



# **Geometric modeling in particle physics community**

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# Outline

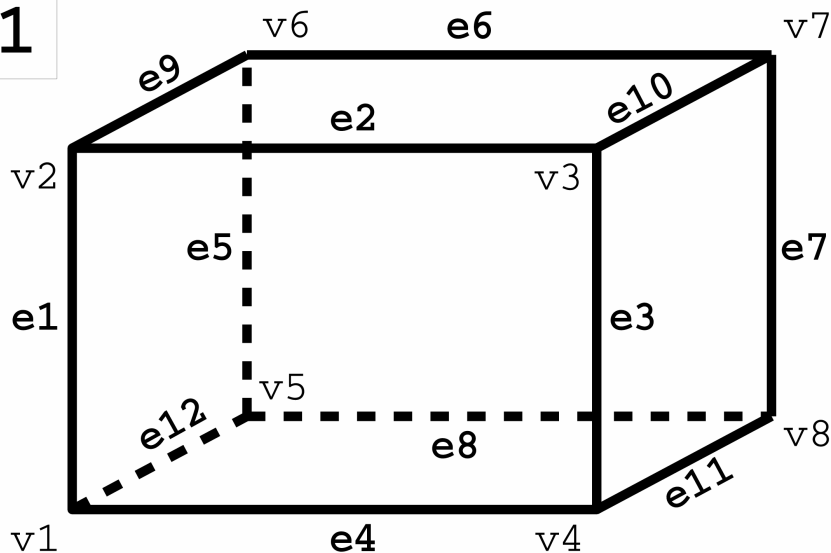
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- Geometry representations:
  1. BREP – CAD systems;
  2. CSG – GEANT4, ROOT;
  3. Polygonal – 3dMax, Maya, Blender, ...
    - Triangulated – all 3d applications;
  4. FEM – ANSYS, COMSOL, Abaqus, Nastran, ...
- Conversion possibilities;
- “CATIA-GDML geometry builder”;
  - Use-cases.

# 1. Boundary REPresentation (BREP), solid, p.1

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**S1**



**v** - vertex  
**e** - edge  
**f** - face  
**S** - solid

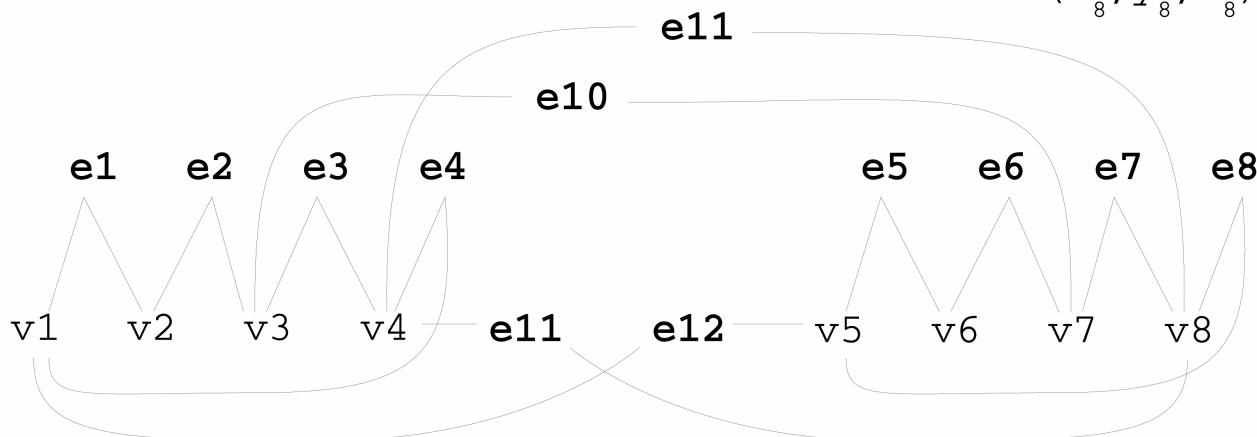
v1  $(x_1, y_1, z_1)$   
v2  $(x_2, y_2, z_2)$   
v3  $(x_3, y_3, z_3)$   
v4  $(x_4, y_4, z_4)$   
v5  $(x_5, y_5, z_5)$   
v6  $(x_6, y_6, z_6)$   
v7  $(x_7, y_7, z_7)$   
v8  $(x_8, y_8, z_8)$

**Point** – a 3-tuple of coordinates.

**Vertex** – a topological entity which lies on a geometrical point.

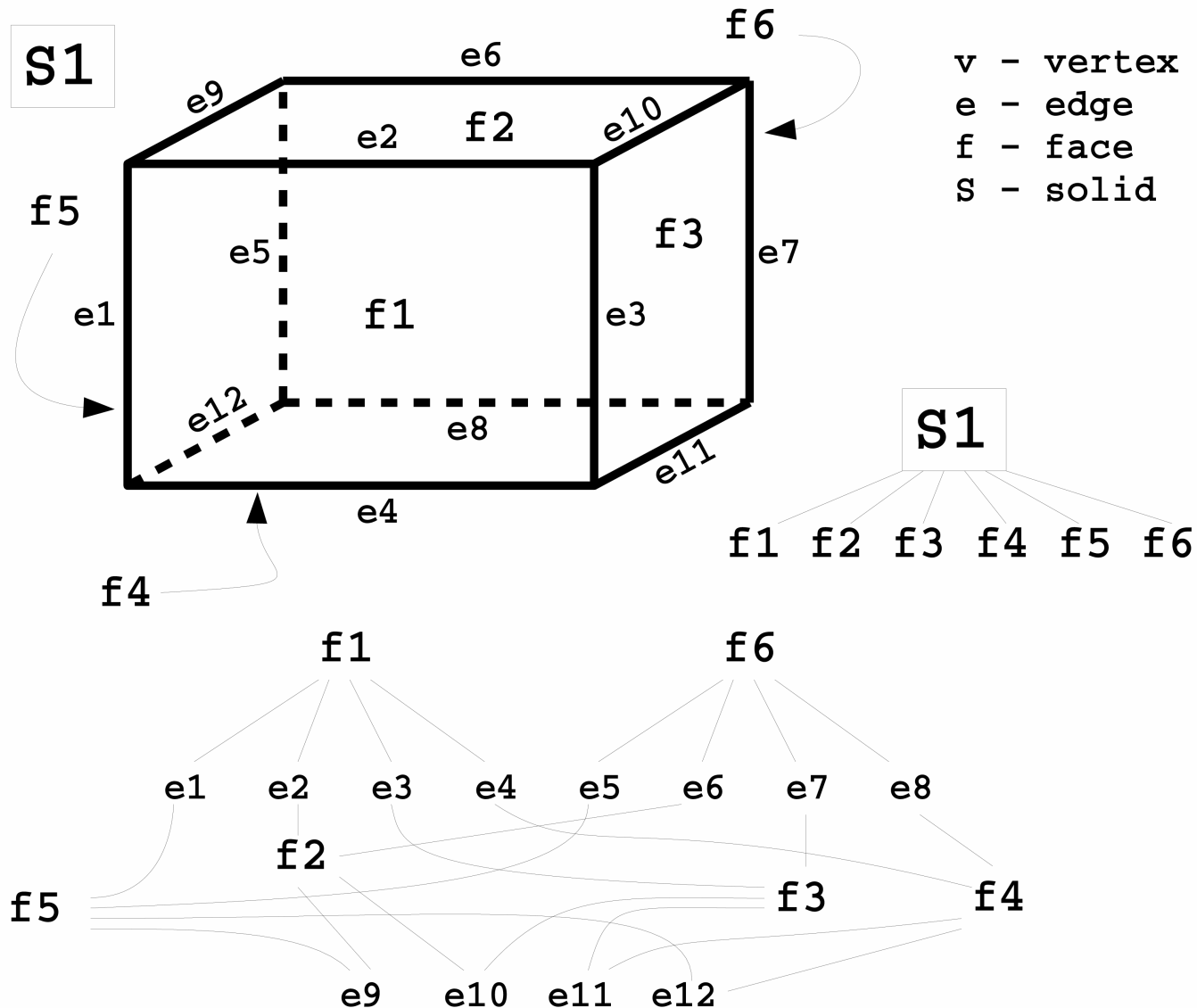
**Line** – an equation (usually a parametric equation of 1 parameter  $p$ ) which defines a set of points in 3d – a 3d curve.

**Edge** – a topological entity which lies on the line and is limited by 2 vertices.



# 1. Boundary REPresentation (BREP), solid, p.2

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**Surface** – an equation (usually a parametric equation of 2 parameters  $u, v$ ) which defines a set of points in 3d – a 3d surface.

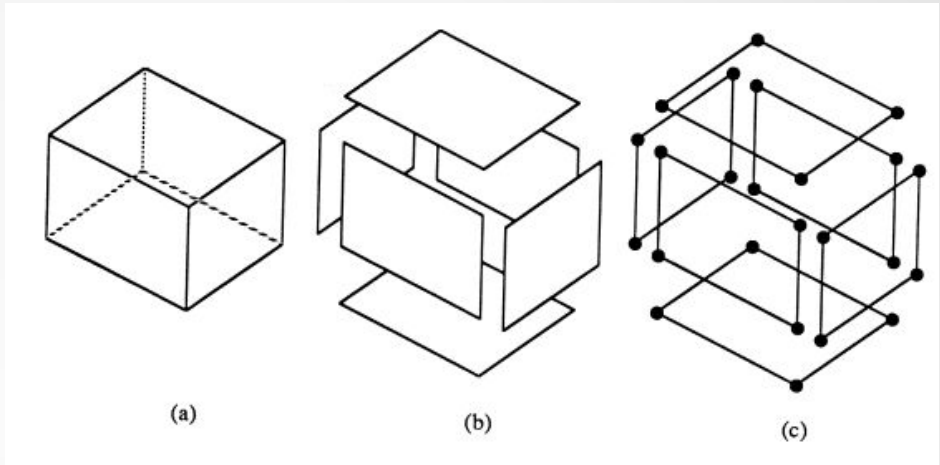
**Face** – a topological entity which lies on a surface and is limited by a closed loop of edges.

**Solid** is an object limited by a closed shell of faces.

# 1. BREP summary

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- Used in CAD systems.
- The most generic method to represent geometry in computer.

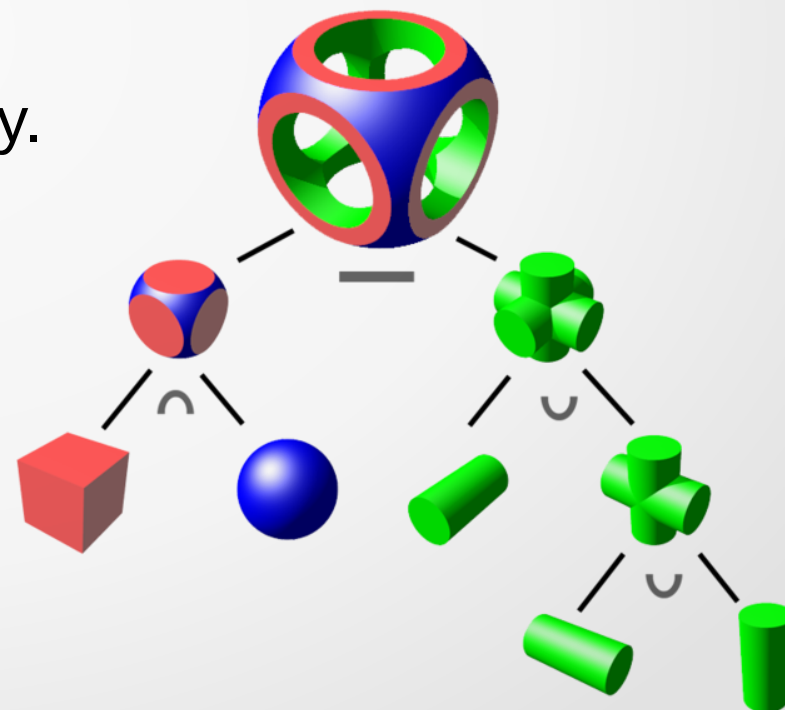
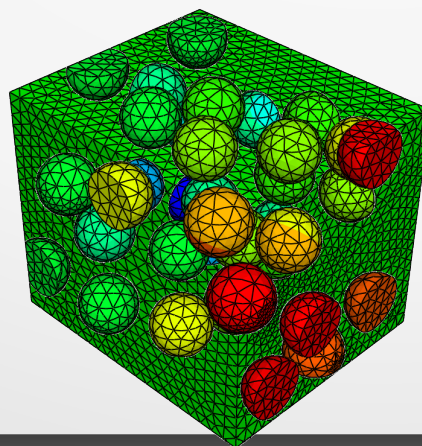


- BREP allow not only solids, but separate surfaces, lines, and points.
- Most popular exchange formats are STEP and IGES.
- Primary goal – precise representation of any geometry using complex math, if needed.

## 2. Constructive Solid Geometry (CSG)

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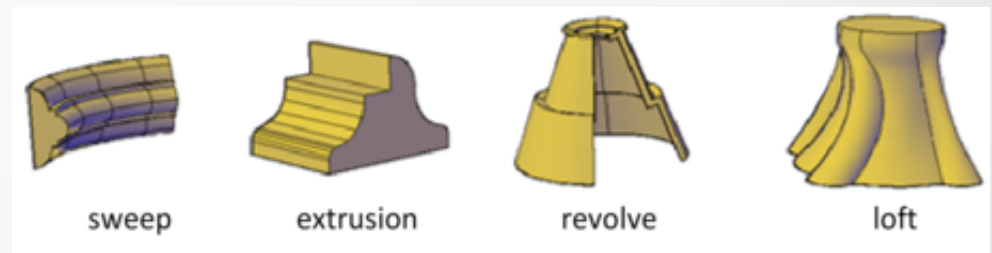
- Primitives – box, parallelepiped, hollow tube section, hollow cone section, hollow sphere section, trapezoids, etc...
- Boolean operations – Union, Subtraction, Intersection
- Geometry specification – list of bodies, each body being a Boolean tree.
- Used in CAD systems in their infancy.
- Currently used by GEANT/ROOT and in some very specific fields.



# 1. CAD approach to building BREP

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- Shape:
  - Create planar sketches;
  - Create datum elements – axes, planes;
  - Create a solid using one of the four basic features – pad, shaft, rib, multi-section solid;
  - Modify created solid using one of the four basic features.
  - CAD system builds BREP.
- Volume hierarchy:
  - Infinite space with no material;
  - All shapes within this space without overlaps (in a normal situation).
- Geometry specification – complex tree of products – only logical grouping.

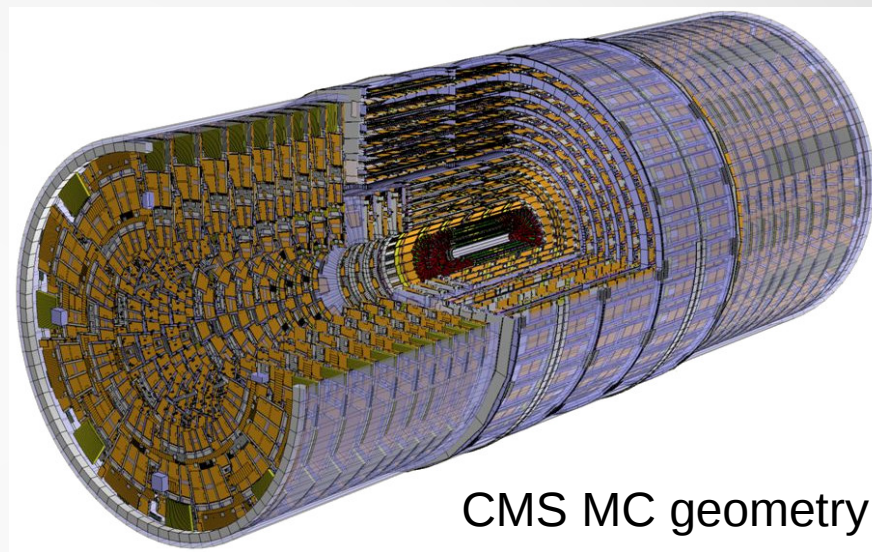




## 2. GEANT/ROOT approach

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- Geometry for Monte Carlo (MC) simulation of particles propagation.
- Shape:
  - CSG.
- Volume hierarchy:
  - Primary goal – unambiguously define material in each point in space;
  - Minimize geometry definition size (in Mb);
  - Thus – volumes (logical) and nodes (physical volumes), positioning matrices.
- Declarative geo description, ROOT “C” macro, advanced software packages (SimpleGeo – dead project, CAD converter – very unstable)



CMS MC geometry



### 3. Polygonal geometry

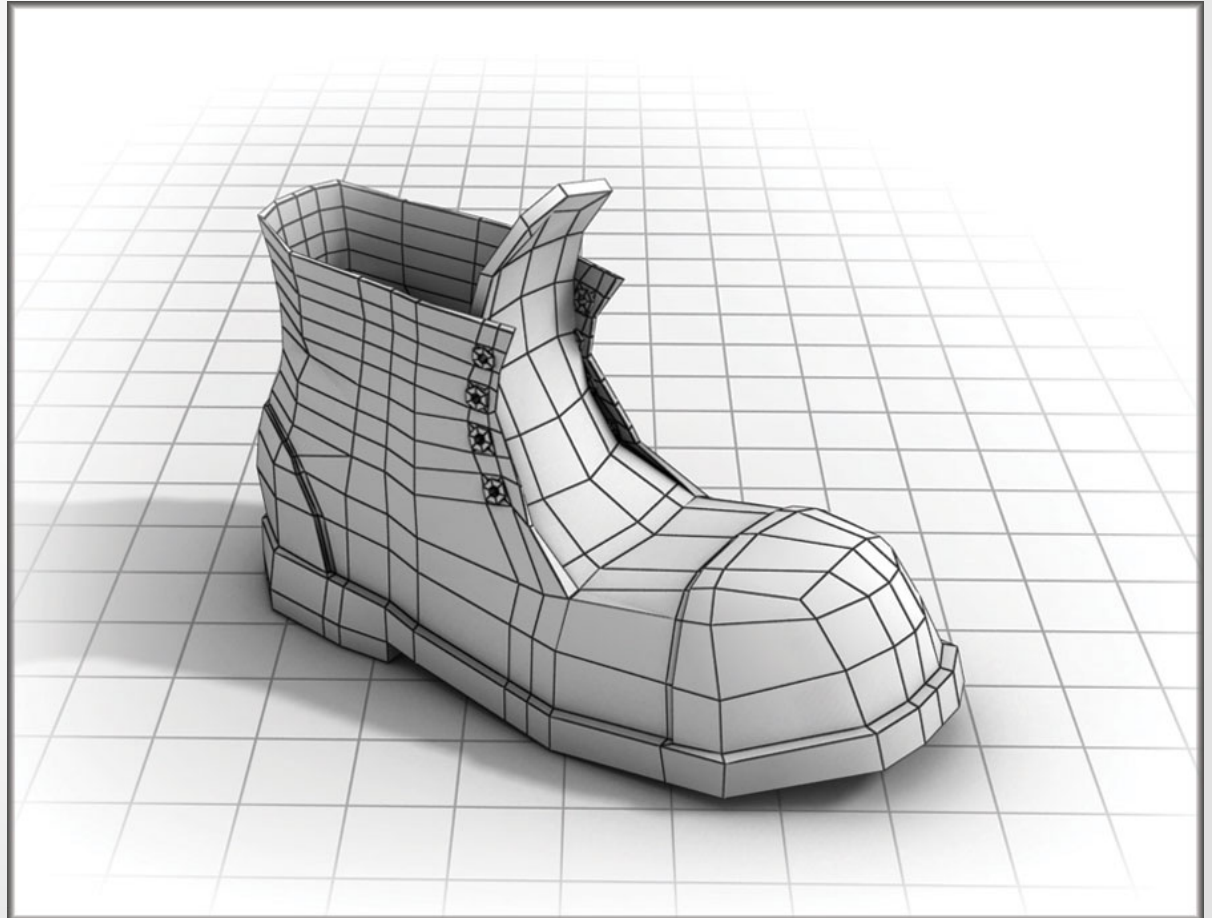
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Polygons are easily converted into triangles.  
Triangles are rendered very fast – this is GPU's primary design goal.  
Polygonal geometry is used for visualization, for photo-realistic images generating, cartoons, video games, etc...

Software like Autodesk 3dMax, Autodesk Maya, Blender is used to build, edit and render polygonal geometry.

Polygons can hardly be used to describe solids (with no holes in boundaries).

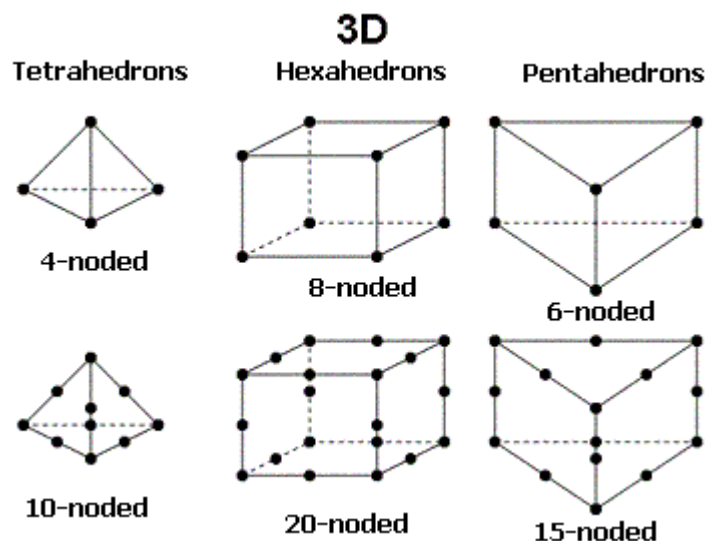
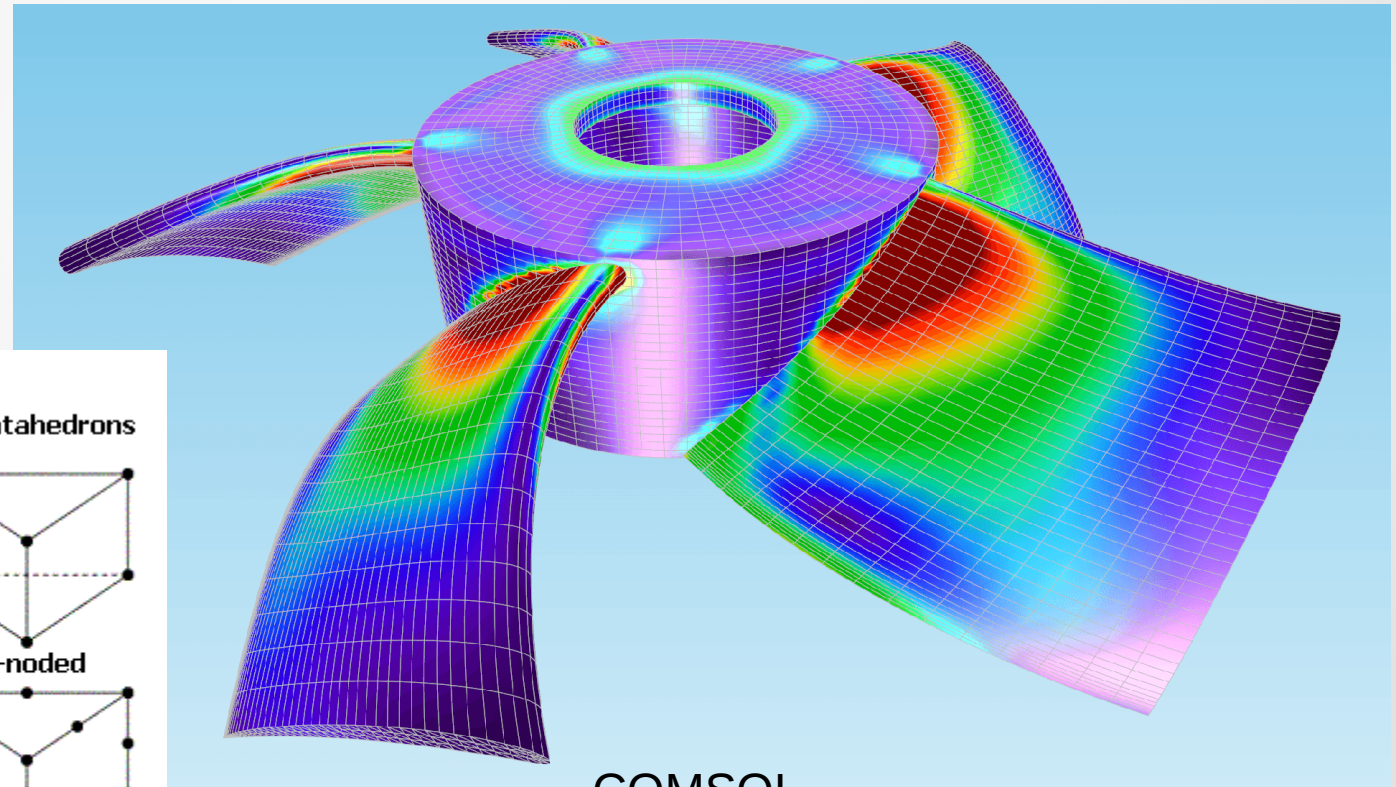
Primary goal –  
nice picture.



# 4. Finite-element geometry

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- Used by finite-element model (FEM) solvers to perform physics simulations: mechanical, hydrodynamics, thermodynamics, etc...
- The solid is represented as a set of adjacent finite elements, most used being tetrahedra.

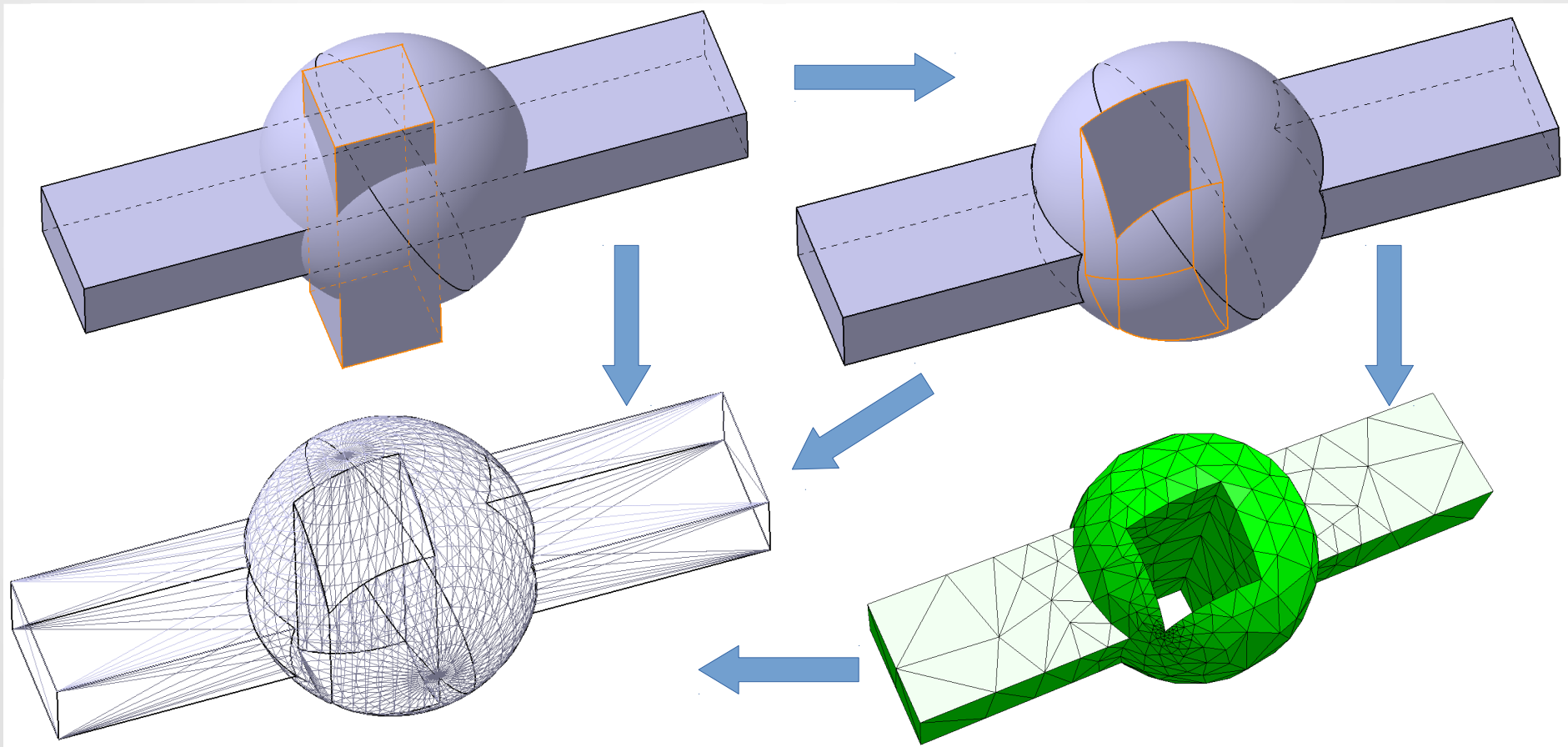


# BREP – CSG – FEM – Polygonal

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CSG: Boolean – separate operands

CSG: Boolean, visually equiv. to BREP



Polygonal (triang.) for visualization

FE-model, only triangulated surfaces are seen

# Conversion

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- **CSG** into **BREP** – easily! Full and automatic conversion is possible. All CAD systems can do that. OpenCASCADE Technology library provides C++ functions to do that.
- **BREP (CSG)** into **polygonal** (triangulated) – almost as easy! Approximation of original smooth surfaces using Delaunay algorithm. Needs precision parameter value set by the user and quality control in the end.
- **BREP (CSG)** into **FEM** – well-developed semi-automatic procedure. Most FEM software can do that, some specialized packages exist.
- **Polygonal (FEM)** into **BREP** – (a) reverse polygonalization impossible, (b) direct conversion (each polygon into a face) – plain but almost senseless.
- **BREP** into **CSG** – **impossible**, thus different specialized solutions such as “CATIA-GDML geometry builder”.

# CATIA-GDML geometry builder

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- [https://gitlab-hybrilit.jinr.ru/cad2gdml/CATIA-GDML\\_geometry\\_builder](https://gitlab-hybrilit.jinr.ru/cad2gdml/CATIA-GDML_geometry_builder)
- S Belogurov et al 2011 J. Phys.: Conf. Ser. 331 032035
- S Belogurov et al 2014 J. Phys.: Conf. Ser. 513 022003
- One prerequisite which stops many potential users: the “Builder” requires CATIA v5 and basic skills of using it.
- However this should not stop you because:
  - (a) any new software requires some learning time and you really don’t need to learn a lot about CATIA to start working with the “Builder”.
  - (b) JINR has CATIA licenses.
  - (c) we are here to help you.



# CATIA-GDML geometry builder

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- Create a new product document;
- Give it a name, save it on disk;
- Define volume's shape using **Add shape**, **Poly** and **Boolean**.
- Create volume hierarchy using **Insert**, **Replica**, **ArrayMaker**;
- Define rotations and positions of the volumes using **Point-to-point aligner** and **Measure**;
- Introduce **parameterization**;
- Use **Duplicator** if needed;
- Check that the materials are correctly defined using **Materials manager**;
- Check the model using **Checker**;
- Export the model using **CATIA2GDML**;
- If you are using ROOT or ROOT-based package, perform geometry check.

# Use-cases

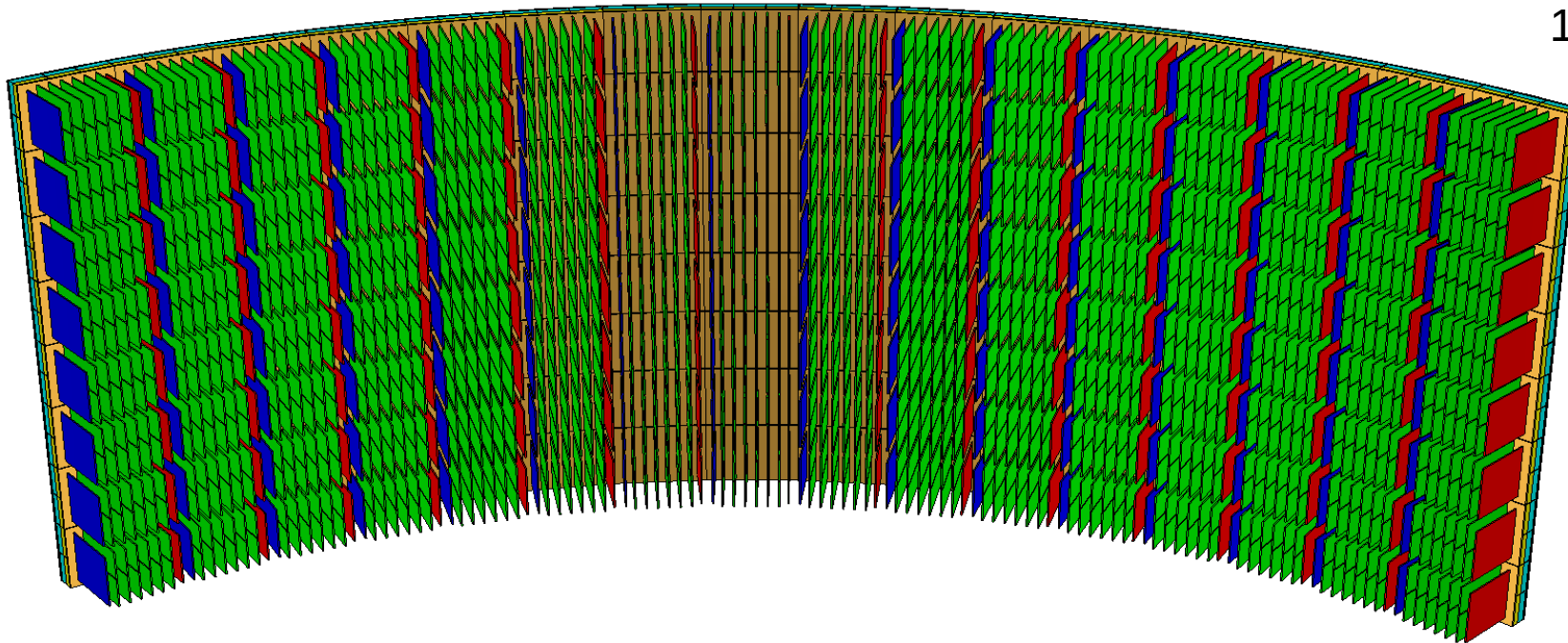
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- Over 7 years we have applied “CATIA-GDML geometry builder” in several projects and we are looking forward to find new users:
  - CBM RICH detector – driving use-case.
  - PANDA Muon system.
  - CMS Muon system, CMS beampipe.
  - R3B “GLAD” cryostat.
  - CBM ECAL support structure, CBM beampipe, CBM MVD, CBM vacuum chamber, CBM magnet.
  - Some other small projects.



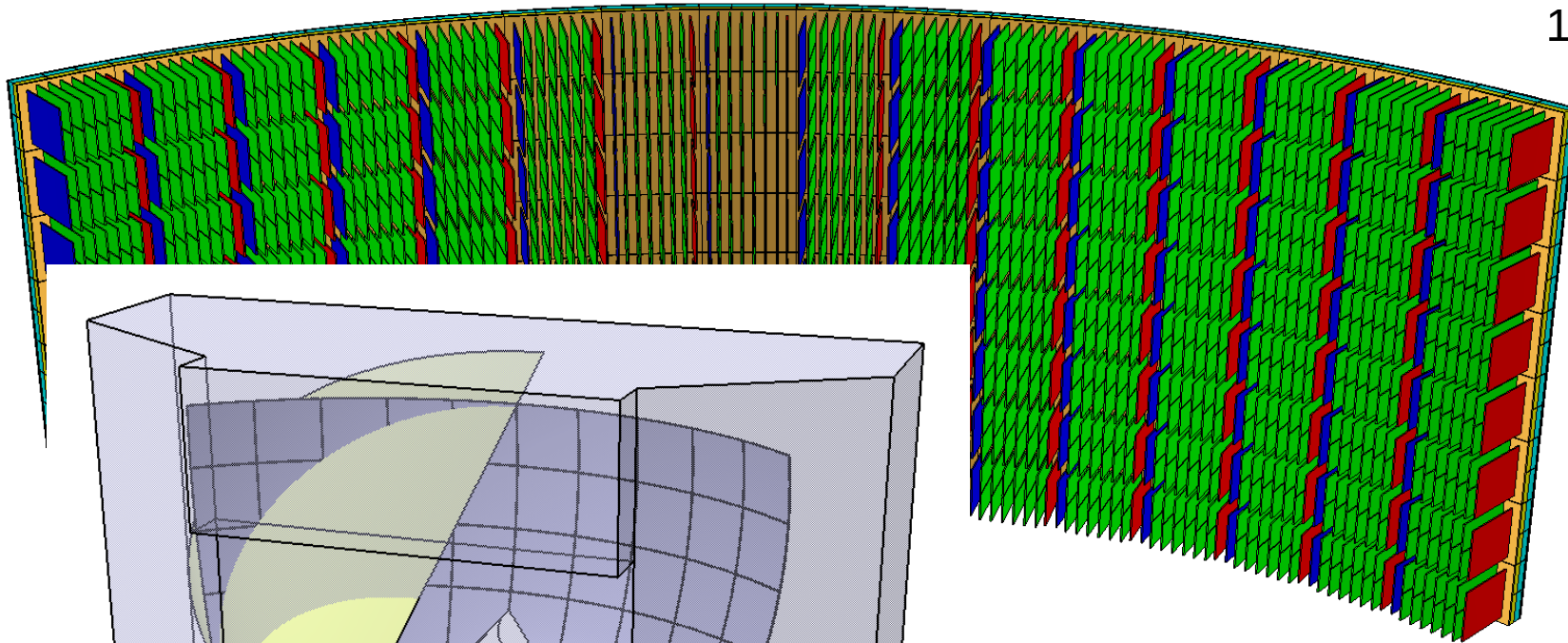
# CBM RICH MC-model

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# CBM RICH MC-model

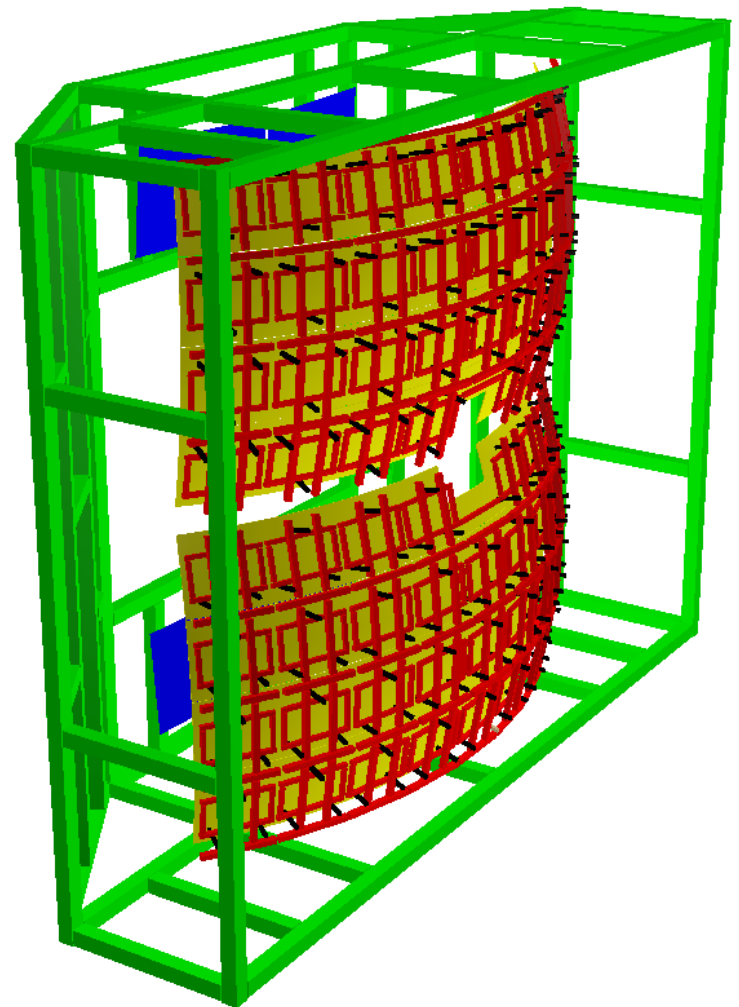
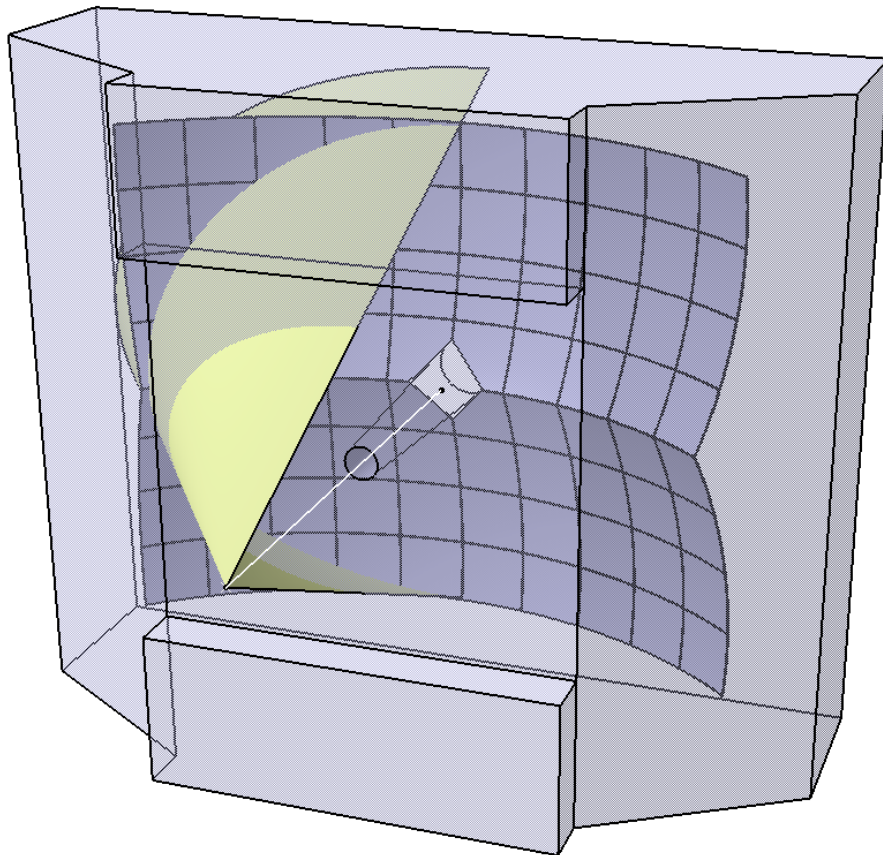
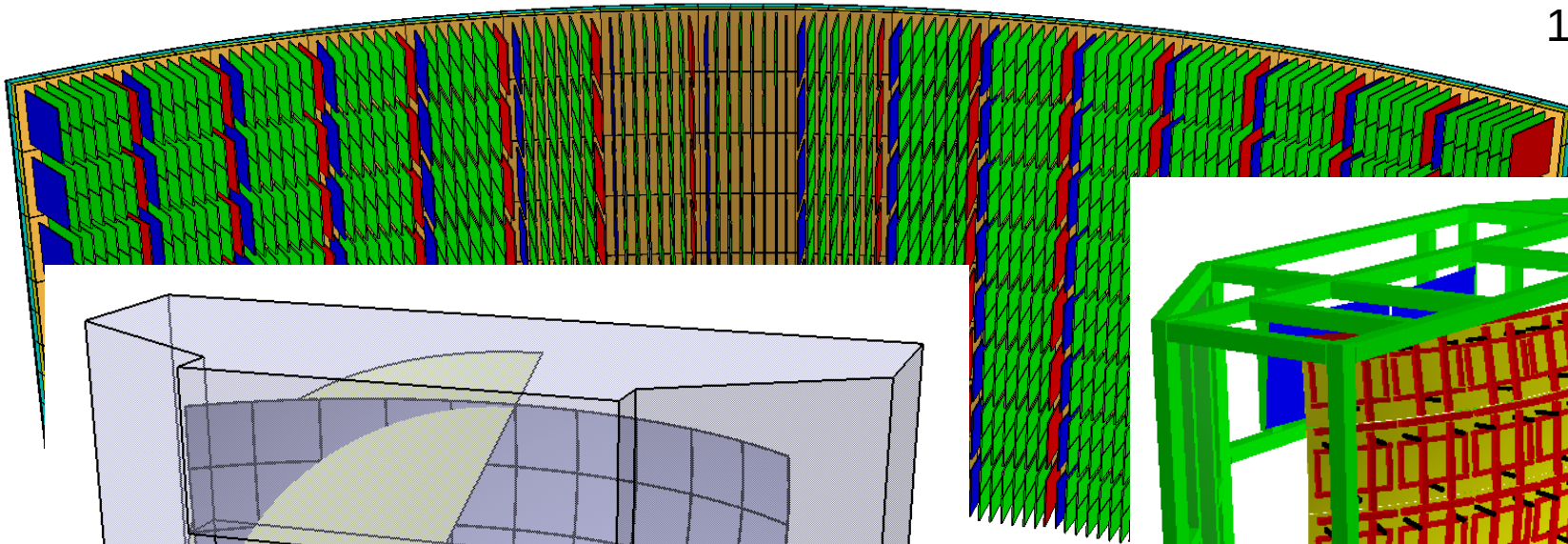
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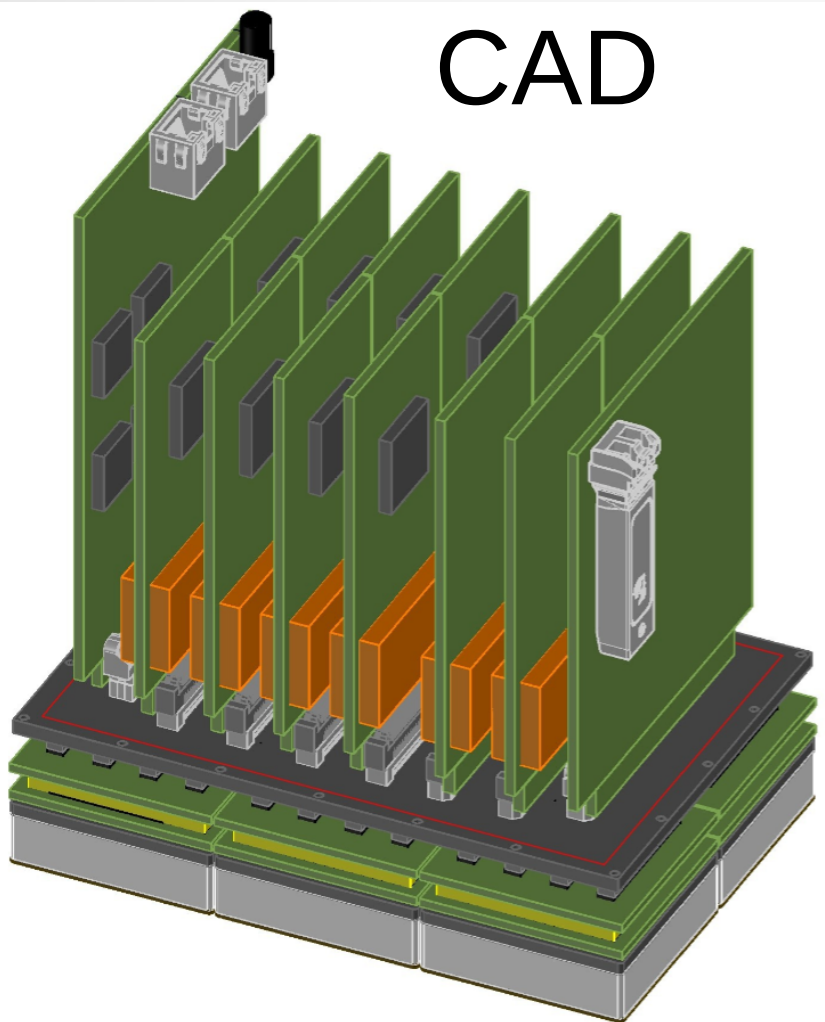
# CBM RICH MC-model

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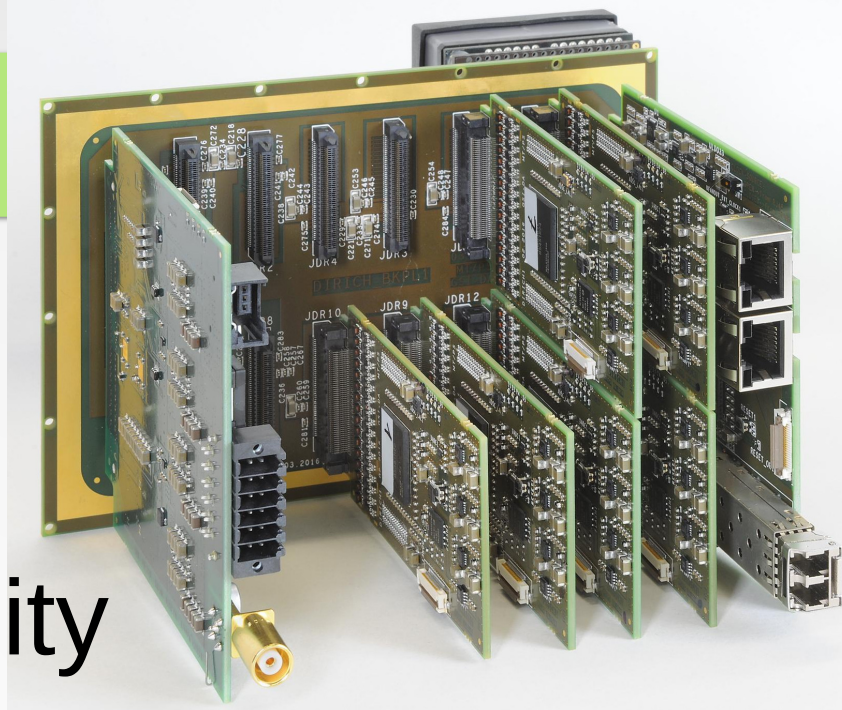


# CBM RICH readout module

CAD



Reality



MC

