Geometry:
Magnetic Field

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Outline

- Defining magnetic field
- Integration of trajectories in field
  - Tunable parameters of propagation in magnetic field
- Other types of field

Describe Your Detector

- To describe your detector you have to derive your own concrete class from G4VUserDetectorConstruction abstract base class.
- Implement the virtual method Construct(), where you
  - Instantiate all necessary materials
  - Instantiate volumes of your detector geometry
- Optionally, implement the virtual method ConstructSDandField(), where you
  - Instantiate your sensitive detector classes and set them to the corresponding logical volumes
  - Instantiate magnetic (or other) field
- Optionally you can define
  - Regions for any part of your detector
  - Visualization attributes (color, visibility, etc.) of your detector elements

How to define a Magnetic field

- To create a (magnetic) field you must instantiate a G4MagneticField object in the ConstructSDandField() method of your DetectorConstruction class
- To define a **uniform magnetic field** use an object of G4UniformMagField:

```
auto magField
   = new G4UniformMagField(G4ThreeVector(0, 0, 1.*tesla));
```

- Non-uniform field : deriving your ‘concrete’ class:
  - Define your own concrete class MyField derived from G4MagneticField and implement GetFieldValue method:

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

  - where point[0..2] represents the position in the global coordinate system and point[3] time
  - field[0..2] return the field value in the given position

How to assign a field to the whole detector

- The magnetic field is applied to geometry with means of G4FieldManager
- A **global field manager** is associated with the 'world' volume
  - It is created by G4TransportationManager already before user detector construction is called
- To associate your field with the world, you must obtain that global field manager:

```
G4FieldManager* globalFieldManager
      = G4TransportationManager::GetTransportationManager()
        ->GetFieldManager();
```

- And then set it in that field manager:

```
globalFieldManager->SetDetectorField(magField);
```

Global and local fields

- Other volumes can override this global field
- An alternative field manager can be associated with any logical volume, it handles then the **local field**
  - By default this is propagated to all its daughter volumes
  - The field must accept **position in global coordinates** and return **field in global coordinates**

```
G4FieldManager* fieldManager = new G4FieldManager(magField);
logVolume->SetFieldManager(fieldManager, true);
```

    – Where `'true'` means to propagate field to all the volumes it contains

Global Magnetic Field

```
void MyDetectorConstruction::CreateSDandField()
{
   // Magnetic field
   MyMagneticField* myField = new MyMagneticField();

   // Field manager
   G4FieldManager* fieldManager
      = G4TransportationManager::GetTransportationManager()
        ->GetFieldManager();
   fieldManager->SetDetectorField(myField);
   fieldManager->CreateChordFinder(myField);

}
```

Local Magnetic Field

```
void MyDetectorConstruction::CreateSDandField()
{
   // Magnetic field
   MyMagneticField* myField = new MyMagneticField();

   // Field manager
   G4Fieldmanager* fieldManager = new G4FieldManager();
   fieldManager->SetDetectorField(myField);
   fieldManager->CreateChordFinder(myField);

   // Set field to a logical volume
   G4bool forceToAllDaughters = true;
   magneticLogical
     ->SetFieldManager(fieldManager, forceToAllDaughters);
}
```

See also basic example B5

Global Field Messenger

- A helper class, G4GlobalMagFieldMessenger, is available since Geant4 10.00
  - It creates **the global uniform magnetic field**
  - **The field** is **activated** (set to the G4TransportationManager object) only when its fieldValue is non zero vector.
  - It can be also used to change the field value (and activate or inactivate the field again

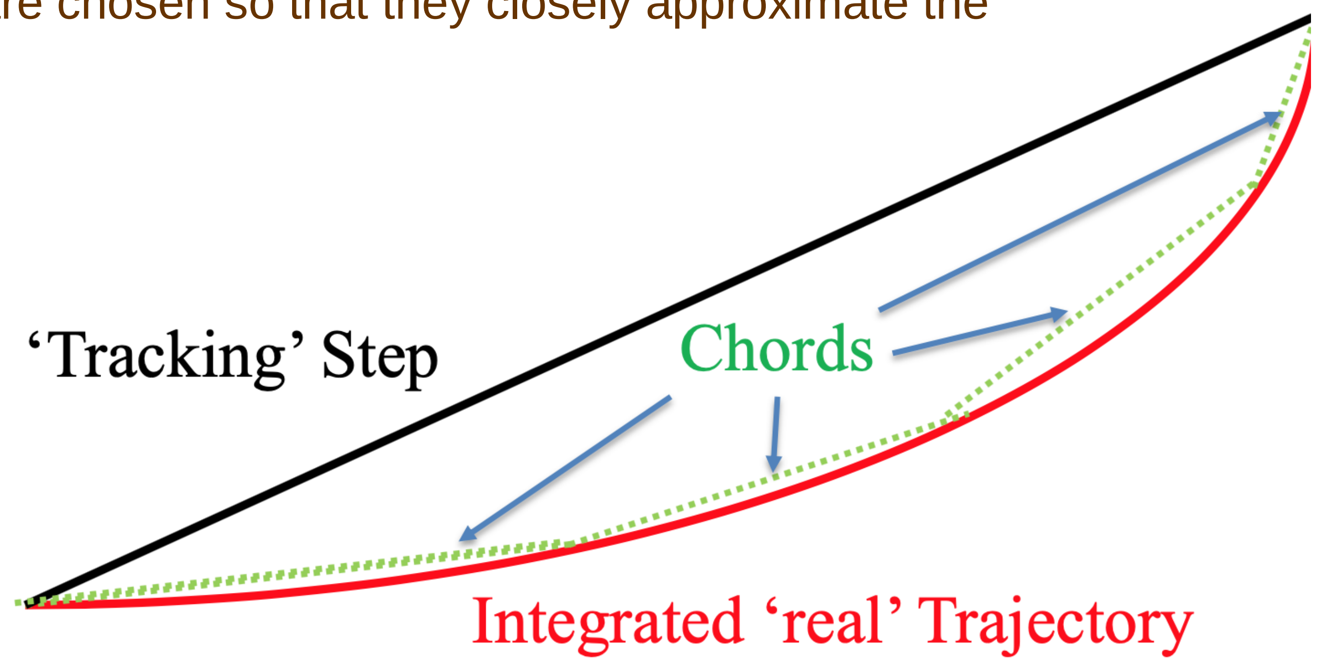
```
void MyDetectorConstruction::CreateSDandField
{
   // Global magnetic field & its messenger
   G4ThreeVector fieldValue = G4ThreeVector();
   G4GlobalMagFieldMessenger* magFieldMessenger
      = new G4GlobalMagFieldMessenger(fieldValue);

   // Register the messenger for deleting
   G4AutoDelete::Register(myFieldMessenger);
}
```

See basic examples B2 and B4

Propagation in Field
Tunable Parameters

Propagation in Field

- 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
- By default Geant4 uses a **Runge-Kutta method** to integrate the ordinary differential equations of motion
- Using the method to calculate the track's motion in a field, Geant4 breaks up this curved path into linear chord segments:
  - Chord segments are chosen so that they closely approximate the curved path

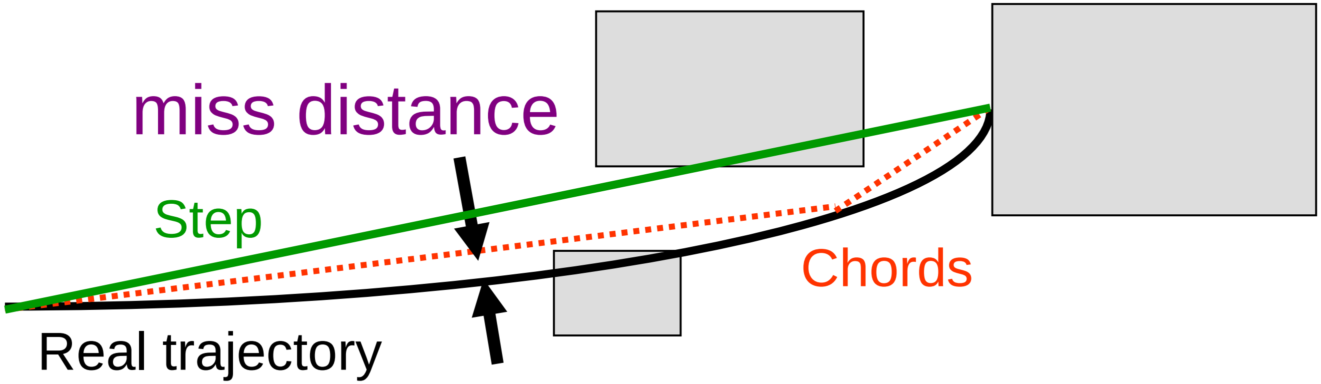


Methods of Integration

- Several other Runge-Kutta ‘steppers’ and other integration methods are available.
  - The established 4th/5th order RK **‘Dormand Prince’** is default
- In specific cases other solvers can also be used:
  - In a uniform field, using a ‘**helix’** – the analytical solution.
  - In a slowly varying, smooth field, methods that **combine helix & RK**
  - High efficiency RK solvers provided in recent releases (‘**FSAL**’, RK steppers with Interpolation)

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"
    - The curved trajectory will be approximated by chords, so that the maximum estimated distance between curve and chord (sagitta) is less than 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".



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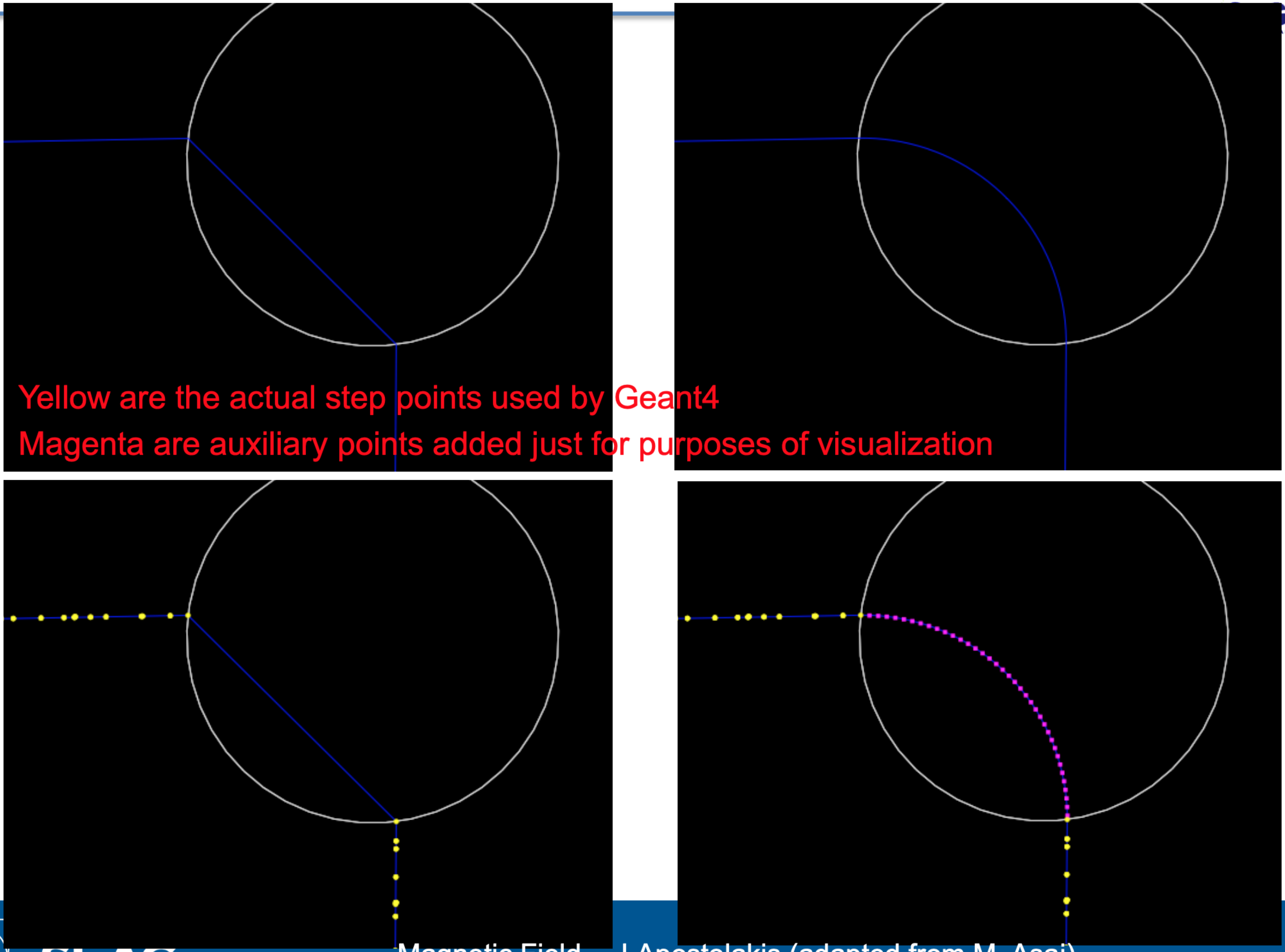
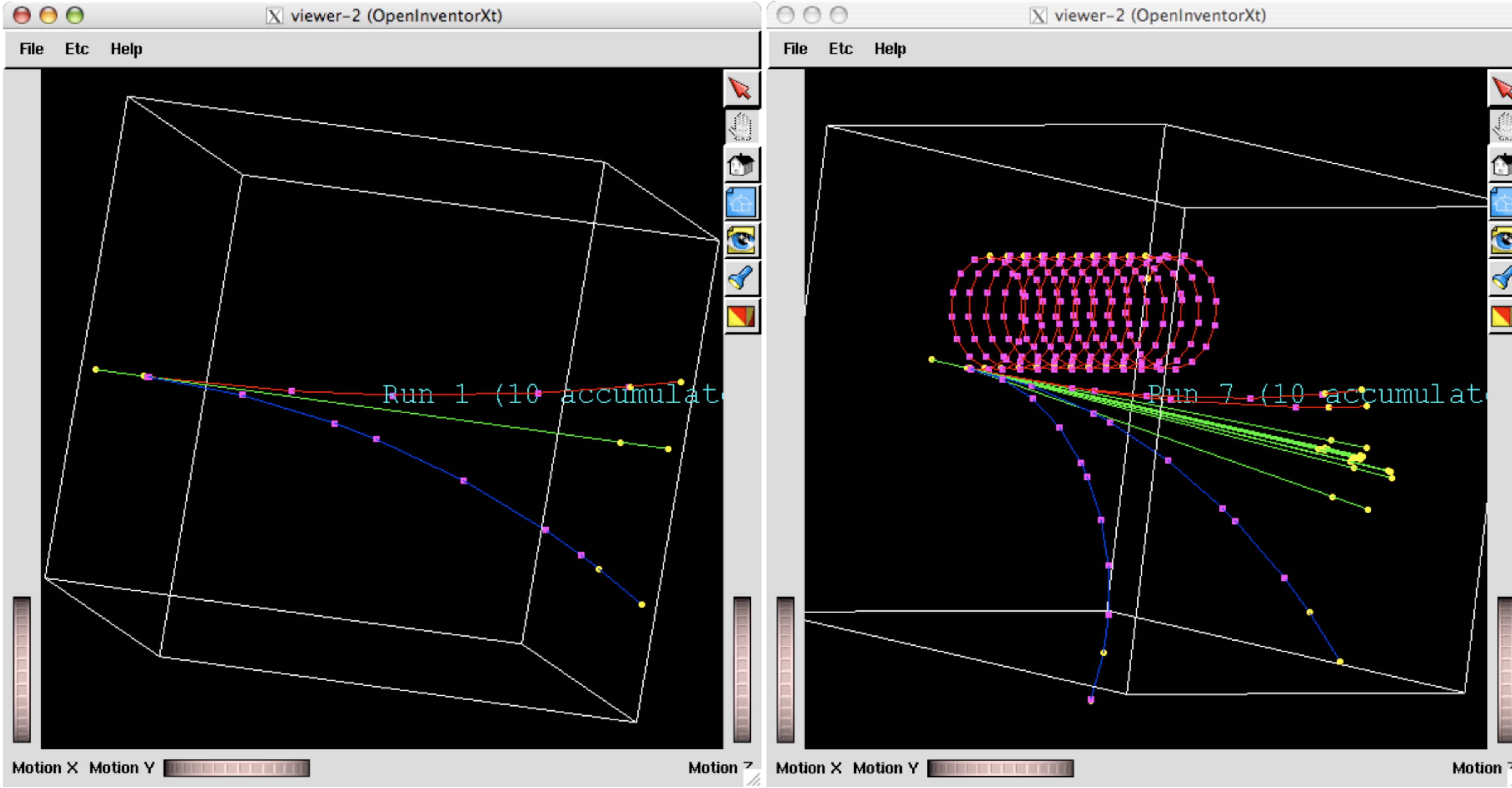
Regular versus Smooth Trajectory



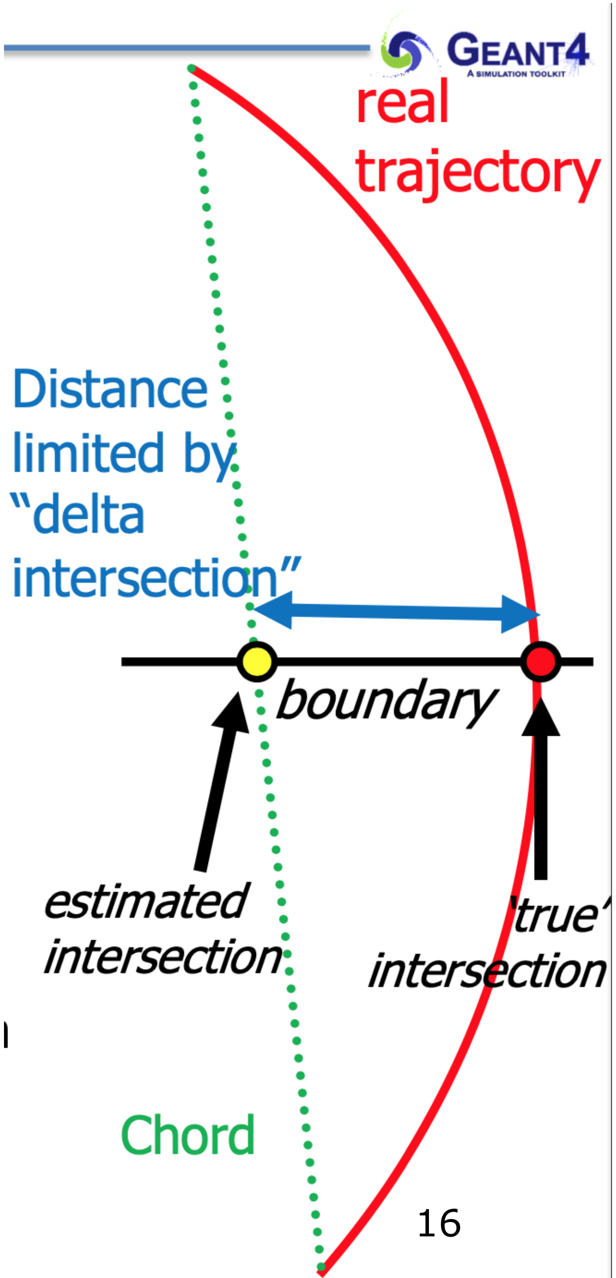
Smooth Trajectory Makes Big Difference for Trajectories that Loop in a Magnetic Field



- 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 ("delta intersection")
  - and the accuracy of the integration of other steps ("delta one step")
- The "delta intersection" parameter is the accuracy to which an intersection with a volume boundary is calculated.
  - If a candidate boundary intersection is estimated to have a precision better than this, it is accepted.
  - This parameter is especially important because it is used to limit a bias that our algorithm (for boundary crossing in a field) exhibits.
    - 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 - 2

- 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 limits the estimated relative 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
- For more look in the Electromagnetic Field section of the Application Developers Guide

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Other types of field

- The user can create their own type of field
  - inheriting from G4VField,
  - using an associated **Equation of Motion** class (inheriting from G4EqRhs) to simulate other types of fields.
  - fields be time-dependent.
- For a few cases Geant4 has an existing class:
  - pure electric field, Geant4 has G4ElectricField (and G4UniformElectricField)
  - combined electromagnetic field, the G4ElectroMagneticField class
- A different Equation of Motion class is used for electromagnetic

- For the full exercise of the options for fields you can browse `examples/extended/field/`
  - E.g.field01 uses alternative integration methods (see file src/F01FieldSetup.cc)
  - field02 demonstrates electric field