Comparison of Simulation Geometry based on ROOT Primitive Solids and Tessellated Solids

by

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for the CBM Collaboration

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Outline

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- Simulation Geometry and Comparison
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  - Simulation Run Time Comparison
  - Geant Processes
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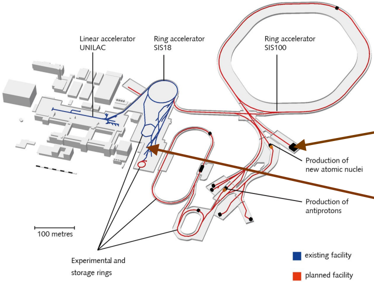
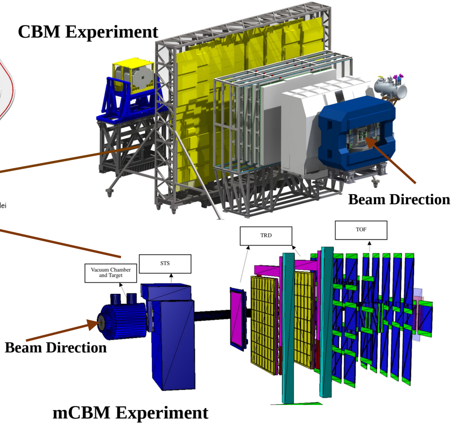
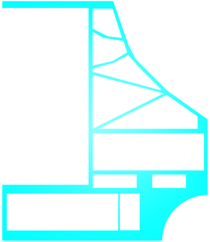
GSI - FAIR Facility and CBM/mCBM Experiment



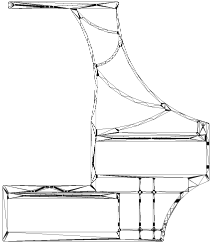


mCBM Experiment: A prototype of full CBM with each detector sub-systems presently installed at the beam facility from SIS-18 accelerator at GSI.

Motivation



(a) C-frames based on ROOT primitive solids.

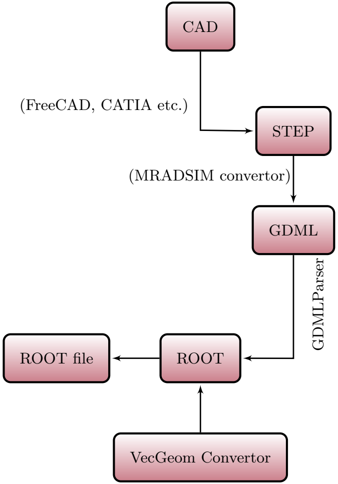


(b) C-frames from CAD model.

C-frames: (a) intricately designed version utilising primitive solids and (b) tessellated solid-based geometry from CAD model to ROOT.

- Tessellated solids offer an efficient alternative to the traditional way of preparing geometries.
- Less error prone, reduce human intervention.
- Fine scaled details in the simulation geometry can be easily added whenever needed.

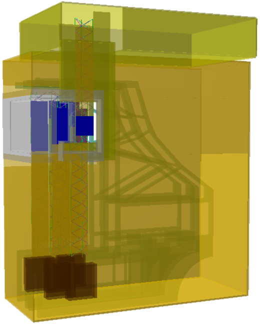
To validate the simplified design of the detector modelled using primitive solids.



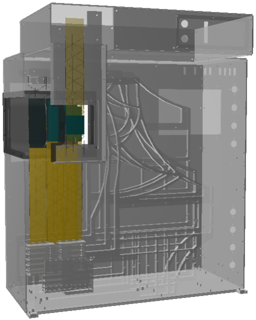
- The geometry created in CAD can be converted through a direct conversion process from the CAD's STEP/STL file format to Geometry Description Markup Language (GDML), which is an XML-based format.
- ROOT GDMLParser used to read the GDML file and creation of detector assemblies in ROOT macro.
- Conversion of geometry using VecGeom convertor and save the output in the root file.

For further details and discussion regarding CAD-To-ROOT method, see our poster on Thursday,
https://indico.cern.ch/event/1338689/contributions/6010572/

Geometry Description: ROOT Primitive Solids and Tessellated Solid based mSTS geometry



(a) Simplified ROOT primitive solids based mSTS geometry.

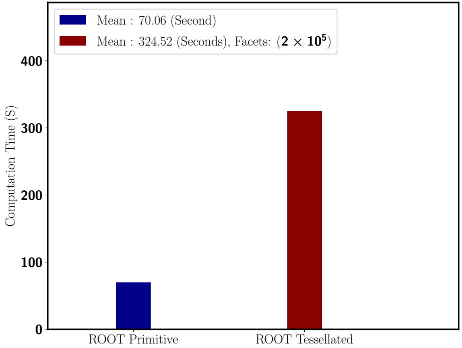


(b) Tessellated solid-based mSTS geometry from CAD to ROOT.

In the tessellated solid-based geometry, the level of detail is significantly higher compared to the geometry constructed from ROOT primitive solids, with up to $2{\times}10^5$ individual facets enhancing geometric precision.

Simulation: Run Time Comparison

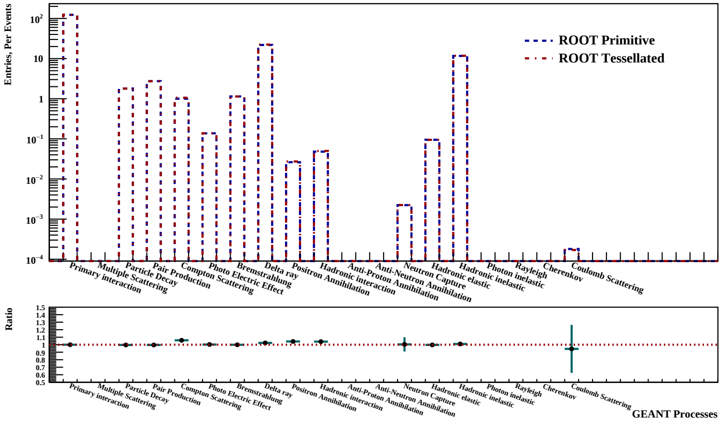
- Ni - Ni collison 1.93 AGeV/c, UrQMD model based mbias events.
- GEANT 4 used during event transport.
- For the transport time only mSTS, Target vacuum chamber and beam-pipe were taken in the setup configuration.
- Computation run time shown here is the mean of 10 jobs with 100 events per job using the Cluster - Virgo 3.0 facility at GSI on the system Model name: Intel Xeon Gold 6248R CPU: 3.00GHz



Run time comparison of ROOT primitive solids and Tessellated solid geometry using ROOT navigator.

Run time increases by more than a factor 4 for tessellated solids compared to the primitive solids

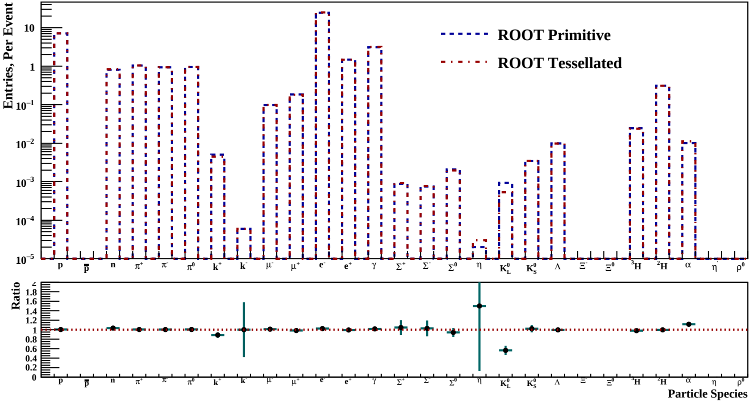
Simulation: Geant Processes



Geant processes during UrQMD event transport through the detector.

No significant difference was observed in Geant processes.

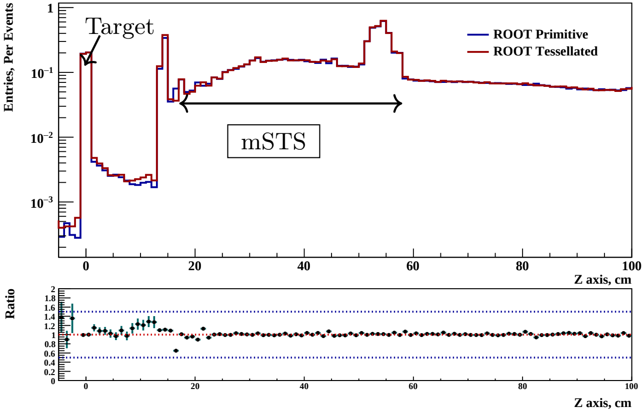
Simulation: Secondary Particles Distribution



Secondary particle distribution based on PDG Id.

No significant difference, however, there are some minor differences for some particle which needs to be investigated.

Simulation: Start Z Vertex for Secondary Particles



StartZ of the secondaries particle

No significant difference in the position of the mSTS detector system.

Summary & Outlook

- **Simplifies Complex Geometry:** Through this exercise, It is clear that converting CAD geometry to GDML and then integrating different volumes into a full simulation geometry simplifies the process for more complex structures.
- **Efficient Over Traditional Methods:** It offers a more efficient alternative to the traditional method of using ROOT TGeo primitive solids and significantly reduces manual effort and time required in preparing geometry.
- **Increased Computational Demand:** However, the trade-off comes in the form of increased computational time demands, which increase considerably with the number of facets.
- **Consistency in Results:** A comparison of the two geometries, based on UrQMD event transport, shows consistency in results, indicating that the geometry prepared by either methods will yield similar results. (if the material definition and approximation of defining volumes are done carefully.)

We will further explore the CAD-To-ROOT methods and how this alternative way can be beneficial for the large scaled CBM experiment.

Acknowledgement

- We express sincere gratitude to A. Gheata, a distinguished member of the SFT R&D group at CERN, for his invaluable assistance in our endeavours.
- We extend our appreciation to I. Hrivnacova and O. Freyermuth, for their invaluable contributions to resolving compatibility issues with the Tessellated solid class in the VGM project and ensuring seamless integration with the current CERN-ROOT 6.33.01 tag branch.

Thank you

Backup Slides

- Composed of a set of planar faces having triangular or quadrilateral shapes.

- **Method 1: Vectorized Geometry (VecGeom)**
  - Geometry modeller library (in development) as part of the GEANT V [4] R&D initiative.
  - Can be complied with ROOT.
  - Has its own navigation functionality with VecGeom[1]Navigator and with Intel Embree[3].
  - Offers traditional functionality with GEANT 3/4.
  - SIMD support in various flavours (multi-particle API, single-particle API)

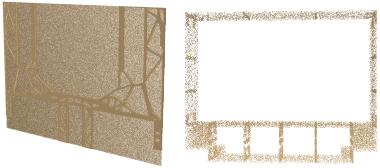
[1] https://gitlab.cern.ch/VecGeom/VecGeom
[2] S. Wenzel et al, https://cds.cern.ch/record/2718832/files/AIDA-2020-SLIDE-2020-028.pdf
[3] https://www.embree.org/

- **Method 2: TGeoArbN**
  - Under development at Bonn University and utilised by PANDA experiment for ECAL.
  - Not yet published.
  - STL (meshed) file from the CAD model can be directly used in ROOT for simulation geometry preparation.
  - Compatible with both GEANT 3/4.
  - Also includes the Octree partitioning functionality for speeding up simulation. [a] [b]

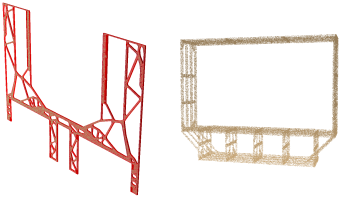
[a] Presentation on Wednesday by Ben Salisbury, https://indico.cern.ch/event/1338689/contributions/6010098/ which publicly introduces TGeoArbN.
[b] Poster on Thursday by Simon, https://indico.cern.ch/event/1338689/contributions/6010572/

[4] Amadio, G., Ananya, A., Apostolakis, J. et al. GeantV. Comput Softw Big Sci 5, 3 (2021). https://doi.org/10.1007/s41781-020-00048-6

Navigation Problem for Tessellated Solid



Random rays are thrown to the volume of the c-frame of the STS detector and the main frame of the TRD detector before the convertor.



Random rays/points thrown to the c-frame of the STS detector and main frame of the TRD detector after using the converter.

- There was a persistency problem for a tessellated solid because it was storing the vertex information, but now it is storing the vertex indices.
- It has been solved in ROOT >= 6.32.02 https://github.com/root-project/root/issues/14283
- Also, in the VGM master branch, now already VGM tag 5.3. https://github.com/vmc-project/vgm/issues/15

In our case ROOT 6.33.01 tag version and VGM master branch used.

Simulation: Run Time

- Ni - Ni collison 1.93 AGeV/c, UrQMD model based mbias events.
- GEANT 4 used during event transport.
- For the transport time only mSTS, Target vacuum chamber and beam-pipe were taken in the setup configuration.
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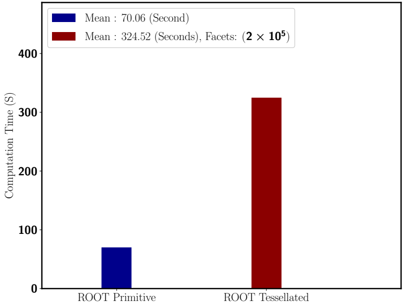
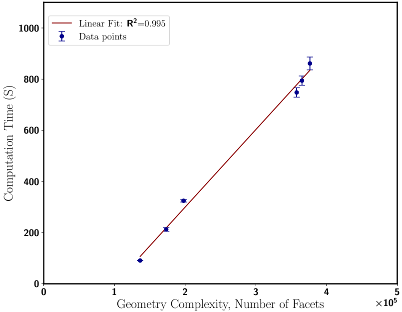
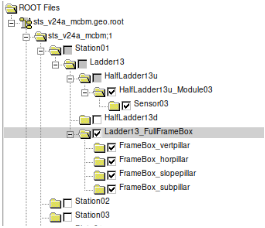




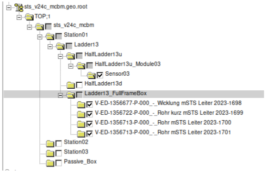
Run time comparison of ROOT primitive solids (left) and Tessellated solid geometry (Right) using ROOT navigator.

Description of Simulation Geometry: (ROOT/Tessellated solids)

- The geometry is generated from CAD to ROOT through a direct conversion process from the CAD's STEP file format to Geometry Description Markup Language (GDML), which is an XML-based format.
- One has the flexibility to create assemblies according to their preferences. However, in our case, we replicate the exact volume assembly as previously done. (No need to make changes in the existing classes !!)



mSTS v24a assembly



mSTS v24d assembly

```cpp
// Load gdml file //
const char* gdmlFileName = "New_mCBM_Geometry.gdml";
// Get the ROOT geometry from the loader
TGeoVolume* gdmlVolume = TGDMLParse().GDMLReadFile(gdmlFileName);
if (!gdmlVolume) {
cerr << "Error: Failed to load GDML file: " << gdmlFileName << endl;
return;
}
cout << "Physical Volume: " << gdmlVolume->GetNdaughters() << endl;
for (int inode = 0; inode < gdmlVolume->GetNdaughters(); inode++) {
TGeoNode* fNode = (TGeoNode*)gdmlVolume->GetNodes()->At(inode);
TGeoVolume* fVol = fNode->GetVolume();
TString nodeName = fVol->GetName();
if ((unitName == "Unit1" && (nodeName.Contains("V-ED-1039470-P-000_-_mSTS C-Frame Unit 00-2") )) ) {
stationAssembly->AddNode(fVol, inode, new TGeoTranslation(0.0, 0.0, 0.0));
}
```

Convertor for CAD to GDML for ROOT/GEANT

To read GDML file:

- ROOT uses `TGDMLParser`
- GEANT uses `G4GDMLParser`

```xml
  <position name="__v___sol_0__30950" x="-7.500000e+00" y="-2.836569e+02" z="-5.774566e+02" unit="mm"/>
  <position name="__v___sol_0__30951" x="-7.500000e+00" y="-2.834408e+02" z="-5.778781e+02" unit="mm"/>
  <position name="__v___sol_0__30952" x="-7.500000e+00" y="-2.832460e+02" z="-5.783099e+02" unit="mm"/>
  <position name="__v___sol_0__30953" x="-7.500000e+00" y="-2.830729e+02" z="-5.787508e+02" unit="mm"/>
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  <position name="__v___sol_0__30955" x="-7.500000e+00" y="-2.827938e+02" z="-5.796558e+02" unit="mm"/>
  <position name="__v___sol_0__30956" x="-7.500000e+00" y="-2.826884e+02" z="-5.801176e+02" unit="mm"/>
  <position name="__v___sol_0__30957" x="-7.500000e+00" y="-2.826061e+02" z="-5.805841e+02" unit="mm"/>
  <position name="__v___sol_0__30958" x="-7.500000e+00" y="-2.825472e+02" z="-5.810541e+02" unit="mm"/>
  <position name="__v___sol_0__30959" x="-7.500000e+00" y="-2.825118e+02" z="-5.815265e+02" unit="mm"/>
</define>
<materials>
  <material name="Galaxy" Z="1" formula="H">
    <D value="1e-25" unit="g/cm3"/>
    <atom value="1.0"/>
  </material>
</materials>
<solids>
  <box name="__box_world__" x="1.000000e+04" y="1.000000e+04" z="1.000000e+04" lunit="mm"/>
  <tessellated name="__sol_0_">
    <triangular vertex1="__v___sol_0__00000" vertex2="__v___sol_0__00001" vertex3="__v___sol_0__00002" type="ABSOLUTE"/>
    <triangular vertex1="__v___sol_0__00003" vertex2="__v___sol_0__00001" vertex3="__v___sol_0__00000" type="ABSOLUTE"/>
    <triangular vertex1="__v___sol_0__00004" vertex2="__v___sol_0__00005" vertex3="__v___sol_0__00006" type="ABSOLUTE"/>
    <triangular vertex1="__v___sol_0__00007" vertex2="__v___sol_0__00005" vertex3="__v___sol_0__00004" type="ABSOLUTE"/>
    <triangular vertex1="__v___sol_0__00008" vertex2="__v___sol_0__00005" vertex3="__v___sol_0__00007" type="ABSOLUTE"/>
    <triangular vertex1="__v___sol_0__00009" vertex2="__v___sol_0__00005" vertex3="__v___sol_0__00008" type="ABSOLUTE"/>
    <triangular vertex1="__v___sol_0__00010" vertex2="__v___sol_0__00005" vertex3="__v___sol_0__00009" type="ABSOLUTE"/>
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    <triangular vertex1="__v___sol_0__00015" vertex2="__v___sol_0__00016" vertex3="__v___sol_0__00017" type="ABSOLUTE"/>
```

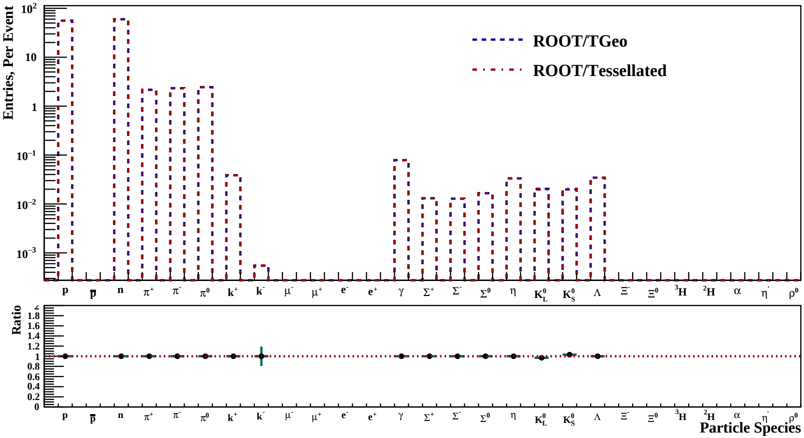
Information stored in gdml file after conversion from CAD STEP file

MRADSIM MATTER RADIATION INTERACTIONS SIMULATOR [l]

- Developed by BEAMIDE, National Institute for Nuclear Physics of Italy (INFN)
- It is being used for a radiation matter simulation for a space and earth-based technology to study radiation effects.
- Also provides a conversion tool from CAD to GDML.

[l] https://www.mradsim.com/
https://www.mradsim.com/about-mradsim/

Primary Particle Distribution



Primary particle distribution based on PDG id.