default)			[2.633, 2.697]	[48, 193]	
Outer Photoresist		Photoresist 64 µm	[2.633, 2.697]	[193, 204]	
Inner peek ring		Peek 5 mm	[2.697, 7.697]	[26, 39]	
Gas2 (drift)		Neon/Ethane/CF4 5 mm	[2.697, 7.697]	[39, 195]	
Outer Al ring		Al 5 mm (called outerpeek in fmt.pl)	[2.697, 7.697]	[195, 204]	
Drift electrode		Cu 12 µm	[7.697, 7.709]	[42, 185]	
PCB-drift		FR4 200 µm	[7.709, 7.909]	[25, 204]	
Ground		Cu 12 µm modeled by a uniform 5 µm layer to account for 44% filling fraction	[7.909, 7.914]	[25, 204]	
HV covers	2 HV covers. 2nd one at 180° with the one described here. Sédi drawing 6 2075 – DM – 1240 105.				
	Flat top	Al 1 mm	[9.115, 10.115]	[200, 224.8]	[46.245, 73.755]
	Lateral edge	Al	[2.615, 9.115]	[204, 223.8]	[46.245, 46.5]
	Lateral edge	Al	[2.615, 9.115]	[204, 223.8]	[73.5, 73.755]
	External edge	Al	[2.615, 9.115]	[223.8, 224.8]	[46.245, 73.755]
Connectors	2x8 connectors. In each group of 8, apply 15° rotations to the one described here. Then rotation of 180° to get the second group of 8. Connector + end of cable are very roughly modeled, both from the drawing and from looking at the object. A sector shape was adopted for simplicity, although it is rectangular (but differences within errors at this radial distance). Samtec drawing MEC8-135-02-XD-RA1				
	Connector	PCB 3 mm (an approximation for the plastic part)	[2.615, 5.615]	[205.9, 213.3]	[93.2, 101.8]
	Connector	Al 0.5 mm arbitrarily on top of first element	[5.615, 6.115]	[205.9, 213.3]	[93.6, 101.4]
	Cable end	PCB 2 mm (an approximation for the cover part)	[4.115, 6.115]	[213.3, 225.3]	[93, 102.6]
	Soldering	Al 0.7 mm	[6.115, 6.815]	[216.5, 224.0]	[95, 100.6]

<table>
<tr><td rowspan="4">Signal cables</td><td colspan="5">Their description is divided into a (short) radial part just outwards each connector and a much less realistic longitudinal part. Since the cables do not run straight along z, this later part was modeled by homogeneous 120 degrees sectors corresponding to 8 cables, with an effective thickness to account for the ratio of 18 mm cable width over 15 degrees sector (2 sectors per disk). These sectors extend longitudinally from the upstream end of the FMT mother volume to the upstream end of the cable radial parts for each disk.
See BMT below for comments on the cable composition and thickness.</td></tr>
<tr><td rowspan="2">Radial part (extension and spacing between layers arbitrary)</td><td>Cu 87.6 µm</td><td>[4.115, 4.203]</td><td rowspan="2">[225.3, 241.2+i*1.7] (i = disk# - 1)</td><td rowspan="2">[95.305, 99.695]</td></tr>
<tr><td>Peek 1.056 mm</td><td>[4.203, 5.257]</td></tr>
<tr><td rowspan="2">Longitudinal part</td><td>Cu 87.6*0.281 µm</td><td rowspan="2">From 298.3 abs. to 4.115 rel.</td><td>[240.879, 240.904] +i*1.7</td><td rowspan="2">[90-210] and [270-30]</td></tr>
<tr><td>Peek 1.056*0.281 mm</td><td>[240.904, 241.2] +i*1.7</td></tr>
<tr><td rowspan="3">Inner screws</td><td colspan="5">9 inox screws, each one deduced from the other by a 40° rotation. In order to avoid overlap with several other volumes, head and body of screws are separated, placed respectively upstream and downstream of the detector, their length halved and density doubled. Approximate dimensions of screw communicated by David A. Position on Sédi drawing 6 2075 – DM – 1240 – 013 & 133.</td></tr>
<tr><td>Head</td><td>Inox cylinder, 2.5 mm, radius, 1.5 mm length</td><td>[-1.5, 0]</td><td rowspan="2">Centered at r = 30 mm</td><td rowspan="2">Centered at ϕ = 3.6°</td></tr>
<tr><td>Body</td><td>Inox cylinder, 1.25 mm, radius, 3 mm length</td><td>[7.914, 10.914]</td></tr>
<tr><td colspan="3">Neglected: HV cables, gas cables and feed through, several (outer) screws</td><td></td><td></td><td></td></tr>
</table>

Elements highlighted in yellow are within the path of particles detected in FMT. Their total thickness amounts to **0.725% radiation length** (per disk; for details on calculation, see \\dapnia\data\manip\Clas12\11_Simulation\simulation_forward_sim_forward_MG.xlsx – reserved access). The darker yellow is for the above defined active zone (drift). The sketch below illustrates the content of this table.


FR4 200µ
Cu 12µ
Peek 5mm
Al 5mm
Fenêtre Active
Plots photoresist 196µ x 3%
grille 18µ
FR4 200µ PCB piste
FR4 2mm
Rohacell 3 → 2mm
FR4 2mm
FR4 200µ PCB masse
Fenêtre Drift
+25µ de colle
résist 20µ 81%
kapton 50µ
Cu pistes 12µ 81%
Cu pistes intérieures 12µ 2%
Cu 12µ 50% masse
7894?
7694?
7682
2692
2614
2486
2436
2424
2224
2212
212
12
0
450

Supporting structure

These are fixed in angle by the corresponding attachments on the BMT-FMT peek interface. The z positions in the table below are given relative to the above z_o.

Element	Sub-element	Description	$[z_{min}, z_{max}]$ (relative to z_o)	$[R_{min}, R_{max}]$ mm	$[\varphi_{min}, \varphi_{max}]$ deg.
Supports for D1, 2, 4 and 5	2 of each, at 180° from each other. Sédi drawing 6 2075 – DM – 1240 001 and 003.				
	Flat sector	Al 2 mm	[-2, 0]	[205, 225]	[58, 92]
	2 attachments	Al 5 mm	[-2, +3]	[225, 240]	[58, 62] ([58, 63.5] for D1)
					[88, 92] ([86.5, 92] for D1)
Supports for D3 and 6	2 of each, at 180° from each other. Sédi drawing 6 2075 – DM – 1240 002.				
	Flat sector	Al 2 mm	[-2, 0]	[205, 225]	[58, 122]
	3 attachments	Al 5 mm	[-2, +3]	[225, 240]	[58, 62]
					[88, 92]
					[118, 122]
Spacers	2 of each pair, at 180° from each other. Sédi drawing 6 2075 – DM – 1240 004 and 005, approximated by copper (instead of brass) cylinder, 2.3 mm in radius as weighted average of different parts, length filling the gap between 2 disk attachments. 5 sets of these spacers (nothing after D6).				
	2 spacers	Cu 6.9 mm long (8.9 between D3 and D4), 2.3 mm radius	[3, 9.9] (D3-D4: [3, 11.9])	Centered at r = 236 mm	Centered at ϕ = 59°
					Centered at ϕ = 91°

Barrel Micromegas Tracker (BMT)

Mother volume (made of air): z_{min} = 298.3 -2*385 = -471.7 mm, z_{max} = 298.3 mm, φ_{min} = 0°, φ_{max} = 360°, R_{min} = 140 mm, R_{max} = 240 mm. z_{max} corresponds to the most downstream part of BMT, its closing plate and the attachments for the FMT on the BMT-FMT peek interface; it is also taken as z_{min} for the FMT mother volume.

Unless indicated otherwise, volumes in the BMT tables below are cylinders or cylindrical **sectors** ("Tube" for Geant). The other type is "Box". There are a few cases where "Box" and "Tube" elements were made tangent to each other, instead of a perfect continuity, but this is a good approximation as it occurs over small distances (or azimuthal angle range).

Most elements were positioned longitudinally with respect to the PCB downstream end at z=290.3 mm.

There was no effort in implementing a detailed description of structural elements upstream the active zone (large polar angles).

Active zones

Each of the 6 layers is made of 3 identical detectors, or tiles. The table below gives the radial position of the most upstream element of a detector (R_o = BMT_radius_layerk in parameter file). The **active zone** (drift space, Gas2 in bmt.pl) is **between R_o + 0.415 mm and R_o + 3.415 mm** for all tiles. The longitudinal (z) and azimuthal (φ) extensions of the active zones are also given (the z position and length of layers 1, 4 and 6 corrected by Maxime). The φ extension is given by a fixed inter-tile distance (24.7 mm) at a variable radius.

Layer	Name	R_o (mm)	[z_{min}, z_{max}] (mm)	[φ_{min}, φ_{max}] (deg., for tile 1)
1	CR4-C	145.731	[-126.07, 246.25]	[34.856, 145.144]
2	CR4-Z	160.731	[-127.77, 244.98]	[34.402, 145.598]
3	CR5-Z	175.731	[-148.69, 271.9]	[34.027, 145.973]
4	CR5-C	190.731	[-148.23, 272.25]	[33.710, 146.290]
5	CR6-Z	205.731	[-169.6, 275.2]	[33.439, 146.561]
6	CR6-C	220.731	[-169.55, 275.25]	[33.206, 146.794]

For each detector tile

The R positions in the table below are given relative to the above R_o. For all detector elements except the PCB and drift kapton window, the z and φ coverage is given by the above defined active zone (AZ). This is obviously not the case in the real detector and will be corrected later. However, the incidence in terms of material in the path of particles should be small. Each tile is deduced from the previous one by a 120° rotation. The carbon rods and arcs (and maybe the upstream Al arcs) are on the path of some particles entering CTOF and CND, and also on the BMT path for some curved trajectories. Units: mm, degrees.

Element	Sub-element	Description	$[R_{min}, R_{max}]$ (relative to R_o)	$[z_{min}, z_{max}]$	$[\varphi_{min}, \varphi_{max}]$ (for L1/tile1)
Coverlay		Kapton 50 µm	[0, 0.050]	AZ	AZ
Ground		1.584 µm = Cu 12 µm * .132 (average value between Z, 0.082, and C, 0.182)	[0.050, 0.052]		
PCB		FR4 100 µm	[0.052, 0.152]	[-421.7, 290.3] (for all layers)	[31.179, 148.821] (fixed 6 mm at R_0 with no PCB)
Strips		Cu 12 µm – filling fraction absorbed in the definition of the material for each layer	[0.152, 0.164]	AZ	AZ
Kapton strips		Kapton 75 µm	[0.164, 0.239]		
Resistive strips		Resistive paste 20 µm – filling fraction absorbed in the definition of the material for each layer	[0.239, 0.259]		
Gas1 (amplification)		Argon 95%/Isobutane 128 µm	[0.259, 0.387]		
Photoresist pillars in amplification gap and in 64 µm above the mesh completely negligible (in average)					
Mesh 60/18		Inox 18 µm - effective thickness = 0.36 * 18 µm absorbed in the definition of the material	[0.387, 0.405]		
Gas2 (drift)		Argon 95%/Isobutane 3 mm	[0.405, 3.405]		
Photoresist pillars in drift space for drift foil completely negligible (in average)					

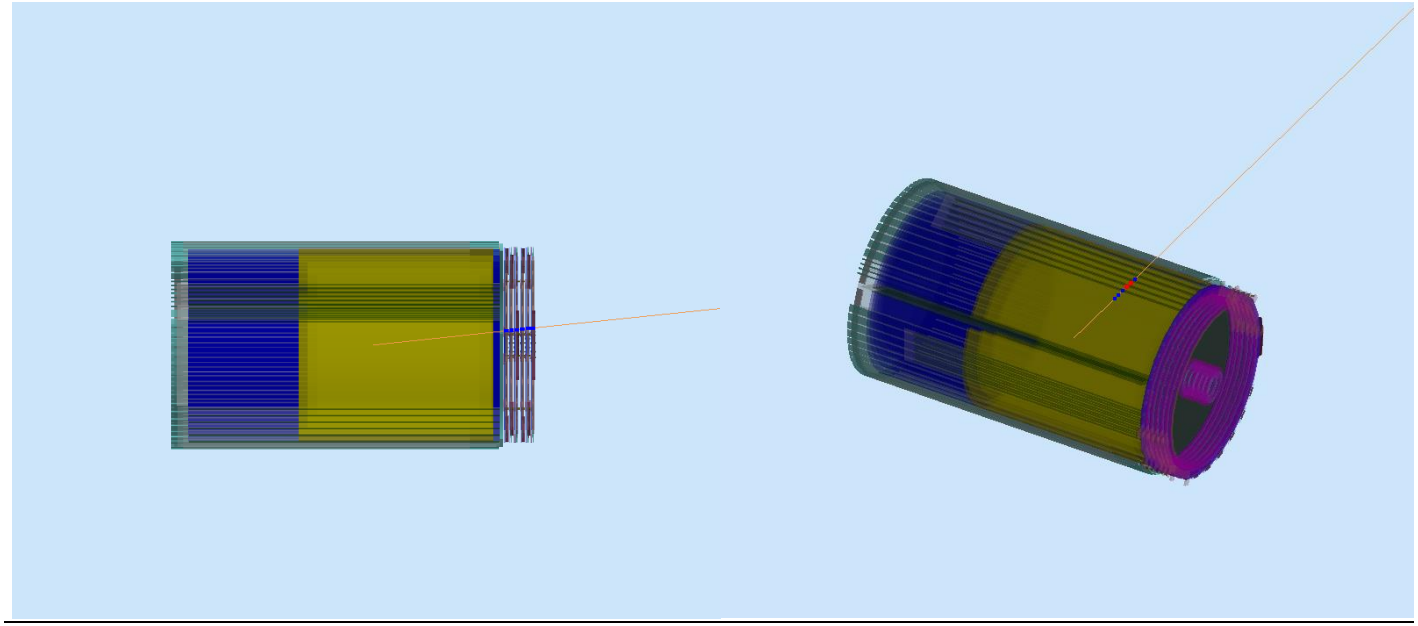
<table>
<tr><td>Drift electrode</td><td></td><td>Cu 5*0.024=0.12 µm for all layers except 6C full 5 µm</td><td>[3.405, 3.405]
[3.405,3.410] 6C</td><td></td><td></td></tr>
<tr><td>Drift foil</td><td></td><td>Kapton 250 µm</td><td>[3.405, 3.655]
[3.410,3.660] 6C</td><td>[-158.7, 290.3] CR4
[-188.52, 290.3] CR5
[-200.7, 290.3] CR6</td><td>[31.152, 148.848]
(6 mm at $R_0 + R_{min}$
with no kapton)</td></tr>
<tr><td>Ground</td><td></td><td>Cu 5*0.082=0.41 µm</td><td>[3.655, 3.655]
[3.660,3.660] 6C</td><td>AZ</td><td>AZ</td></tr>
<tr><td rowspan="3">C-rods</td><td colspan="5">2 straight hollow rods, 3 mm x 3 mm x 710 mm (“Box”). Sédi drawing 6 2075 – DM – 1500 201 & 202. Azimuthal position given by a fixed 4.5 mm from both edges of the 120° sector (hence layer dependent).</td></tr>
<tr><td>1</td><td rowspan="2">C of adjusted density</td><td rowspan="2">Centered
at R_0 + 0.269
(146, 161, …)</td><td rowspan="2">[-419.7, 290.3]</td><td>Centered
at 31.766°</td></tr>
<tr><td>2</td><td>Centered
at 148.234°</td></tr>
<tr><td rowspan="5">Arcs</td><td colspan="5">4 arcs per tile, section 3 mm x 3 mm. Sédi drawing 6 2075 – DM – 1500 207 & 211 (for CR6-Z). Azimuthal range given by a fixed 6 mm from both edges of the 120° sector (hence layer dependent, in contact with above C-rods). z-position layer dependent.</td></tr>
<tr><td>1</td><td>C fiber</td><td rowspan="4">Centered
at R_0 + 0.269
(146, 161, …)</td><td>Centered at
287.8 for all layers</td><td rowspan="4">[32.355, 147.645]</td></tr>
<tr><td>2</td><td>C fiber</td><td>256.8, 279.4, 281.8
for CR4, 5, 6</td></tr>
<tr><td>3</td><td>Al</td><td>-148.2, -178.02, -190.2</td></tr>
<tr><td>4</td><td>Al</td><td>-156.2, -186.02, -198.2</td></tr>
<tr><td colspan="3">Neglected: small holes, notches….</td><td></td><td></td><td></td></tr>
</table>

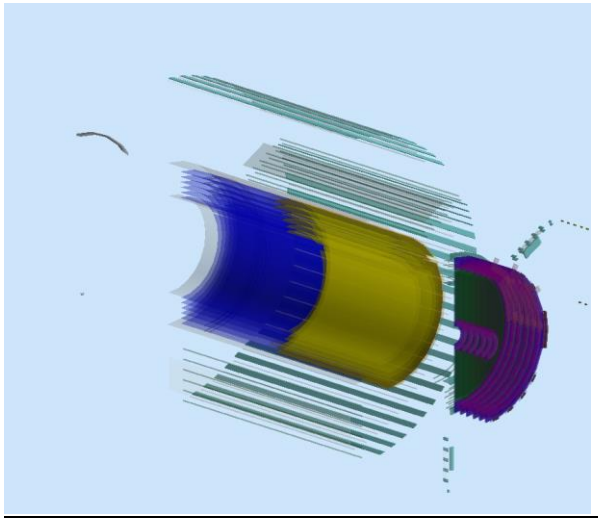
Elements highlighted in yellow are within the path of particles detected in BMT. Their total thickness amounts to about **0.35% radiation length** (per layer). The darker yellow is for the above defined active zone (drift).

Supporting structure and cables

Element	Sub-element	Description	$[z_{min}, z_{max}]$ mm	$[R_{min}, R_{max}]$ mm	$[\varphi_{min}, \varphi_{max}]$ deg.
Inner tube		C fiber, 732 mm long, 1 mm thick. SIS drawing 71 2075 DM 1302 001	[-448.7, 290.3]	[140, 141]	[0, 360]
Stiffeners	3 C slabs dividing the 3 sectors, 736 mm long, section 92.5 mm x 2 mm. SIS drawing 71 2075 DM 1302 005. Modeled in 2 separate slabs to avoid overlap with FMT-interface. "Box".				
	1	C-fiber, 719 mm-long main part	[-445.7, 273.3]	[141.5, 233.996]	Centered at 30°, 150° and 270°
	2	C-fiber, 17 mm-long downstream end	[273.3, 290.3]	[144.5, 233.996]	
Arcs	3 arcs upstream, one for each 120° sector; does not cover 7.5 mm at each sector end. SIS drawing 71 2075 DM 1302 007.				
		Inox	[-453.7, -438.7]	[229, 234]	[31.876, 148.124] (tile 1)
Cover		C fiber, 744 mm long, 1 mm thick. SIS drawing 71 2075 DM 1302 009	[-453.7, 290.3]	[234, 235]	[0, 360]
Rods	C fiber rods to guide FMT cables and gas feed. Their exact position should be measured at assembly time. For now, equally spaced. Per sector: 17 rods of section 3 x3 and 2 (for gas) of section 4 x 4. 655 mm long. SIS drawing 71 2075 DM 1302 010 & 011. "Box"				
	3x3	C fiber	[-433.7, 221.3]	Centered at 236.5	tile 1 1st rod at 40.91°, 18 others with 5.45° rotations
	4x4			237	
FMT cables	2 cables on each of the first 16 inter-rod spaces are summed together in the thicknesses below. The downstream end will have to be reexamined to continue the cables into the FMT volume. Upstream end arbitrary (cables arbitrarily centered on mother volume, no connectors implemented for BMT). Width 18 mm. Cu and polyester effective (flat) contents deduced from Hitachi drawing KZ12-262. Exact positions to be measured. "Box"				
		Cu effective thickness 2 x 87.6 µm	[-465.7, 292.3]	Centered at 235.544	tile 1 1st cables at 46.36°, 15 others with 5.45° rotations
		Polyester effective thickness 2 x 1.054 mm. Material approximated by peek material (chemical composition and density close enough)		Centered at 236.527	

FMT gas	2 gas tubes on each of the last 2 inter-rod spaces. Polypropylène ext radius 2 mm, int radius 1 mm. Approximated by peek material (not so good but within errors of the overall description). Same remark as for cables for the z-extension.				
		"Peek" tube	[-465.7, 292.3]	Centered at 237	tile 1 1st pair at 133.56° and 136.285°, the other one with 5.45° rotation
Overcover		200 µm foil, modeled by pcb material	[-433.7, 290.3]	[239.01, 239.21]	[0, 360]
FMT-interface	A complete description would be too long here, the info below is only qualitative (the coded part is realistic). SIS drawing 71 2075 DM 1302 003. All in peek material.				
	Rings	3 inner rings and 2 outer rings	[273.3, 298.3] (overall extension)		[0, 360]
	Branches	3 branches connecting inner and outer rings. "Box".			Centered at 30°, 150°, 270 °
	Attachments for stiffeners	3 (sectors) x 2 (rows on each side of a branch) x 6 (layers) elements. "Box"			
	Attachments for FMT	2 x 2	[292.3, 298.3]	[234, 240]	[-2.03, 3.53] [26.47, 32.03] and other pair with 180° rot.
Closing plate		C fiber, 0.5 mm thick. SIS drawing 71 2075 DM 1302 004	[297.8, 298.3]	[146, 217]	[0, 360]





(These figures from the 2016 version: do not include the signal cables in the FMT volume)