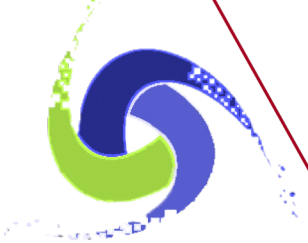


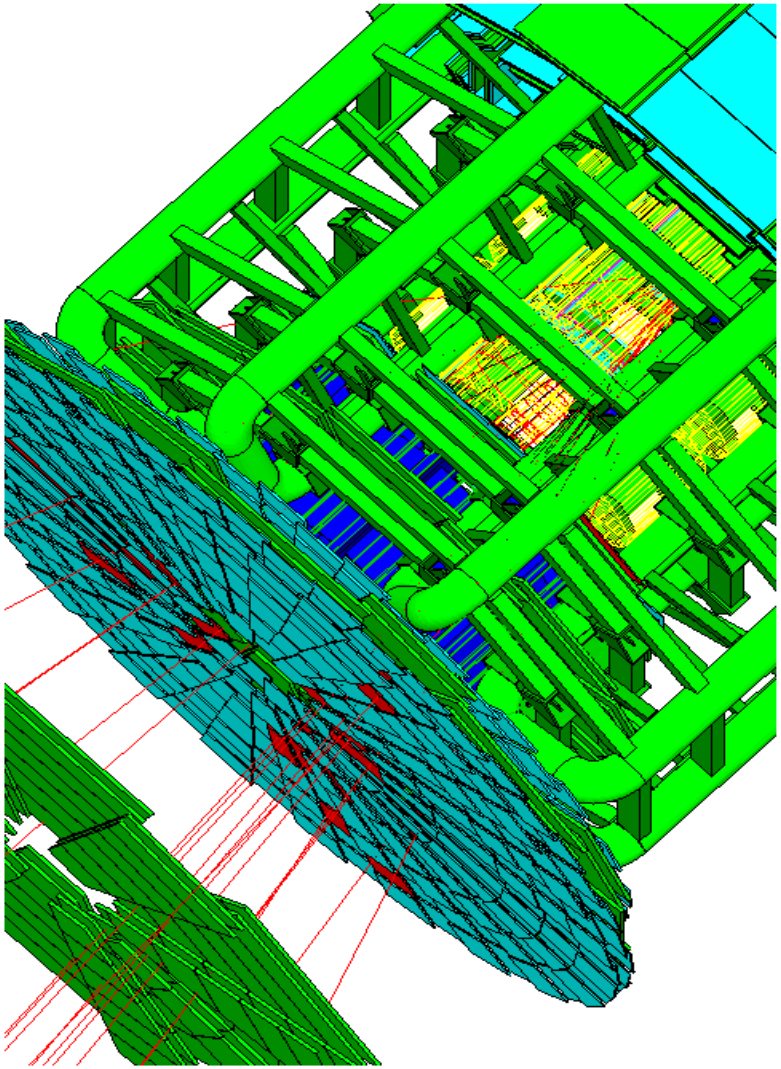
GEANT4
A SIMULATION TOOLKIT
Version 10.5

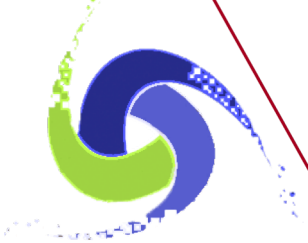
Geometry III

Makoto Asai (SLAC)
Geant4 Tutorial Course

Contents

- Magnetic field
- Field integration and other types of field
- GDML/CAD interfaces
- Geometry checking tools
- Geometry optimization





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Defining a magnetic field

Magnetic field (1)

- Create your Magnetic field class. It must be instantiated in ConstructSDandField() method of your DetectorConstruction
  - Uniform field :
    - Use an object of the G4UniformMagField class

```
G4MagneticField* magField =
    new G4UniformMagField(G4ThreeVector(1.*Tesla,0.,0.);
```

  - Non-uniform field :
    - Create your own concrete class derived from G4MagneticField and implement **`GetFieldValue`** method.

```
void MyField::GetFieldValue(
        const double Point[4], double *field) const
```

    - Point[0..2] are position in global coordinate system, Point[3] is time
    - field[0..2] are returning magnetic field

Global and local fields

- One field manager is associated with the 'world' and it is set in G4TransportationManager
- Other volumes can override this
  - An alternative field manager can be associated with any logical volume
    - The field must accept position in global coordinates and return field in global coordinates
  - By default this is propagated to all its daughter volumes

```
G4FieldManager* localFieldMgr
      = new G4FieldManager(magField);
logVolume->setFieldManager(localFieldMgr, true);
```

where '**true**' makes it push the field to all the volumes it contains, unless a daughter has its own field manager.

- Customizing the field propagation classes
  - Choosing an appropriate stepper for your field
  - Setting precision parameters

Magnetic field (2)

```
MyField* fMyField = new MyField();
G4Fieldmanager* fFieldMgr = new G4FieldManager();
fFieldMgr->SetDetectorField(fMyField);
fFieldMgr->CreateChordFinder(fMyField);
G4bool forceToAllDaughters = true;
fMagneticLogical->SetFieldManager(fFieldMgr,
                                  forceToAllDaughters);
// Register the field and its manager for deleting
G4AutoDelete::Register(fMagneticField);
G4AutoDelete::Register(fFieldMgr);
```

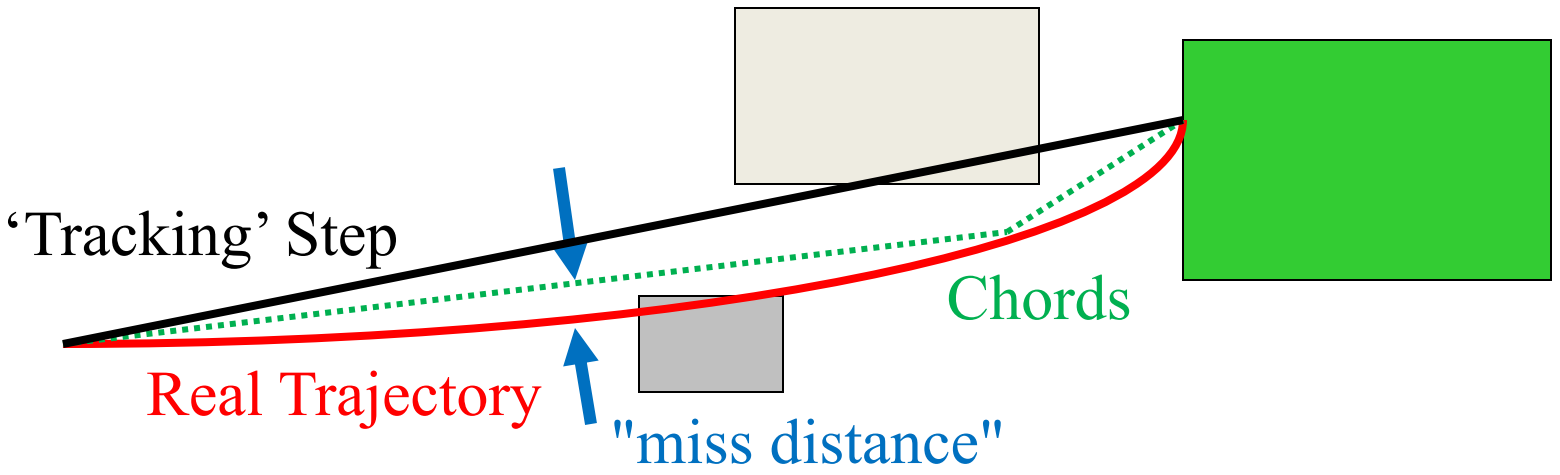
- /example/basic/B5 is a good starting point

Field integration

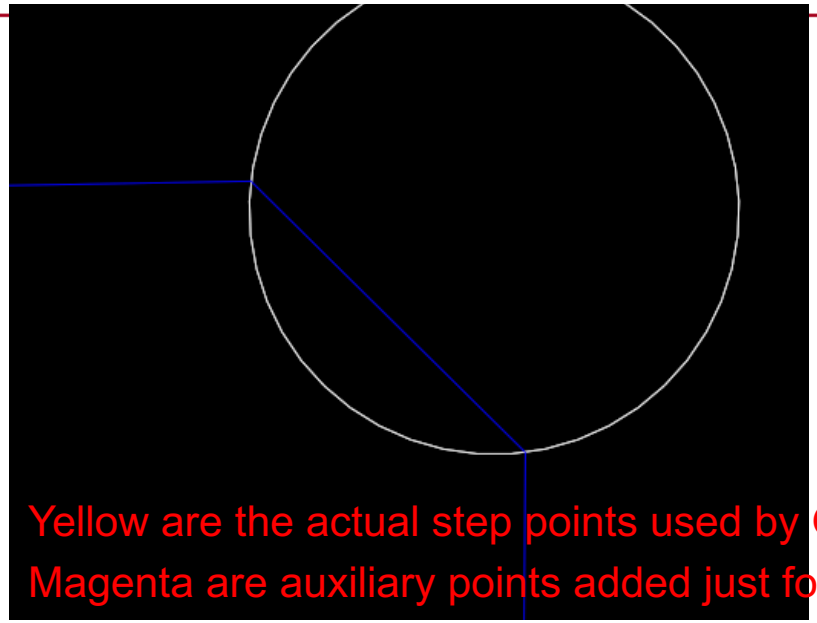
- In order to propagate a particle inside a field (e.g. magnetic, electric or both), we solve the equation of motion of the particle in the field.
- We use a Runge-Kutta method for the integration of the ordinary differential equations of motion.
  - Several Runge-Kutta 'steppers' are available.
- In specific cases other solvers can also be used:
  - In a uniform field, using the analytical solution.
  - In a smooth but varying field, with RK+helix.
- Using the method to calculate the track's motion in a field, Geant4 breaks up this curved path into linear chord segments.
  - We determine the chord segments so that they closely approximate the curved path.

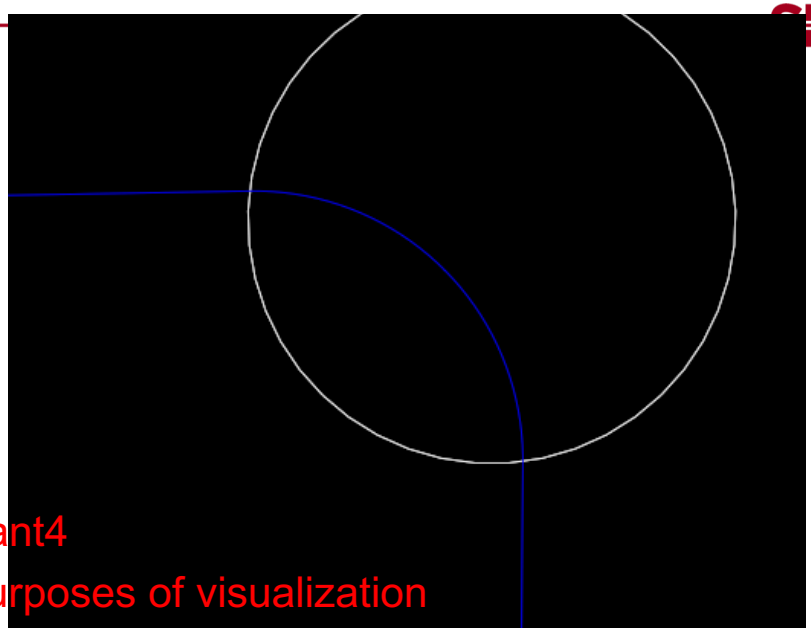
Tracking in field

- We use the chords to interrogate the G4Navigator, to see whether the track has crossed a volume boundary.
- One physics/tracking step can create several chords.
  - In some cases, one step consists of several helix turns.
- User can set the accuracy of the volume intersection,
  - By setting a parameter called the “miss distance”
    - It is a measure of the error in whether the approximate track intersects a volume.
    - It is quite expensive in CPU performance to set too small “miss distance”.



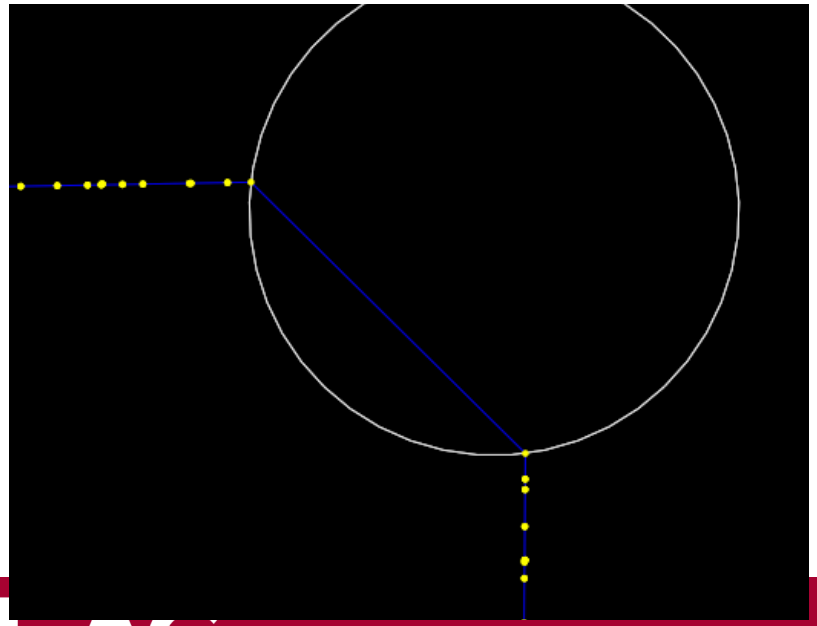
Regular versus Smooth Trajectory

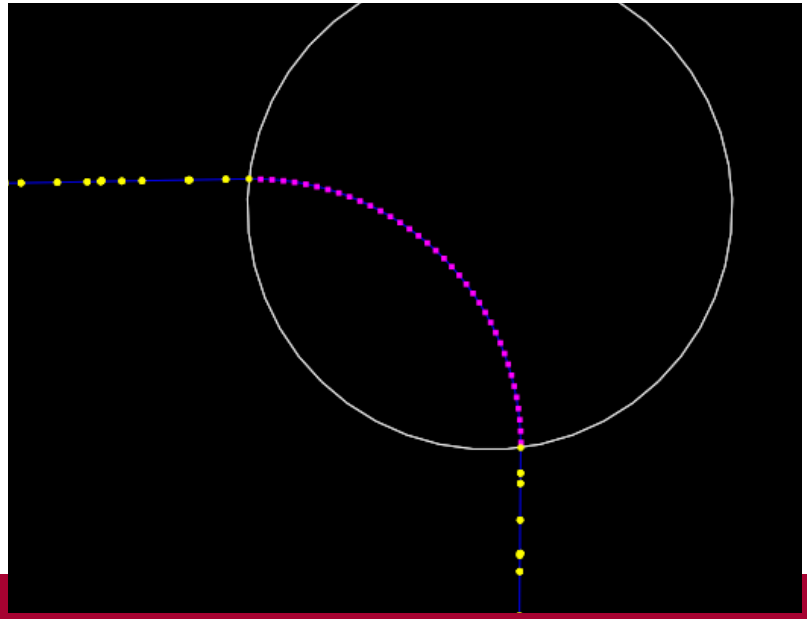




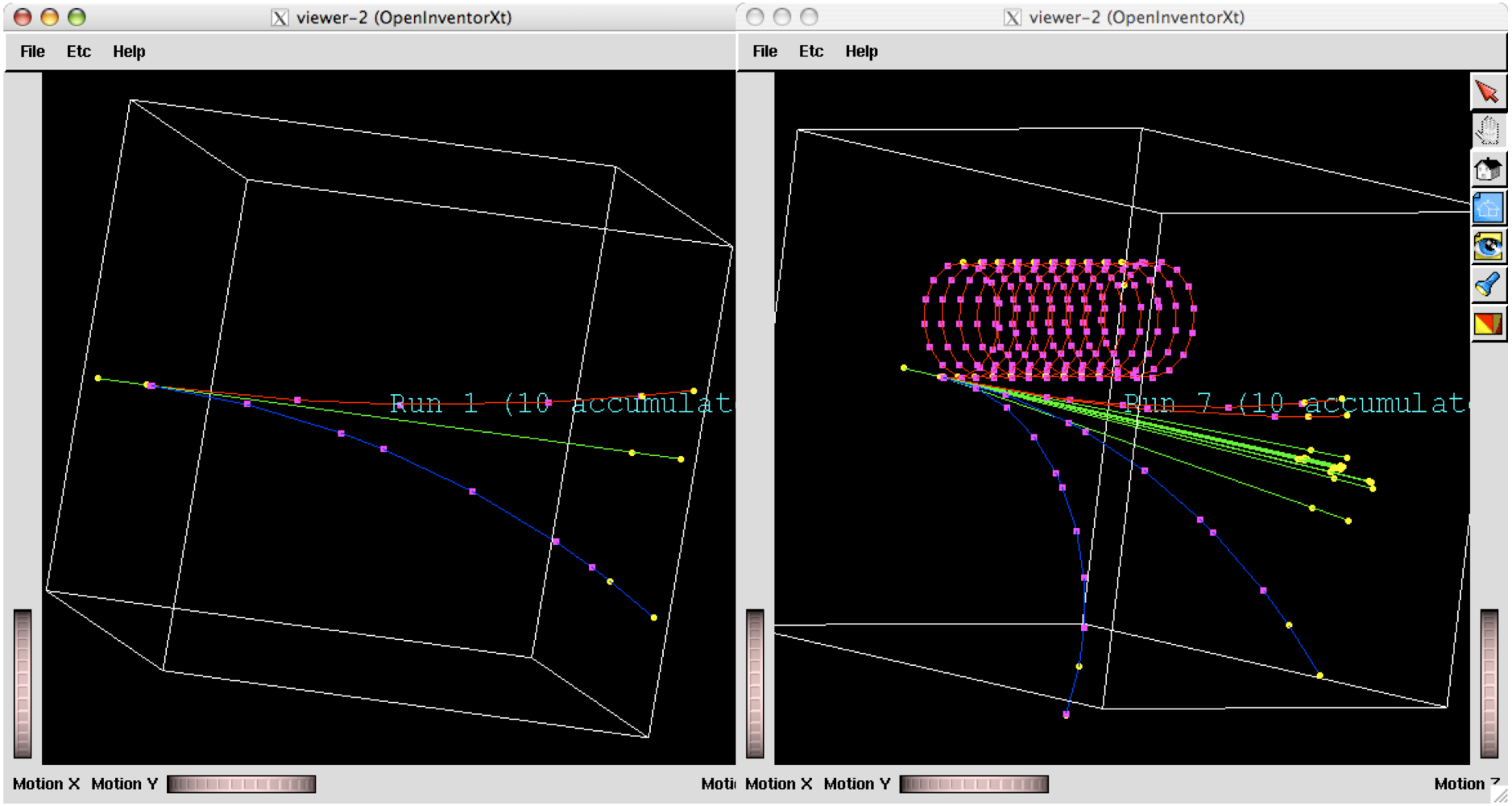
Yellow are the actual step points used by Geant4

Magenta are auxiliary points added just for purposes of visualization





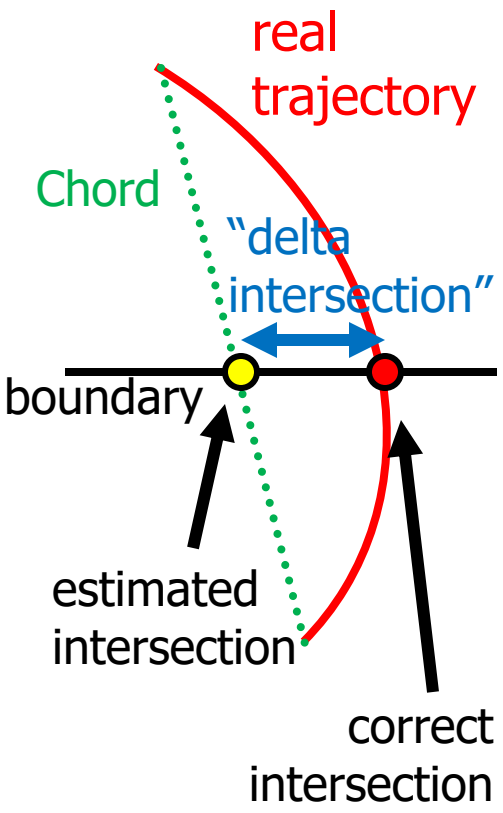
Smooth Trajectory Makes Big Difference for Trajectories that Loop in a Magnetic Field



- Yellow dots are the actual step points used by Geant4
- Magenta dots are auxiliary points added just for purposes of visualization

Tunable parameters

- In addition to the "miss distance" there are two more parameters which the user can set in order to adjust the accuracy (and performance) of tracking in a field.
  - These parameters govern the accuracy of the intersection with a volume boundary and the accuracy of the integration of other steps.
- The "delta intersection" parameter is the accuracy to which an intersection with a volume boundary is calculated. This parameter is especially important because it is used to limit a bias that our algorithm (for boundary crossing in a field) exhibits. The intersection point is always on the 'inside' of the curve. By setting a value for this parameter that is much smaller than some acceptable error, the user can limit the effect of this bias.

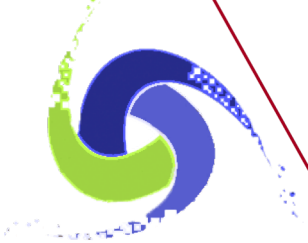


Tunable parameters

- The “delta one step” parameter is the accuracy for the endpoint of 'ordinary' integration steps, those which do not intersect a volume boundary. This parameter is a limit on the estimation error of the endpoint of each physics step.
- “delta intersection” and “delta one step” are strongly coupled. These values must be reasonably close to each other.
  - At most within one order of magnitude
- These tunable parameters can be set by

```
theChordFinder->SetDeltaChord( miss_distance );
theFieldManager->SetDeltaIntersection( delta_intersection );
theFieldManager->SetDeltaOneStep( delta_one_step );
```

- Further details are described in Section 4.3 (Electromagnetic Field) of the Application Developers Manual.



GEANT4

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Field integration
and
Other types of field

Customizing field integration

- Runge-Kutta integration is used to compute the motion of a charged track in a general field. There are many general steppers from which to choose, of low and high order, and specialized steppers for pure magnetic fields.
- By default, Geant4 uses the classical fourth-order Runge-Kutta stepper (G4ClassicalRK4), which is general purpose and robust.
  - If the field is known to have specific properties, lower or higher order steppers can be used to obtain the results of same quality using fewer computing cycles.
- In particular, if the field is calculated from a field map, a lower order stepper is recommended. The less smooth the field is, the lower the order of the stepper that should be used.
  - The choice of lower order steppers includes the third order stepper G4SimpleHeum, the second order G4ImplicitEuler and G4SimpleRunge, and the first order G4ExplicitEuler. A first order stepper would be useful only for very rough fields.
  - For somewhat smooth fields (intermediate), the choice between second and third order steppers should be made by trial and error.

Customizing field integration

- Trying a few different types of steppers for a particular field or application is suggested if maximum performance is a goal.
- Specialized steppers for pure magnetic fields are also available. They take into account the fact that a local trajectory in a slowly varying field will not vary significantly from a helix.
  - Combining this in with a variation, the Runge-Kutta method can provide higher accuracy at lower computational cost when large steps are possible.
- To change the stepper

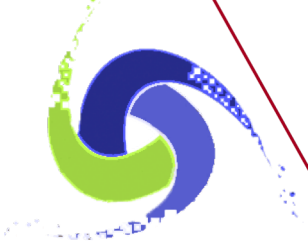
```
theChordFinder
   ->GetIntegrationDriver()
   ->RenewStepperAndAdjust( newStepper );
```

- Further details are described in Section 4.3 (Electromagnetic Field) of the Application Developers Manual.

Other types of field

- The user can create their own type of field, inheriting from G4VField, and an associated Equation of Motion class (inheriting from G4EqRhs) to simulate other types of fields. Field can be time-dependent.
- For pure electric field, Geant4 has G4ElectricField and G4UniformElectricField classes. For combined electromagnetic field, Geant4 has G4ElectroMagneticField class.
- Equation of Motion class for electromagnetic field is G4MagElectricField.

```
G4ElectricField* fEMfield
    = new G4UniformElectricField( G4ThreeVector(0., 100000.*kilovolt/cm, 0.) );
G4EqMagElectricField* fEquation = new G4EqMagElectricField(fEMfield);
G4MagIntegratorStepper* fStepper = new G4ClassicalRK4( fEquation, nvar );
G4FieldManager* fFieldMgr
    = G4TransportationManager::GetTransportationManager()-> GetFieldManager();
fFieldManager->SetDetectorField( fEMfield );
G4MagInt_Driver* fIntgrDriver
    = new G4MagInt_Driver(fMinStep, fStepper,
                          fStepper->GetNumberOfVariables() );
G4ChordFinder* fChordFinder = new G4ChordFinder(fIntgrDriver);
```



GEANT4
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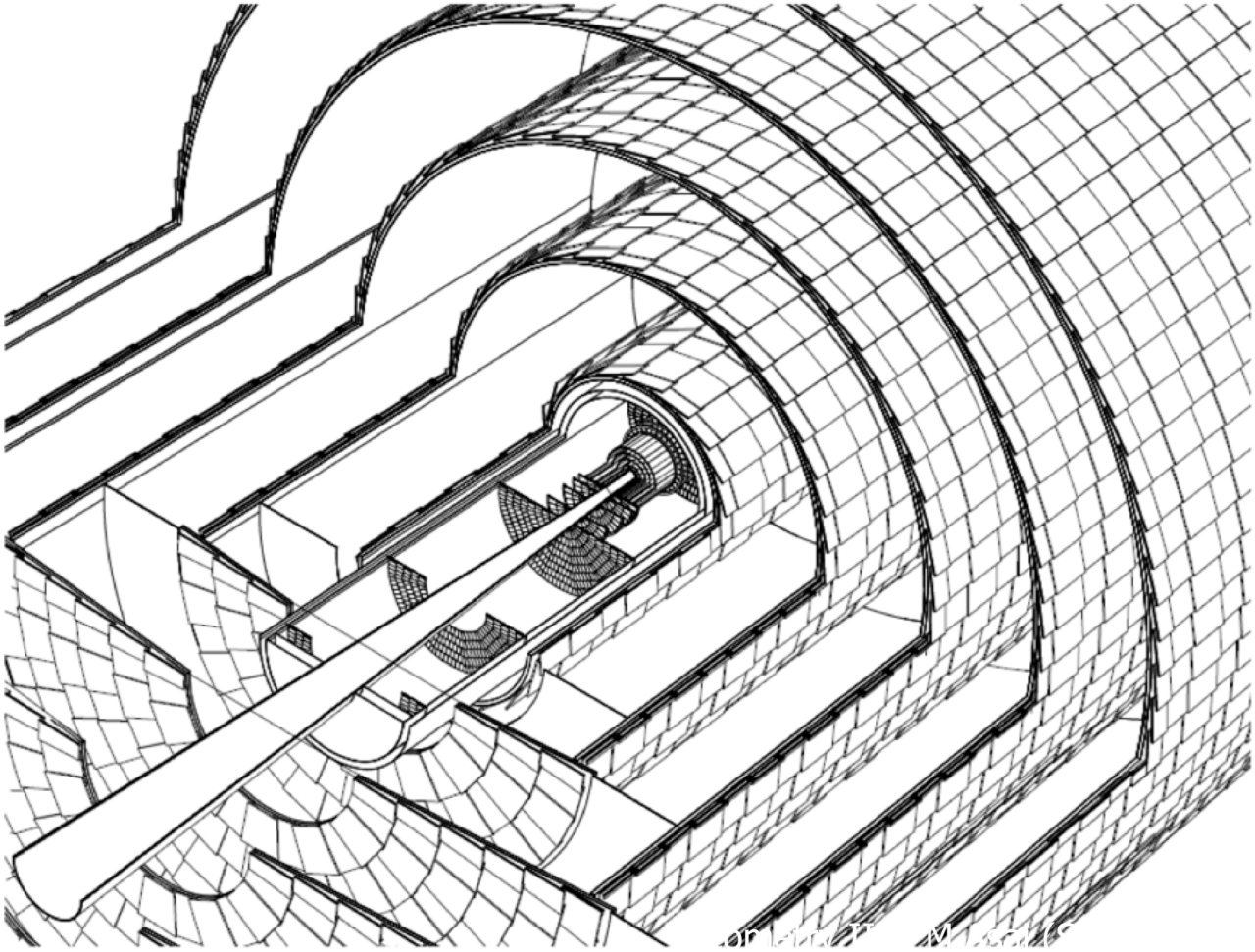
Version 10.5

GDML/CAD interfaces

GDML and CAD Interfaces

- Up to now, the course has shown how to define materials and volumes from C++.
- This part of slides shows some alternate ways to define geometry at runtime by providing a file-based detector description.



Silicon Pixel & Microstrip Tracker for Collider Detector
N. Graf, J. McCormick, LCDD, SLAC

GDML : Geometrical Description Modeling Language

- An XML-based language designed as an application independent persistent format for describing the geometries of detectors.
  - Implements “geometry trees” which correspond to the hierarchy of volumes a detector geometry can be composed of
  - Allows materials to be defined and solids to be positioned
- Because it is pure XML, GDML can be used universally
  - Not just for Geant4
  - Can be format for interchanging geometries among different applications.
  - Can be used to translate CAD geometries to Geant4
- XML is simple
  - Rigid set of rules, self-describing data validated against schema
- XML is extensible
  - Easy to add custom features, data types
- XML is Interoperable to OS’s, languages, applications
- XML has hierarchical structure
  - Appropriate for Object-Oriented programming
  - Detector/sub-detector relationships

GDML structure

- Contains numerical values of constants, positions, rotations and scales that will be used later on in the geometry construction.
  - Uses CLHEP expressions
- Constants

  <constant name="length" value="6.25"/>
- Variables

  <variable name="x" value="6"/>
  - Once defined, can be used anywhere later, e.g.

    <variable name="y" value="x/2"/>

    <box name="my_box" x="x" y="y" z="x+y"/>
- Positions

  <position name="P1" x="25.0" y="50.0" z="75.0" unit="cm"/>
- Rotations

  <rotation name="RotateZ" z="30" unit="deg"/>
- Matrices

  <matrix name="m" coldim="3" values=" 0.4 9 126
  8.5 7 21
  34.6 7 9"/>

GDML structure

- Simple Elements

```
<element Z="8" formula="O" name="Oxygen" >
    <atom value="16" />
</element>
```

- Material by number of atoms (“molecule”)

```
<material name="Water" formula="H2O">
    <D value="1.0" />
    <composite n="2" ref="Hydrogen" />
    <composite n="1" ref="Oxygen" />
</material>
```

- Material as a fractional mixture of elements or materials, (“compound”):

```
<material formula="air" name="Air" >
    <D value="0.00129" />
    <fraction n="0.7" ref="Nitrogen" />
    <fraction n="0.3" ref="Oxygen" />
</material>
```

GDML solids

- Box
- Cone Segment
- Ellipsoid
- Elliptical Tube
- Elliptical Cone
- Orb
- Paraboloid
- Parallelepiped
- Polycone
- Polyhedron
- Sphere
- Torus Segment
- Trapezoid (x&y vary along z)
- General Trapezoid
- Tube with Hyperbolic Profile
- Cut Tube
- Tube Segment
- Twisted Box
- Twisted Trapezoid
- Twisted General Trapezoid
- Twisted Tube Segment
- Extruded Solid
- Tessellated Solid
- Tetrahedron

GDML Boolean solid

- The Boolean operations union, subtraction and intersection are also supported, e.g.

```
<box name="box_1" x="1" y="5" z="20" />
<box name="box_2" x="4" y="4.5" z="18" />
<union name="union" >
    <first ref="box_1" />
    <second ref="box_2"/>
    <positionref ref="union_position" />
    <rotationref ref="union_rotation" />
</union>
```

GDML volumes

- Volumes are created from solids and materials that were previously defined in this or a linked GDML file
- Both logical and physical volumes are defined in one

```
<volume name="World">
    <materialref ref="Air"/>
    <solidref ref="WorldBox"/>
    <physvol>
    <volumeref ref="vol0"/>
        <positionref ref="center"/>
        <rotationref ref="identity"/>
    </physvol>
</volume>
```

Importing GDML file

- GDML files can be directly imported into Geant4 geometry, using the GDML plug-in facility:

  #include “G4GDMLParser.hh”

- Generally you will want to put the following lines into your DetectorConstruction class:

  G4GDMLParser parser;

  parser.Read(“geometryFile.gdml”);

  G4VphysicalVolume* W=parser.GetWorldVolume();

- To include the Geant4 module for GDML,
  - Install the XercesC parser (version 2.8.0 or 3.0.0)

    http://xerces.apache.org/xerces-c/download.cgi
  - Set appropriate environment variables when G4 libraries are built
- Examples available in:

  $G4INSTALL/examples/extended/persistency/gdml

Importing CAD geometry

- Users with 3D engineering drawings may want to incorporate these into their Geant4 simulation as directly as possible
- Difficulties include:
  - Proprietary, undocumented or changing CAD formats
  - Usually no connection between geometry and materials
  - Mismatch in level of detail required to machine a part and that required to transport particles in that part
- CAD is never as easy as you might think (if the geometry is complex enough to require CAD in the first place)
- CADMesh is a direct CAD model import interface for GEANT4 optionally leveraging VCGLIB, and ASSIMP by default. Currently it supports the import of triangular facet surface meshes defined in formats such as STL and PLY. A G4TessellatedSolid is returned and can be included in a standard user detector constructor.
  - https://code.google.com/p/cadmesh/
- One output format most CAD programs do support is STEP
  - Not a complete solution, in particular does not contain material information
  - There are movements under way to get new formats that contain additional information, but none yet widely adopted.

Converting STEP to GDML

- Imperfect, but still helpful solutions are tools to convert STEP to GDML and provide the user a way to add materials information
- There are two cases where existing CAD programs have added GDML export features. Since these CAD programs can also read in STEP, they can be used as STEP to GDML converters.
  - Neither option is free, neither option works perfectly
  - ST-Viewer
    - http://www.steptools.com
  - FastRad
    - GDML export extension was funded by European Space Agency
    - Not free except for limited, trial mode that can handle only a small number of volumes
    - http://www.fastrad.net/
- Discussion of these solutions takes place in the Geant4 Persistency forum:

  http://hypernews.slac.stanford.edu/HyperNews/geant4/get/persistency.html
- Useful technical note:
  - Linking computer-aided design (CAD) to Geant4-based Monte Carlo simulations for precise implementation of complex treatment head geometries., Constantin et. al., Phys Med Biol. 2010 Apr 21;55(8):N211-20. Epub 2010 Mar 26

CADMesh

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  - https://code.google.com/p/cadmesh/
  - http://arxiv.org/pdf/1105.0963.pdf

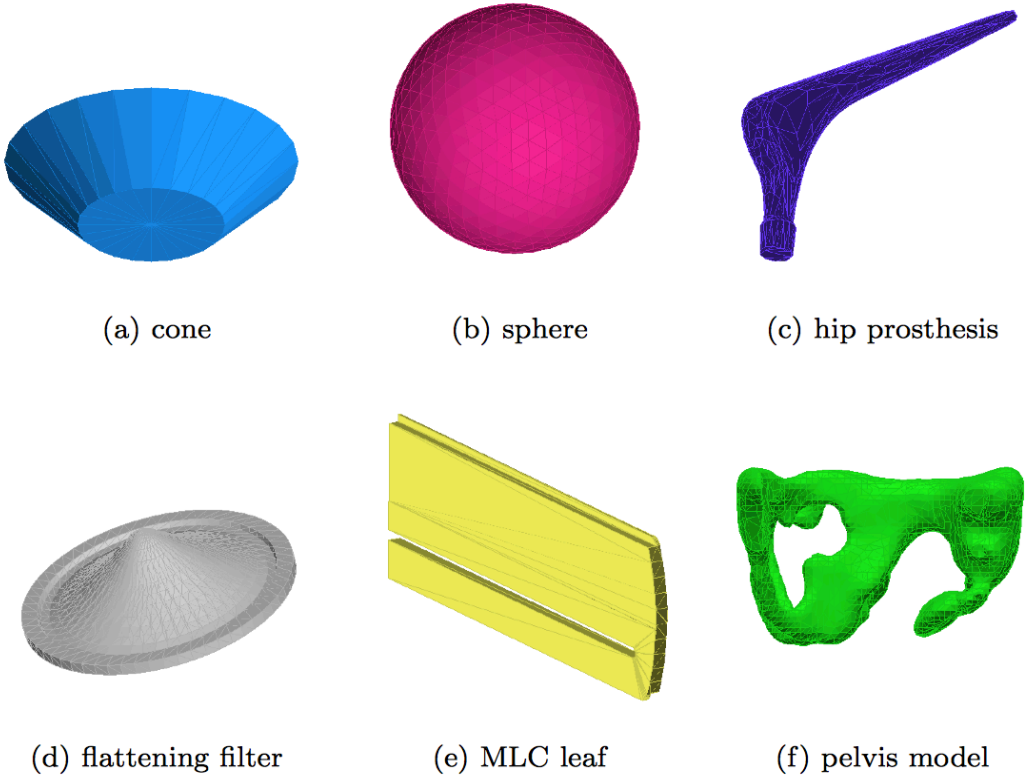
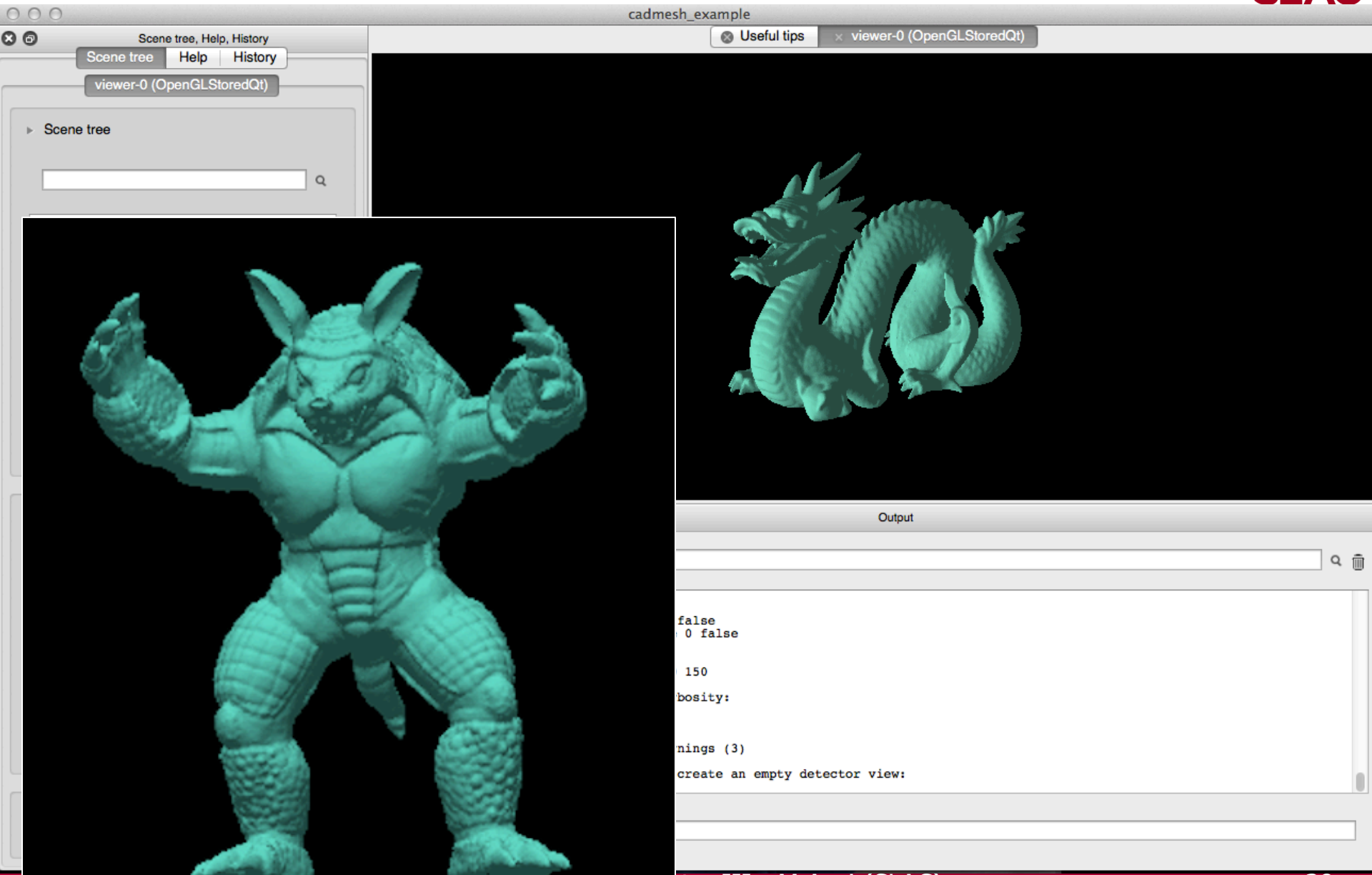


Fig. 3 Six test geometries loaded directly into GEANT4 using the proposed CAD interface and visualised using the GEANT4 OpenGL viewer.

CADMesh


cadmesh_example
Scene tree, Help, History
Scene tree
Help
History
viewer-0 (OpenGLStoredQt)
Scene tree
Useful tips
viewer-0 (OpenGLStoredQt)
Output
false
0 false
150
bosity:
nings (3)
create an empty detector view:

Loading CADMesh solid

- CADMesh provides a G4TessellatedSolid object (a kind of G4VSolid).

```
#include “CADMesh.hh”
G4VPhysicalVolume* MyDetectorConstruction::Construct()
{
  …
  CADMesh cadMesh;
  G4VSolid* aSolid = cadMesh.LoadMesh( file_name, file_type );
  G4LogicalVolume* aLV = new G4LoficalVolume( aSolid, material, “name” );
  G4VPhysicalVolume* aPV = new G4PVPlacement( 0,
     G4ThreeVector(x,y,z), aLV, “name”, motheLV, 0, 0 );
  …
```

Attila

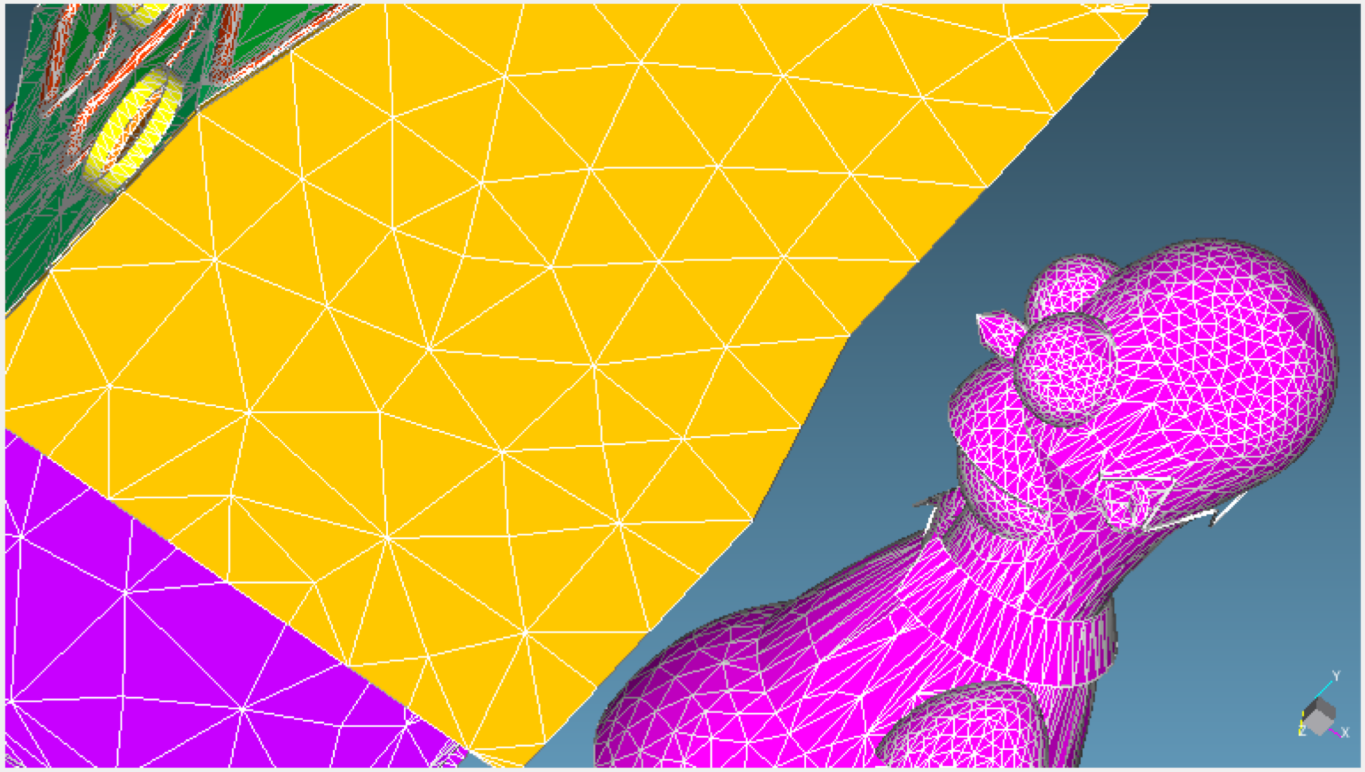
Input Editor: GloveBox* [Project: GloveBox]

Panels

- General
- Mesh Geometry
- Cross Section Library
- Energy Group Attributes
- Material Editor
- Region Attributes
- MCNP Controls
- Fixed Source
- Boundary Values
- Solver Controls
- DMP Controls
- Output Controls
- Activation Controls
- Custom Reports
- MCNP Importances
- MCNP Weight Windows

View As: (•) Regions ( ) Materials

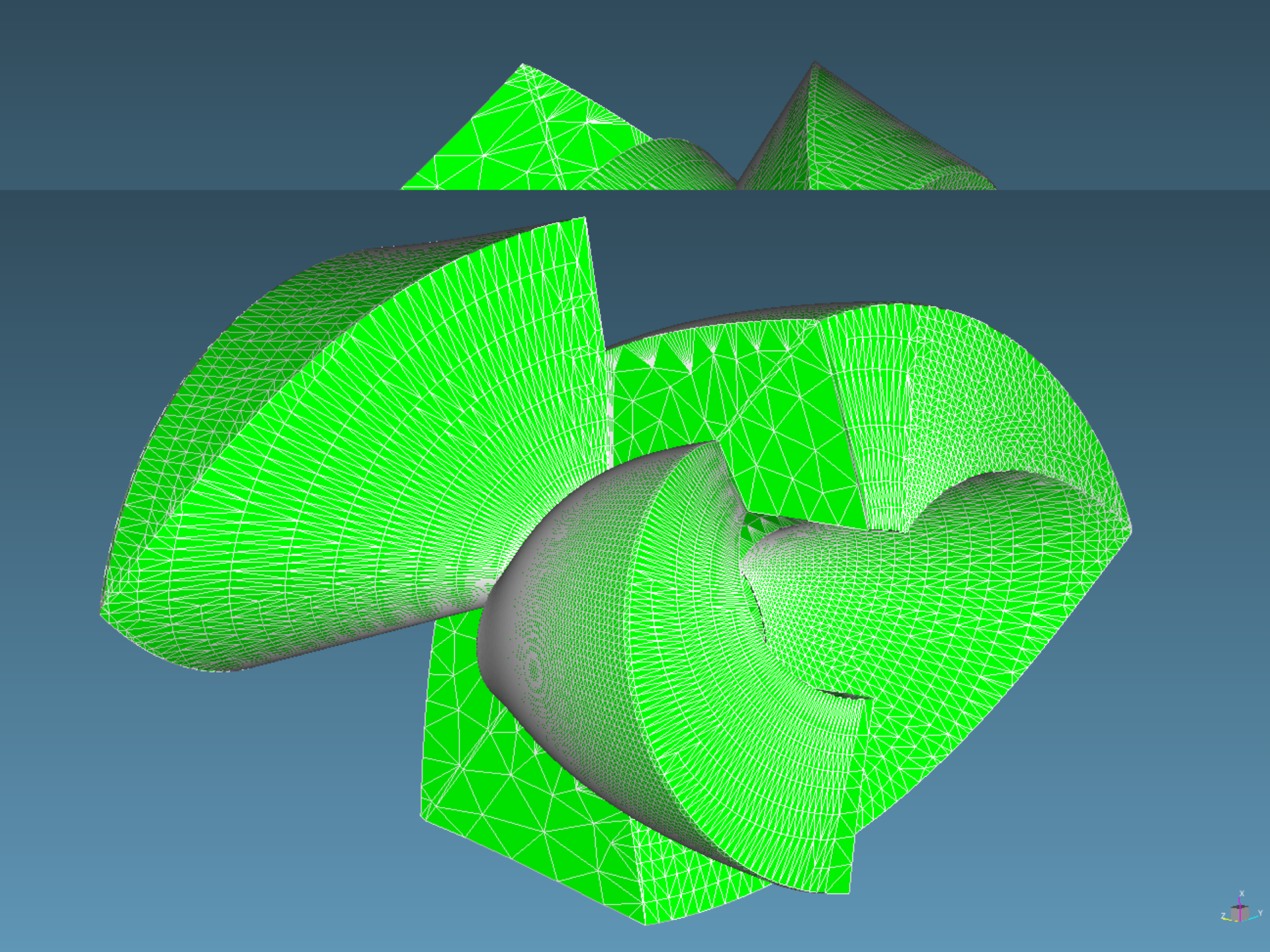
Cell Flag	User Region	Material	Density Scale	Scattering Degree
6 : Gloves_Lead	Gloves_Lead	Lead	1	default (0)
7 : Cladding	Cladding	Stainless Steel	1	default (0)
8 : LeadShielding	LeadShielding	Lead	1	default (0)
9 : Box_LeftSide	Box_LeftSide	Stainless Steel	1	default (0)
10 : Box_RightSide	Box_RightSide	Stainless Steel	1	default (0)
11 : Box_Bottom	Box_Bottom	Stainless Steel	1	default (0)
12 : Box_Top	Box_Top	Stainless Steel	1	default (0)
13 : Source	Source	Stainless Steel	1	default (0)
14 : Operator	Operator	Water	1	default (0)

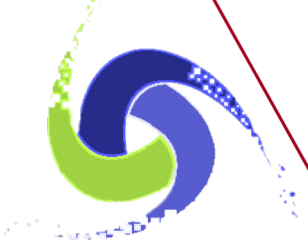


Run Attila!

Run MCNP!

Help





GEANT4

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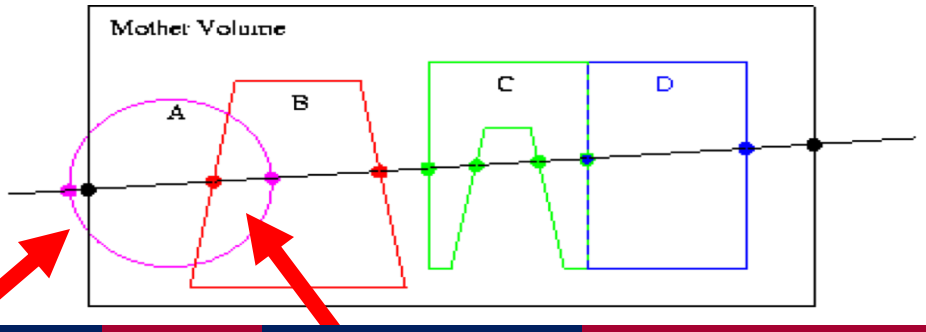
Geometry checking tools

Debugging geometries

- An protruding volume is a contained daughter volume which actually protrudes from its mother volume.
- Volumes are also often positioned in a same volume with the intent of not provoking intersections between themselves. When volumes in a common mother actually intersect themselves are defined as overlapping.
- Geant4 does not allow for malformed geometries, neither protruding nor overlapping.
  - The behavior of navigation is unpredictable for such cases.
- The problem of detecting overlaps between volumes is bounded by the complexity of the solid models description.
- Utilities are provided for detecting wrong positioning
  - Optional checks at construction
  - Kernel run-time commands
  - Graphical tools (DAVID, OLAP)



Optional checks at construction

- Constructors of G4PVPlacement and G4PVParameterised have an optional argument “pSurfChk”.

```
G4PVPlacement(G4RotationMatrix* pRot,
   const G4ThreeVector &tlate,
   G4LogicalVolume *pDaughterLogical,
   const G4String &pName,
   G4LogicalVolume *pMotherLogical,
   G4bool pMany, G4int pCopyNo,
   G4bool pSurfChk=false);
```

- If this flag is true, overlap check is done at the construction.
  - Some number of points are randomly sampled on the surface of creating volume.
  - Each of these points are examined
    - If it is outside of the mother volume, or
    - If it is inside of already existing other volumes in the same mother volume.
- This check requires lots of CPU time, but it is worth to try at least once when you implement your geometry of some complexity.

Debugging run-time commands

- Built-in run-time commands to activate verification tests for the user geometry are defined
  - to start verification of geometry for overlapping regions based on a standard grid setup, limited to the first depth level

    `geometry/test/run` or **`geometry/test/grid_test`**
  - applies the grid test to all depth levels (may require lots of CPU time!)

    `geometry/test/recursive_test`
  - shoots lines according to a cylindrical pattern

    `geometry/test/cylinder_test`
  - to shoot a line along a specified direction and position

    `geometry/test/line_test`
  - to specify position for the **`line_test`**

    `geometry/test/position`
  - to specify direction for the **`line_test`**

    `geometry/test/direction`

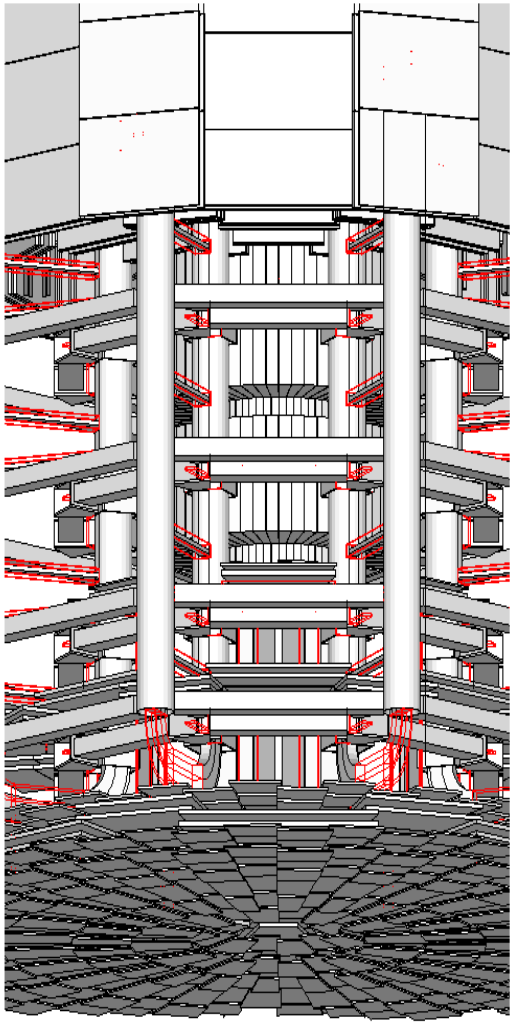
Debugging run-time commands

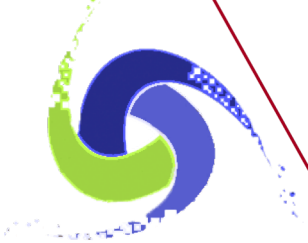
- Example layout:

```
GeomTest: no daughter volume extending outside mother detected.
GeomTest Error: Overlapping daughter volumes
    The volumes Tracker[0] and Overlap[0],
    both daughters of volume World[0],
    appear to overlap at the following points in global coordinates: (list
   truncated)
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    240           -240      -145.5      -145.5     0       -145.5      -145.5
Which in the mother coordinate system are:
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    . . .
Which in the coordinate system of Tracker[0] are:
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    . . .
Which in the coordinate system of Overlap[0] are:
  length (cm)    ----- start position (cm) -----  ----- end position (cm) -----
    . . .
```

Debugging tools: DAVID

- DAVID is a graphical debugging tool for detecting potential intersections of volumes
- Accuracy of the graphical representation can be tuned to the exact geometrical description.
  - physical-volume surfaces are automatically decomposed into 3D polygons
  - intersections of the generated polygons are parsed.
  - If a polygon intersects with another one, the physical volumes associated to these polygons are highlighted in color (red is the default).
- DAVID can be downloaded from the Web as external tool for Geant4
  - http://geant4.kek.jp/~tanaka/





GEANT4

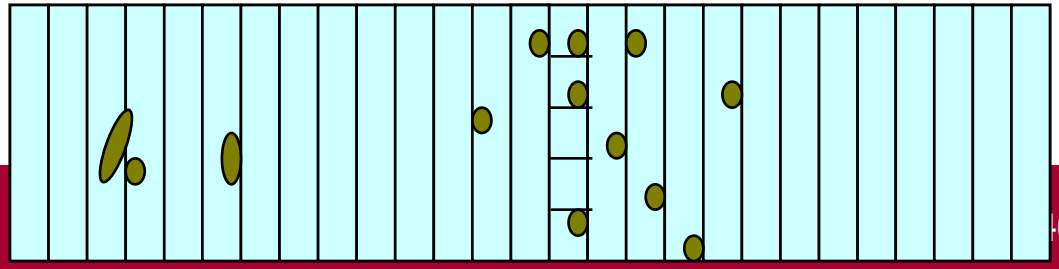
A SIMULATION TOOLKIT

Version 10.5

Geometry optimization ("voxelization")

Smart voxelization

- In case of Geant 3.21, the user had to carefully implement his/her geometry to maximize the performance of geometrical navigation.
- While in Geant4, user's geometry is automatically optimized to be most suitable to the navigation. - "Voxelization"
  - For each mother volume, one-dimensional virtual division is performed.
  - Subdivisions (slices) containing same volumes are gathered into one.
  - Additional division again using second and/or third Cartesian axes, if needed.
- *"Smart voxels"* are computed at initialisation time
  - When the detector geometry is *closed*
  - Does not require large memory or computing resources
  - At tracking time, searching is done in a hierarchy of virtual divisions



Detector description tuning

- Some geometry topologies may require 'special' tuning for ideal and efficient optimisation
  - for example: a dense nucleus of volumes included in very large mother volume
- Granularity of voxelisation can be explicitly set
  - Methods **`Set/GetSmartless()`** from **`G4LogicalVolume`**
- Critical regions for optimisation can be detected
  - Helper class **`G4SmartVoxelStat`** for monitoring time spent in detector geometry optimisation
    - Automatically activated if **`/run/verbose`** greater than `1`

```
Percent      Memory      Heads     Nodes    Pointers     Total CPU    Volume
-------      ------      -----     -----    --------     ---------    -----------
  91.70          1k          1        50          50          0.00    Calorimeter
   8.30          0k          1         3           4          0.00    Layer
```

Visualising voxel structure

- The computed voxel structure can be visualized with the final detector geometry
  - Helper class **`G4DrawVoxels`**
  - Visualize voxels given a logical volume

```
G4DrawVoxels::DrawVoxels(const G4LogicalVolume*)
```

  - Allows setting of visualization attributes for voxels

```
G4DrawVoxels::SetVoxelsVisAttributes(…)
```

  - useful for debugging purposes