Recommended SIS100 subsystem positions for simulation of the future CBM experiment at FAIR

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Introduction

In response to concerns voiced by the Technical Coordinator and CBM Collaboration Board, the two authors conducted an extensive comparison of CAD and GEANT geometries for each subsystem of the future CBM experiment at FAIR. The CAD geometry of a subsystem is used to tackle the many manufacturing challenges in its design and are submitted by a subsystem engineer to us (staff at FAIR/GSI) in other to coordinate the process between subsystems and the technical inclusion of a subsystem into the global design of the experiment. The GEANT geometry of a subsystem is generated by a physicist typically working within a subsystem group to be used to computationally validate that the subsystem is suitable for requirements and quantify the detectors sensitivity. These are shared among subsystem groups in CbmRoot geometry repository not only to be used to plan important hardware and software data processing provisions for real data analysis but also to model the CBM experiment to investigate key fundamental physics questions the CBM experiment may address. It is suspected that good communication between the engineering and simulation personnel within a subgroup is not always guaranteed.

The approach of our comparison study was to meticulously compare the dimensions and positions of the CAD and GEANT geometries for each subsystem. Often particular attention needed to be focused on the distance between sensitive layers of the detectors and the target as a crucial factor in maintaining accuracy between the simulation of detector response and future experimental data. Unfortunately during the course of the survey, it became apparent that unacceptable divergence between the CAD and GEANT geometries had become commonplace across multiple detector subsystems over the last number of years which required immediate action by the subsystem teams to rectify. Our study was communicated immediately within the CBM collaboration at several internal presentations and discussion rounds as well as at CBM Collaboration week in October 2020 [1]. Change requests to the respective subsystem groups, focused on corrections in the lengths and placement along the beam line with inconsistencies of width and height seen as less crucial initially as their inaccuracies were contained with the subsystem and not propagated to downstream subsystems. The critical issues were immediately addressed by the respective subsystem groups which meant size variation and shifts of more than one meter in some cases.

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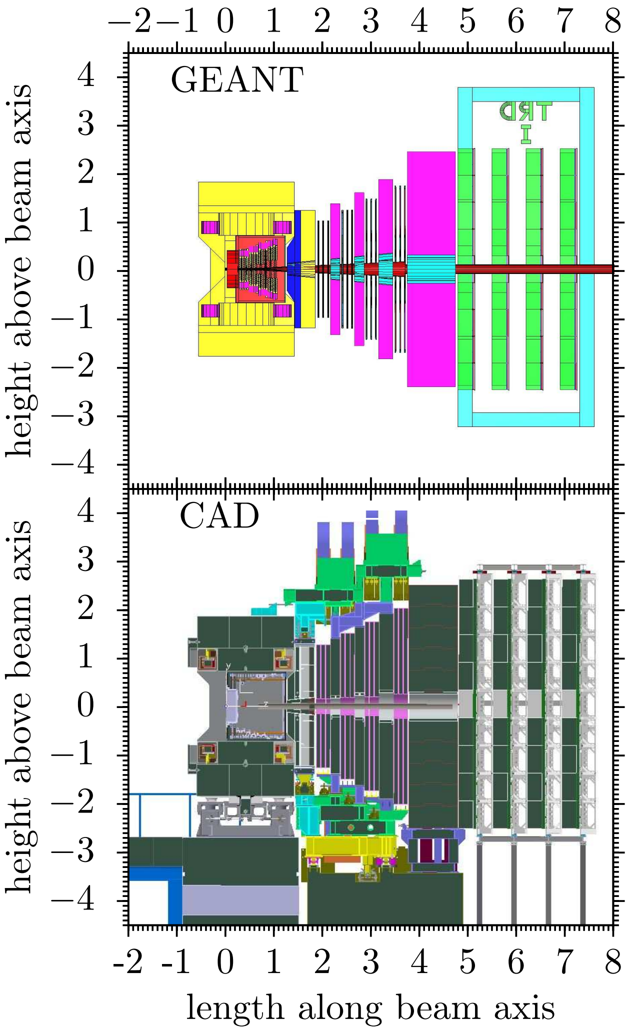

Figure 1: The default J/ψ muon setup of the CBM experiment in its compact configuration. The GEANT geometries (top) and the CAD geometries (below) are displayed as their orthogonal projection onto the x=0 plane with front material ($x < 0$) clipped to allow visual penetration of subsystems.

This document does not report on the changes made to individual detector subsystem over the last few months as these are recorded in the subsystem sections of the CBM progress report, in several technical notes and elsewhere. Instead this report's aim is to address the communication issue which may have lead to this divergence and to emphases the currently recommended geometries for simulation and their agreed placement considering physical limitations. This is intended to ensure that simulation studies have maximum impact in helping steer engineering design. In particular, this documents contains standard dimension and placement information for each subsystem as can be best agreed between the GEANT and CAD geometries. It should be strongly emphasised that most information in this report will change in the coming years as technical and physics decisions are made before manufacture of the subsystems and the final construction of the CBM cave at FAIR. It is however a reasonable anticipation that these changes will become less consequential and less frequent as day zero of our experiment approaches. The data in this report is the best current knowledge for the placement of geometries of the future CBM experiment and may be used for configuration of simulations during year 2021 A.D. but ought to be considered defunct soon thereafter.

Official Experiment Setups

In preparation for the start of the CBM experiment and its investigation of the physics frontier, there are four standard setups of the experiment which are widely distributed within the CbmRoot software framework and encouraged for preparatory simulation. These setups differ in the types of detectors and subsystems installed as well as their placement with respect to the target and their internal configuration. Tab. 1 lists the default GEANT geometries recommended to be used for simulation of the CBM experiment when it is configured to be in the Electron setup, the Hadron setup, the J/ψ muon setup and the low mass vector mesons (LMVM) setup. The detector selection for each of these setups listed in this table coincide with those defaults in legacy setup files in the CbmRoot geometry repository and are not necessarily a recommended detector set for specific physics investigations.

SUB	Electron	Hadron	J/ψ	LMVM
MAG	v20a	v20a	v20b	v20b
PIPE	v16b_1e	v16b_1e	v20a_1m	v20a_1m
MVD	v20c_tr	v20c_tr	-	-
STS	v19a	v19a	v19a	v19a
RICH	v17a_1e	-	-	-
MUCH	-	-	v20a*jpsi	v20a*lmvm
TRD	v20b_1e	v20b_1h	v20b_1m	v20b_1m
TOF	v20b_1e	v20b_1h	-	-
PSD	v20a	v20a	-	-
PLAT	v13a	v13a	v13a	v13a

Table 1: The 2020 geometry versions recommended for each subsystem (SUB) for simulation of electron, hadron, Jψ and low mass vector meson (LMVM) experimental setups of the CBM experiment at FAIR. The '*' abbreviates '_sis100_1m_' in the tag name.

Subsystems' Geometries Summary

Fixed Position Subsystems

The magnet's GEANT geometries comes in a variant with clamps 'v20a' and without clamps 'v20b' as listed in Tab. 1 and as a visible in Figs. 1 and 2. The clamps are used when the Ring Imaging Cherenkov (RICH) detector is installed on the mount directly behind the magnet, Fig. 2. The 19 cm long field clamps limit the stray field of the magnet to a maximum of around 0.5 mT in the RICH photon detectors [2] and lead to the difference, between the two versions seen in Tab.2, in distance between the target and the magnet's most upstream point. A mini rail allows the RICH to be pushed neatly into position between the top and bottom clamps [3]. When the MUCH is instead required, the clamps are removed and it is pushed into place by a hydraulic drive, moving the whole array of sensors and absorbers perpendicular to the beam axis [4] .

The first absorber of the MUCH matches the shape of the magnet, so that a part of it slides inside the yoke before operation. It is noted that the CAD measurements remain the same due to the frames required to hold the detector layers and absorbers in place irrespective of whether the MUCH is in a configuration with three absorbers or with four absorbers. In the case of the "START" configuration, the space of the 4th absorber is still needed for additional mounting brackets that counter the otherwise uneven weight distribution and so there is no space saving from using one less absorber. Behind the MUCH, a 5th absorber may be installed, in particular for the J/ψ setup, which is visible in the CAD panel of Fig. 1. In the case of the GEANT geometries, the MUCH comes in three variants, one optimised for simulation of low mass vector mesons (LMVM) with 4 absorbers and one for J/ψ setups which has all 5 absorbers as default. A "START" geometry, "v20b" is also available with 3 absorbers and 2 GEM stations for Au beams less than 4A GeV. The 5th absorber consumes 1 m length of the experiment and can be seen as the large pink

SUB	width	height	length	position
MAG	4.4	3.7	2.0	-0.6
MAG (clamps)			2.38	-0.79
MVD (TR)	0.8	0.8	0.525	0.04
MVD (VX)				0.01
STS	2.38	1.423	1.338	0.3
RICH	6.0	5.478	2.2	1.788
MUCH (J/ψ)	5.0	5.0	3.52	1.25
MUCH (LMVM)	3.88	4.03	2.5	1.25
MUCH (START)	3.258	3.258	1.6	1.25
5th Absorber	5.0	5.0	1.0	3.77

Table 2: Position and dimensions of stationary detectors. All measurements are in meters, width is the left to right view looking at the subsystem (SUB) from the beam perspective, height is vertical, and lengths are along the beam axis. The subsystems are centred on the beam axis.

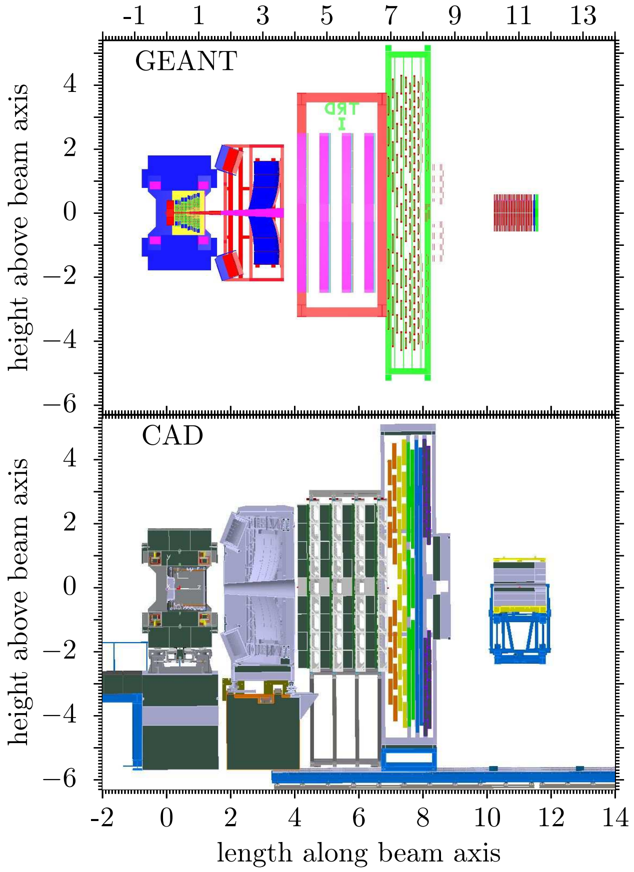

Figure 2: The Electron setup of CBM experiment in its compact configuration. The GEANT geometries (top) and the CAD geometries (below) are displayed in their orthogonal projection onto the x=0 plane with material closest the observer clipped to allow visual penetration of the subsystems. All subsystems are placed in their default positions except the PSD which is centred on the beam axis at 10.2 m from the target.

rectangle before the transition radiation detector (TRD) in the GEANT panel of Fig. 1 and as the green rectangle in the CAD panel of the same figure. Although, not observable in our diagram, the proportion of the block, also green, immediately below the 5th absorber is entirely removable when not needed. However, when installed it reduces the closest placement possibilities of downstream detectors by up to 1 meter, cp. difference between min and min* columns of Tab. 3.

Enclosed inside the magnet yoke between its two coils [5], the silicon tracking system (STS) box is placed such that its 2nd station is positioned at the centre of the magnet, ergo its magnetic field. The STS forms the basis of the tracking and reconstruction for the CBM experiment and therefore present in all the standard experiment setups. Germane information regarding the CAD and GEANT geometries of the STS are contained in the Technical Note, Ref.[6], and the references therein. The "v19a" version of the STS geometries is currently recommended for all four setups, although as some recent changes are waiting approval to the STS CAD, it is expected that an updated GEANT geometries will follow soon. Inside the STS enclosure, adjacent to the target with a few centimetres, the micro-vertexing detector (MVD) is situated. The MVD GEANT geometries come in two variants, or modes, one intended for vertexing (vx) and one intended for tracking (tr), where the internal sensor module design, their configuration and spacing between modules are modified. Details are the recorded in the technical note [7]. The currently recommended "v20c_tr" for tracking simulation where the most upstream volume of the sensor layer comes to 4 cm from the target and "v20c_vx" for simulation using vertexing mode where the upstream volume of the sensor is 1 cm from the target. Although the beam pipe is not a focus of this manuscript, we note that it is currently under active technical consideration and several CAD geometries were received. The two beam pipe geometries listed in Tab. 1, one to be used in conjunction with the RICH and one when the MUCH is instead installed, are therefore expected to change in the coming year. It is noted that for all geometries which are relatively close and in fixed position with respect to the target, i.e. all those in Tab. 2 use the target as their internally defined origin in the GEANT root file. It has been proposed that this may change in the future. Tab. 2 contains the measured dimension and placement according to the CAD model for the fixed position subsystems.

Detectors on Rails

Detectors listed in Tab. 3 are further from the target than those in Tab. 2 and are mounted on a system of rails which is visible in the bottom half of the CAD panel of Fig. 2. This allows them to vary their position with respect to the target. The "min" column of Tab. 3 contains the minimum distance between the centre of the target on the beam axis and the most upstream part of each detector projected on the beam axis. In Cartesian coordinates defined with the target as its origin, this would be the standard z component of the vector to the most upstream point of the detector. For the special case when the MUCH's fifth absorber is installed, such as for Fig. 1, the closest placement of the detectors in Tab. 3 are pushed back, and the new closest position relative to the target is listed in the "min*" column. In general the closer a detector is to the target, the greater the total interactions of the beam and target which falls under the steradian suspended by the height and width of its sensors. It is therefore of active interest for many detector subgroups to keep the values in the "min" and "min*" as small as possible, and the *compact configuration* of a setup is thus a useful configuration to study and simulate. It should be cautioned however that these compact positions as yet do not take safety margins and gaps between the detectors into account but merely prevent material collisions between the detectors. The furthest distance that each detector may be placed from the target is the same across all setups and is shown under the "max" column of Tab. 3. The

SUB DET	width	height	length	placement range min	min*	max
TRD	9.9	8.55	2.9	4.1	4.8	12.2
TOF	13.5	10.78	2.19	6.9	7.7	15.1
BFTC	1.98	1.98	0.59	9.4	10.0	16.2
PSD	4.85	10.04	1.96	10.1	10.9	18.3
lat.				-0.9	-0.9	0.9
vert.				-0.7	-0.7	0.7
angle				-3°	-3°	3°

Table 3: The position and dimension for the downstream detectors. Dimensions, not labelled, are in meters from the target to the most upstream point of the subsystems projected onto the beam axis where the “min” column contains the closest placement and “max” its furthest placement. The “min*” column contains a modified closest placement when the MUCH’s 5th absorber is installed, cf. Tab. 2. The PSD frame allows it to shift its lateral, vertical and angular placement with respect to the beam axis.

electron setup in its most compact configuration is shown in Fig. 2 with distances from the target corresponding to the “min” column of Tab. 3, whilst Fig. 1 shows the J/ψ setup in its compact configuration where the TRD, the only detector on rails in this setup according to the current defaults shown in Tab. 1, is placed at a position consistent with the value in the “min*” column of Tab. 3. The TRD may be moved on its rail system from 4.1 m to 12.2 m from the target when the 5th absorber of the MUCH and its base is removed. Information regarding the design and mounting frame of the TRD is contained in Ref.[8]. Downstream for the TRD, the Time of Flight (ToF) detector is intended to be omnipresent during the lifetime of the experiment although it may be pushed back to more than 15 m from the target. Its frame extends more than 5 m above the beam axis which is more than 13 m above the ground of the cave although the top and bottom 50 cm of the frame contain no sensors in the current official designs. It is pointed out that the left most sensors of the ToF within 1 meter from the beam axis in the CAD panel of Fig. 2 are invisible in the diagram due to the choice of white being used for both the sensors and the background of the diagram.

Following a presentation [9] at the 36th CBM Collaboration Meeting and its subsequent discussion, it became apparent to the authors of a strong desire within the collaboration to make a consorted effort to make space provision for inclusion of the proposed Beam Fragmentation T0 Counter (BFTC) detector. It is proposed that the BFTC will match the acceptance of the projectile spectator detector (PSD) which is directly downstream. A length of 30 cm for the BFTC with a 20 cm gap to the ToF detector and a 80 cm gap to the PSD was communicated following the results of simulations. As the frame of the ToF detector already allowed for the necessary gap on its side, a 1.1 m length of the beam axis was allocated. Subsequently it has emerged that the size of the BFTC is most likely to be larger than first anticipated. This change would increase the closest approach “min” and “min*” of Tab. 3 of the PSD by 29 cm and the the maximum extension “max” of Tab. 3 for the TRD and the ToF may need to be reduced by the same amount.

As a consequence of its bespoke frame, visible in the CAD panel but absent in the GEANT panel of Fig. 2, the PSD is capable of moving vertically above or below the beam axis, laterally to the left or right of the beam axis, or rotating its pointing angle in the horizontal plane, cf. Ref.[10]. As the manipulator frame has been manufactured and currently being stored in a warehouse, further design modifications are highly unlikely. On the other hand, the rail system on which the PSD manipulator frame will be mounted has not yet been officially submitted. It is for this reason, in the CAD panel of Fig. 2, the PSD is unsupported at present. Although it is noted that a possible design for the mounting frame is contained in this journal in Ref.[10]. The four rows in Tab. 3 give the range of movement for each of these four degrees of freedom. Some of these possible placements are not intended for simulation of normal operation of the experiment but rather for detector calibration. The currently recommended version “v20a” of the PSD geometry may be shifted and moved as desired using its translation matrix within the CbmRoot software packages. The current default placement is at 10.5 m along the beam axis with no vertical displacement shifted to the left of the beam axis by 12.95 cm and rotated by (¾)° in the horizontal plane, in order to be consistent with a 12 AGeV/c beam.

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