Candidate SIS100 beampipe geometries for simulation

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Several new beampipe simulation geometries were created during the course of last two years, though they were not widely distributed, in order not to confuse the community with a myriad of technically unfeasible designs. This decision was counter-balanced by a need to rapidly provide a realistic beampipe geometry which could in tandem influence incremental design improvements. Evidently, as the section of the beampipe which transverses a detector, can heavily affect detector's design, construction, maintenance and operation, detector groups rightly have vested self interest and responsibility to ensure the quality and performance of their section of the pipe. Conversely, the beampipe itself is an extensive subsystem which transverses the entire experiment, affects every detector subsystem, introduces crucial mechanical challenges to overcome by physically connecting detector subsystems and thus requires global-experiment-design-considerations at each step. The beampipe is thus an area were coordination and communication in the spirit of the CBM collaboration is vital to ensure that physics performance is prioritised whilst robustness of the technical design is assured.

Reference [1] of this report, indirectly discusses the creation of the many simulation geometries over the last year based upon the previous ("v16a_1e") default. Each corresponds to the creation of slightly varying trial STS geometries. As some of the geometries in Ref. [1] are the current default beampipe simulation geometries distributed with our DEC21 CBMROOT software release, of particular importance is Tab. [1] which shows which beampipe to use with which STS and then the recommended placement for the target along the nominal beam axis. Ref. [2] contains the technical design considerations used for the STS beampipe section, with some advancements, especially in the beampipe window, which at present are not in the default simulation geometries mentioned above. This is at least partially addressed in Sec. [2] of this document. Ref. [1] also contains the STS back-wall flange which is used, and the target box which is used with some modifications, in Sec. 3 of this manuscript.

From the STS back wall, the beampipe is to transverse the RICH/MUCH section, through the TRD, and the TOF, and finally on to the PSD and the beam dump. Information regarding the technical considerations such as vacuum and connector inlets of the cylindrical beampipe from the TRD on, is contained in Ref. [3] of this report. Ref. [4] contains the beampipe simulation geometry for the entire downstream section. Primarily, it comprises of a downstream cylinder, and the narrowed conic-based tube which transverses the RICH/MUCH. Between these two sections, a bellow assembly (see Ref.[5]) is added to allow a deflection angle for the beam between the downstream cylinder and narrowed conical section. Creation of a sophisticated representation of the bellows for simulation is contained in Ref. [4]. The bellow assembly is responsible for a significant percentage of the overall material budget of the beampipe as part of its structure and supports needs, and it was a noteworthy advance to add a small deflection angle of 1.2° between the STS and RICH/MUCH conic sections, so latter conic could have its directrix significantly reduced, reducing its material budget but more importantly the material budget of the entire bellows part. Ref. [6] highlights this case. It is a necessity for simulation geometries, unlike their CAD equivalents, to have an accurately specified

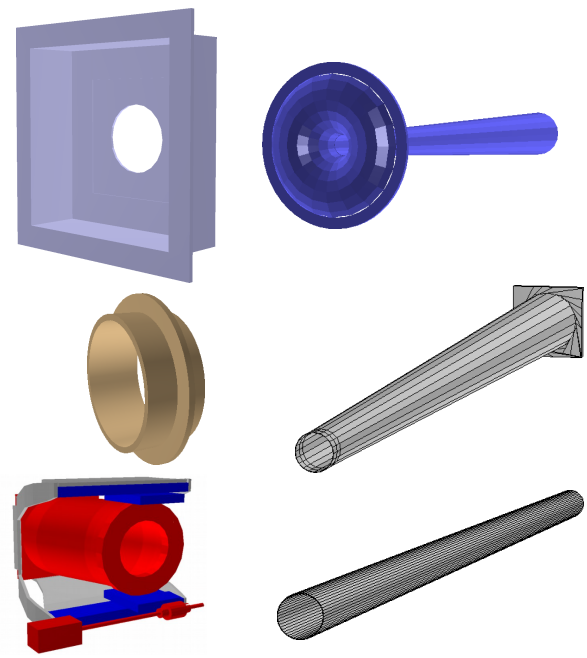

Figure 1: Size of beampipe parts are not to any fixed scale. **Top-left** shows the target box which houses the MVD and target. **Top-right** shows the beampipe window along with a wide conical section. **Middle-left** shows the STS flange which is supported by the back of the STS box. **Middle-right** shows the narrow conical section which transverses through the MUCH/RICH detectors. **Bottom-left** shows the implementation of the bellows. **Bottom-right** shows a simple cylindrical tube used for the downstream section.

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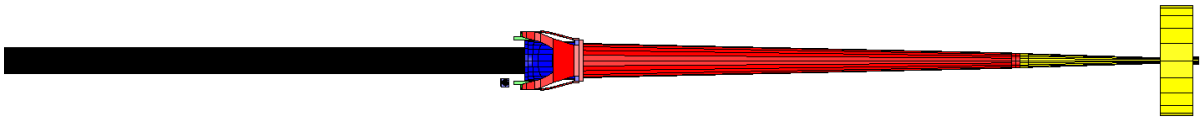

Figure 2: Shows the concatenation of a STS beampipe (v21d) and the undeflected downstream beampipe (v21f) using the method discussed in Sec. 1. The downstream cylindrical part, in black, has been cut short for display purposes.

internal make-up. Composite material and positioning information of parts is contained in Ref. [4] of this report.

The two substantial pseudo-independent efforts of the last two paragraphs are complementary beampipes geometries for simulation which unfortunately create a small confusion for our simulation teams in the CBM collaboration, as highlighted by creation of redmine issues 2424, 2429, and 2431, on how to use these two independently created geometries in conjunction with one another. The next section, Sec. 1, of this document documents a straight forward approach to do this, without the need for code changes to the CBMROOT code base. Later, Sec. 3 provides a single monolith binary which follows the traditional single geometry binary per subsystem approach.

1. Setting-up a simulation

This section documents how to set up our software suite, CBMROOT, to run a basic transport simulation using the two introduced beampipes with correct configuration. Subsequent simulation stages of digitisation and reconstruction follow their normal modus operandi. The basic configuration stage for CBMROOT is via setup files which are placed in the "geometry/setup" folder but must follow strict naming conventions. Using one of the default setup files as a starting sample is a good approach, e.g. open "setup_sis100_hadron.C" in a editor and rename it by changing only the "hadron" part of the filename, i.e. "setup_sis100_newpipe.C". The default beampipe is "v21d" in this sample setup. This is fine to be used for the upstream and STS sections but needs to have the addition of the downstream sections. Here, the user will need to specify the beam energy as different downstream pipe geometries are used for different beam energies. The following lists the downstream beampipes with energy and magnetic field strength pairs such that a full stripped gold ion (Z = 79+) beam (cp. Ref.[4]) hits the beam dump.

- **(pipe_v21e)** Maximum deflection angle.
  beam dump possibly at (0.7m,0,18.82m)
  T = 2 AGeV (P = 2.85 AGeV/c) MF = 50%
  T = 3 AGeV (P = 3.89 AGeV/c) MF = 70%
  T = 4 AGeV (P = 4.91 AGeV/c) MF = 85%
  T = 5 AGeV (P = 5.93 AGeV/c) MF = 100%

- **(pipe_v21h)** maximum kinetic energy for SIS100
  beam dump possibly at (0.225m,0,18.845m)
  T = 11 AGeV (P = 12 AGeV/c) MF = 100%

For example, choosing a 4 AGeV beam, the pipe_v21e may be used with a magnetic field strength of 85% of the nominal 1 T field. This beampipe may be included by simply listing its tag 'v21e' after the upstream beampipe 'v21a' separated by a colon. See Fig. 2 for two pipes joined together in this way.

```
TString pipeGeoTag     = "v21d:v21e";
CbmSetup* setup = CbmSetup::Instance();
setup->SetModule(ECbmModuleId::kPipe, pipeGeoTag);
```

The magnetic field strength should also be changed to:

```
Double_t fieldScale  =  0.85;          // field scaling factor
```

This beampipe configuration does not include the STS flange (middle-left of Fig. 1) which separates the STS wide conical and RICH/MUCH narrowed conical sections of the beampipe. This back-wall flange isolates axial and toroidal vibrations which could cause damage to delicate STS instruments even if their magnitude are small (Ref. [7]). In terms of the transport simulations, the STS back-wall flange is an important addition to the material budget. To include it, the STS team (cf. Ref. [1](Tab. [1] and Fig. [5]) has provided the following STS geometry.

```
TString stsGeoTag     = "v21g"
setup->SetModule(ECbmModuleId::kSts, stsGeoTag);
```

These changes are sufficient to configure this setup file. To run a transport simulation for 10 events, the following command may be executed from the "macro/run" folder

```
cd macro/run
root -l -q 'run_tra_file.C("inputfile", 10, "", "sis100_newpipe")'
```

where "inputfile" is generated URQMD data for the 4 AGeV gold on gold collision. This completes a simulation mini-guide for the *official* full beampipe distributed with the CBMROOT DEC21 release.

2. Updated beam window

A near-target simulation beampipe was created in the GDML language which was based, mostly, on the technical drawing TN ED-1159370-D-001-IO for the purpose of getting sufficient convergence between the CAD and GEANT for the beam window, and also in order to simplify the present beampipe geometry script to allow more rapid implementation of changes in the future. It had already been decided in beampipe meetings, although not updated yet in the CAD, that a cylindrical section in the initial part of the STS beampipe section seen in the technical drawing should be removed in favour of an uninterrupted conical beampipe

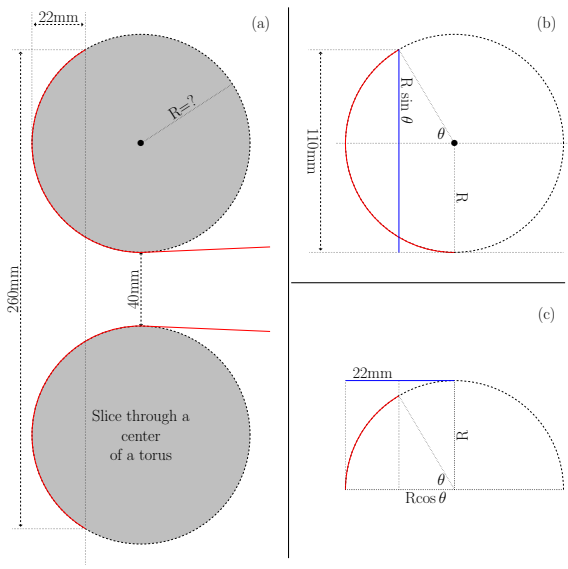

Figure 3: Geometric arguments for fitting a torus shape to approximate the CAD window. The graphic determines the radius of its tube. Details are explained in the text.

section from the window through to the back of the STS box (cf. Ref. [2]). This came about due to FLUKA studies (Ref.[6]) which showed radiation buildup in the kink between the cylindrical and conical regions.

Several challenges are required to be overcome to develop a functioning beampipe which can be used in the vicinity of the target. Unfortunately, CBMROOT expects a certain nodal hierarchy of its volumes, with many fixed nodal names. The MVD detector is to be placed in the "pipevac1" volume of the beampipe. The target is also placed in this structure and its position depends on whether it is generated on the fly in the transport macro or included as a stand-alone subsystem in the setup file.

In order to select a simple shape for the window which approximates the technical drawing's design, the parameters for a cut torus was calculated by the following short geometric arguments. A torus may be thought of as a filled circle which is made solid by revolving it round a central origin in the 3rd dimension until it meets up with itself again after 360° to form the classical doughnut-shape. As such it is defined by two non-equal radii, the radius of revolution, and the radius of the tube R. Figure 3(a) shows the central 2D slice of a torus orientated vertically, and displays the three numerical values extracted from the technical drawing which will define the size and scope of the window section. Namely the diameter of the window should be 260 mm and bulge forward towards the MVD detector and target by 21.81 mm (22 mm) and the opening for the conical section should have a diameter of 40 mm. The main effort will be to determine R with the radius of revolution following simply via the inclusion of half the gap between the two circles, i.e. $R + 20mm$. In Fig. 3(a), the part of the torus which makes up the surface of the window is shown as a red solid line from this perspective.

The symmetry of the top and bottom of Fig. 3(a) allows us to redraw Fig. 3(b) subtracting half the 40 mm gap so we know the distance between the closest and furthest point to the origin on the surface of the window is 110 mm. Writing an equation for the length of the blue line in Fig. 3(b):

$$R \sin\theta + R = 110 \tag{1}$$

A second equation which relates R to the angle θ is sought. Figure 3(c) focuses now on the top semicircle of (b). The numerical value which relates the bulging of the window towards the target, and MVD is included on the diagram. Writing an equation of the length of the blue line in Fig. 3(c):

$$R = 22 + R\cos\theta \tag{2}$$

Combining these two equations and eliminating for θ give the quadratic equation and root.

$$R^2 - 264R + 12584 = 0 \tag{3}$$

$$R = 62.43 \text{ mm} \tag{4}$$

The radius of revolution is half of 40 mm larger, i.e. R_R = 82.43 mm. Solving for θ allows the determination of where to place the cut to obtain the full window shape.

The rest of the near-target beampipe is created in a straight forward fashion after extracting other values from the technical note. The conical section should have a diameter of 80mm at its most downstream section and be 1012 mm in total length. The outer flange for the window is set to 300mm diameter using a short cylinder of 7 mm. Finally, the window is placed 240 mm from the target. The surface of a torus of 0.5 mm thick carbon fibre is used. Full human readable details may be seen in GDML script for this beampipe in the geometry repository of CBMROOT. Top right of Fig. 1 shows the window, its flange, and the conical pipe combined together as a combined upstream beampipe geometry.

3. A monolith binary

As a single geometry binary is supplied for all other subsystems in the CBMROOT simulation environment, it may be expected that a single monolithic beampipe geometry binary is supplied in the near future. This must follow the restrictive hierarchical nodal structure expected by CBMROOT in order to function correctly without the need for code changes between switching of versions. As the beampipe has close proximity to many detector subsystems, there needs to be precise placement with little or no keep out volumes which may create unwanted overlaps. These are known to have a detrimental effect on the consistency of our simulations. Lastly, it is vital that we capitalise on the many advancements in design of a simulation beampipe geometry from our diverse but collective efforts.

These aims are accomplished by writing a beampipe macro which creates empty nodes obeying a fixed nodal

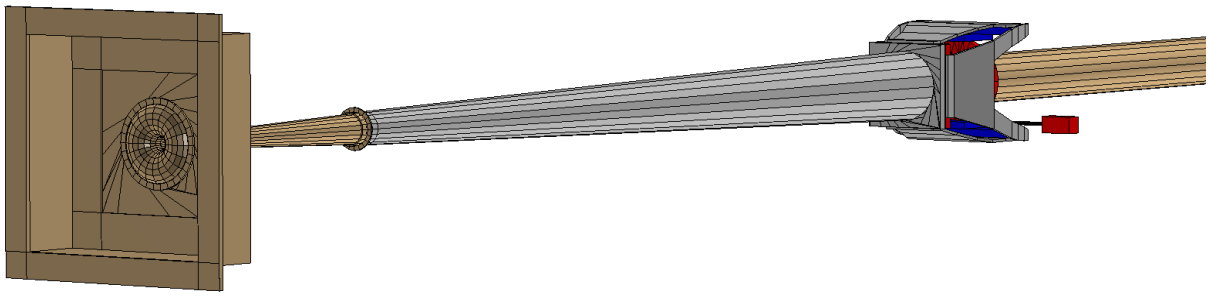

Figure 4: Shows the combined volumes to form beampipe (v22b) consisting of a target box, window, STS section, RICH/MUCH section, bellows, and downstream cylindrical section which has been cropped short for display purposes.

structure. The actual volumes are then cherry-picked from the existing geometry binaries by pointing directly to that binary from the node. Placement information is also extracted and processed with only some small manual effort to specify the change in coordinate systems between the source geometries. The "pipe_v22b" beampipe geometry as shown in Fig. 4 is made up of the independent volumes in Fig. 1. With the exception of the downstream cylinder in the bottom right of the Fig. 1, all other volumes are extracted from existing binaries or GDML scripts. It is a topic of a future decision as to which volumes should belong to the beampipe geometry and which are better incorporated into other detector subsystems. Nevertheless, the target box, cf. Fig.[5] of Ref. [1], is supplied by the STS team with a small edit to cut a circular opening for the window flange. The top right window was already introduced in Sec. 2. The STS flange is extracted from the "sts_v21f" geometry binary whilst the RICH/MUCH narrow conical section is extracted from "pipe_v21f". The version of the bellow assembly then depends on which closest approximates the angle of the downstream tube from the "pipe_v21f", "pipe_v21g", or "pipe_v21h" binary. An extracted bellows is shown in the bottom right of Fig. 4.

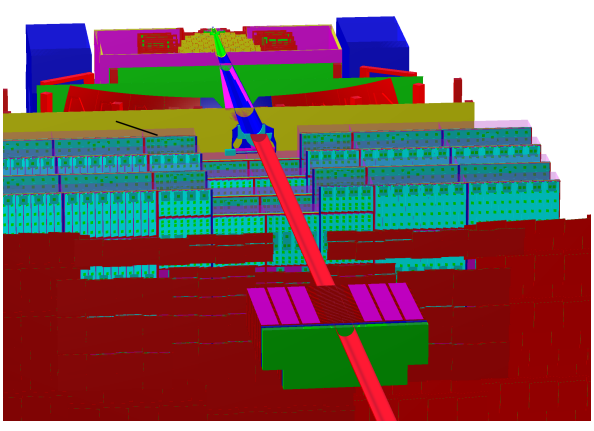

Figure 5: Shows the CBM experiment in its compact electron configuration with the top material ($y > 0$) cut away to reveal the beampipe.

Finally, in order to visualise this beampipe in conjunction with all detector subsystems included, Fig. 5 shows this monolith beampipe from a vertical upstream position. The downstream tube (red) transverses through the PSD (green and magenta), the central openings of the TOF (dark red) and the TRD layers (cyan), and then on to the bellows (blue). The narrowed conic tube transverses the RICH, followed by a wider conic through the STS. Just visible is the beam window (green) at the end of the target box (red). Unlike Sec. [2], the MVD versions 'v20c' should be used with 'pipe_v22b'. Its sensor layers (magenta and green) supported by heat-sinks (red) are followed by the tiny semi-circular disk which is the target (blue). This completes our discussion of the beampipe simulation geometries.

References

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