g2MIGTRACE Tutorial: Storing Output

Kevin Lynch

June 2011

York College
The City University of New York

Outline

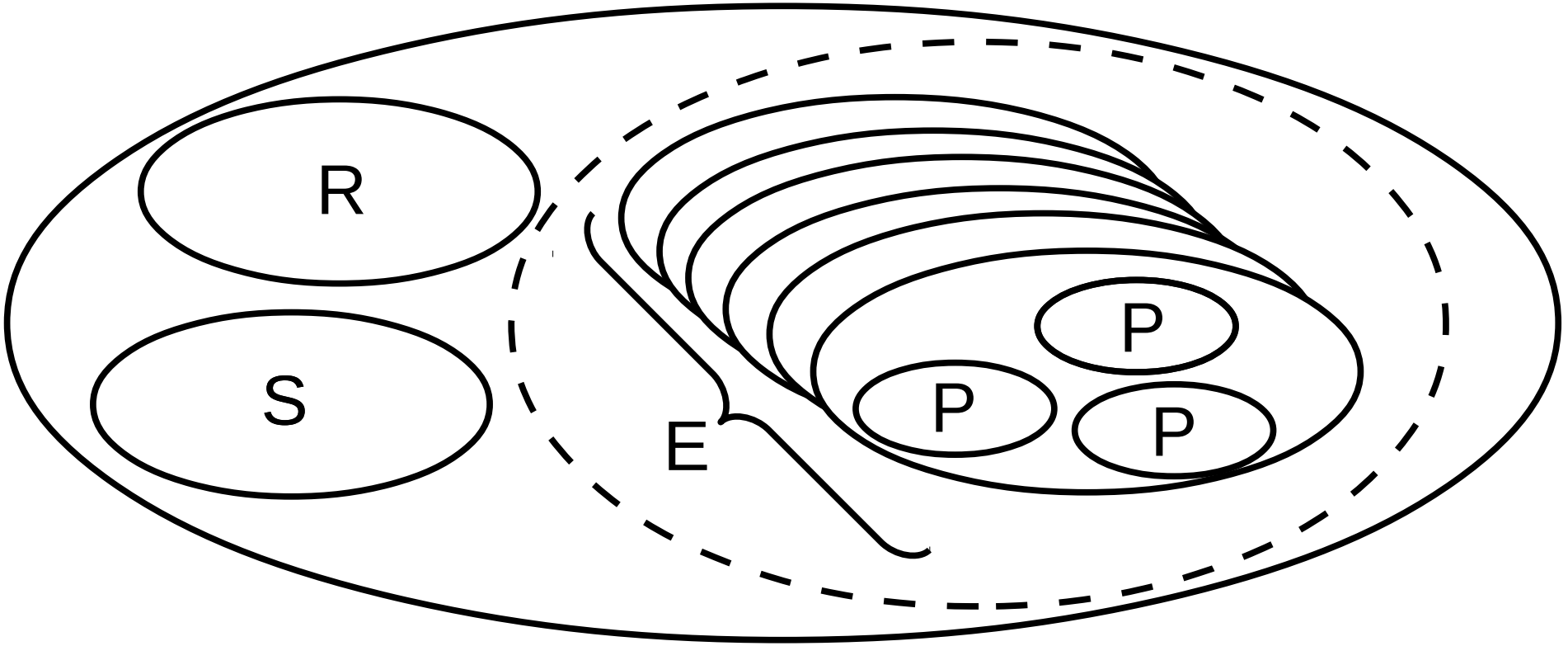
- What already gets output
- Users:
    - Getting g2MIGTRACE to output something
    - Doing something useful with it all
- Developers:
    - How it all works
    - How to add output

So, what does get output?

- Short answer:
  - Nothing!
- Longer answer:
  - If you exert de minimis effort, there are a few things you can get...

Longest answer

- Simulation Metadata
- Run Level Data
    - Collected Event Level Data
        - Particle Level Data



Simulation Metadata

- SVN Revision
- *Git revision*
- *Build time*
- *External library revisions*

Run Level Data

- Physical Object Manager
- *Configuration Parameters*

Event Level Data

- Particle ID Data
- Final Event Status Data
- Inflector Tracking Data
- Ring Tracking Data
    - Spin Tracking Data
- Energy Loss Data
- Calorimeter Hit Data
- *Hodoscope Hit Data*
- *Wire Chamber Hit Data*

What does this look like

```
[krlynch@i-m-so-tired Linux-g++]$ ls
g2MacroFiles/  g2MIGTRACE_20100710015359_run0000.root  g2StudyMacros/
g2MIGTRACE*    g2RunTimeFiles/
[krlynch@i-m-so-tired Linux-g++]$
```

Inside the Root file

```
root [3] .ls
TFile**         ./g2MIGTRACE_20100710015359_run0000.root        g2MIGTRACE output file
 TFile*         ./g2MIGTRACE_20100710015359_run0000.root        g2MIGTRACE output file
  KEY: TParameter<int>  svn_revision;1  Named templated parameter type
  KEY: g2UniqueObjectManager    uom;1
  KEY: TTree    trackerTree;1   Ring Beam Tracking Data
  KEY: TTree    trackTree;1     Track ID Birth Data
  KEY: TTree    eventStatusTree;1       Event final status data
root [4]
```

Users

- Getting g2MIGTRACE output
- Doing something useful with it
    - Aigh! There's the rub....

Getting some output

```
g2MIGTRACE >> ls /g2MIGTRACE/rootStorage/
Command directory path : /g2MIGTRACE/rootStorage/


Guidance :
Root File Storage Management

 Sub-directories :
   /g2MIGTRACE/rootStorage/g2UOM/   Unique Object Manager Query Commands
   /g2MIGTRACE/rootStorage/ringHits/   Ring hit monitor controls
 Commands :
   storageStatus * Determine whether a Root file is created to store simulation results
   basename * Get/set the base filename: <basename>_<datetime>_run<#>.root; omit arg for "get"
   outdir * Get/set the output directory; omit arg for "get"
   inflectorTrackerStatus * Get/set the inflector tracker enable state; omit arg for "get"
   ringTrackerStatus * Get/set the ring tracker enable state; omit arg for "get"
   ringHitStatus * Get/set the ring hit monitor enable state; omit arg for "get"
   caloHitStatus * Get/set the calorimter hit monitor enable state; omit arg for "get"
g2MIGTRACE >>
```

Let's enable Root output

1
```
g2MIGTRACE >> /g2MIGTRACE/rootStorage/storageStatus
/g2MIGTRACE/rootStorage/storageStatus
A Root file will not be output
```
2
```
g2MIGTRACE >> help /g2MIGTRACE/rootStorage/storageStatus


Command /g2MIGTRACE/rootStorage/storageStatus
Guidance :
Determine whether a Root file is created to store simulation results

Parameter : Choice
 Parameter type  : s
 Omittable       : True
 Candidates      : on off get
```
3
```
g2MIGTRACE >> /g2MIGTRACE/rootStorage/storageStatus on
/g2MIGTRACE/rootStorage/storageStatus on
```
4
```
g2MIGTRACE >> /g2MIGTRACE/rootStorage/storageStatus
/g2MIGTRACE/rootStorage/storageStatus
A Root file will be output
g2MIGTRACE >>
```

What do you actually get now?

- A Root File
  - with a long name!
- g2MIGTRACE metadata
  - svn_revision
- The object manager
  - G2UniqueObjectManager ... on which more later
- Particle Data Holder
  - TrackTree
- Event Status Data Holder
  - EventStatusTree
- More on all of these later...

If you want more, you must

- Enable it!
- Write it ... then enable it!

What can you enable?

- Beam Tracking output
    - Ring tracking
    - Inflector tracking
- “Energy Loss” output
    - Generic energy loss
        - Ring hits
    - Specialized energy loss
        - Calorimeter hits
        - *Wire chambers*
        - *Hodoscope tiles*

Ring trackers

```
g2MIGTRACE >> ls /g2MIGTRACE/rootStorage/
Command directory path : /g2MIGTRACE/rootStorage/


Guidance :
Root File Storage Management

 Sub-directories :
   /g2MIGTRACE/rootStorage/g2UOM/   Unique Object Manager Query Commands
   /g2MIGTRACE/rootStorage/ringHits/   Ring hit monitor controls
 Commands :
   storageStatus * Determine whether a Root file is created to store simulation results
   basename * Get/set the base filename: <basename>_<datetime>_run<#>.root; omit arg for "get"
   outdir * Get/set the output directory; omit arg for "get"
   inflectorTrackerStatus * Get/set the inflector tracker enable state; omit arg for "get"
   ringTrackerStatus * Get/set the ring tracker enable state; omit arg for "get"
   ringHitStatus * Get/set the ring hit monitor enable state; omit arg for "get"
   caloHitStatus * Get/set the calorimter hit monitor enable state; omit arg for "get"
g2MIGTRACE >>
```

Ring trackers

```
g2MIGTRACE >> /g2MIGTRACE/rootStorage/ringTrackerStatus
/g2MIGTRACE/rootStorage/ringTrackerStatus
The ring beam trackers are not enabled
g2MIGTRACE >> /g2MIGTRACE/rootStorage/ringTrackerStatus on
/g2MIGTRACE/rootStorage/ringTrackerStatus on
g2MIGTRACE >> /g2MIGTRACE/rootStorage/ringTrackerStatus
/g2MIGTRACE/rootStorage/ringTrackerStatus
The ring beam trackers are enabled
g2MIGTRACE >>
```

Ring Trackers

- `TTree` trackerTree
    - `std::vector<trackerRecord>`
- What's a `trackerRecord`?

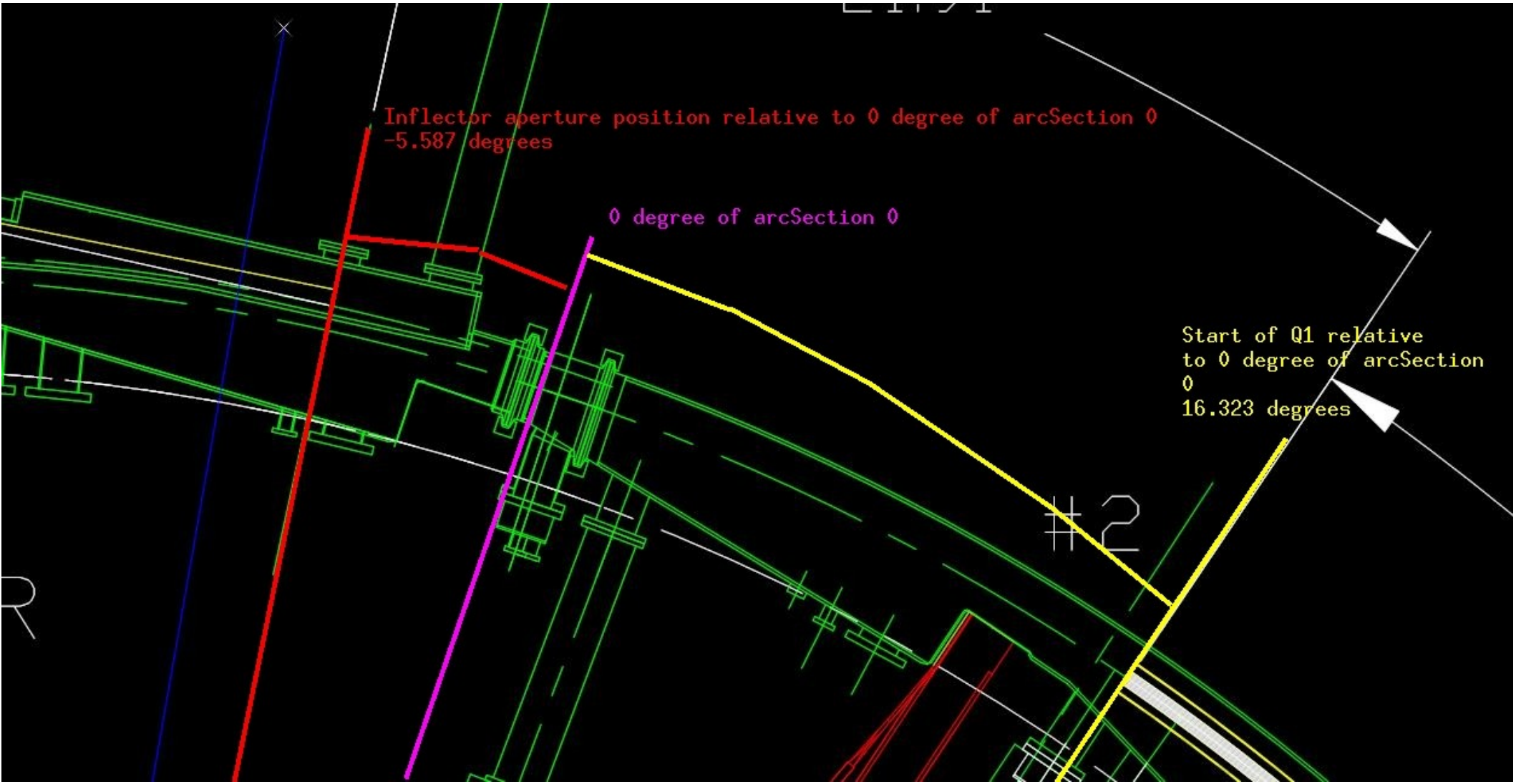
trackerRecord

```
/** Provides a Root storable class to record in-ring beam tracking
    data.  Uses the data recorded by the trackerSD class. */
struct trackerRecord {

  /** Horizontal offset from the central orbit, mm. */
  Float_t rhat;
  /** Vertical offset from the central orbit, mm. */
  Float_t vhat;
  /** Global angular offset downstream of the ar0/arc11 boundary (NOT
      the inflection point!). */
  Float_t theta;
  /** Global event time, ns. */
  Float_t time;

  /** Total momentum, MeV. */
  Float_t p;
  /** Fraction of momentum along the rhat direction. */
  Float_t prhat;
  /** Fraction of momentum along the vhat direction. */
  Float_t pvhat;

  /** Current orbit number since injection. */
  Int_t turn;
  /** Unique volume ID of the current tracking volume; use with the
      g2UniqueObjectManager for volume identification. */
  Int_t volumeUID;
  /** Current track ID; used with the stored trackRecord for particle
      identification. */
  Int_t trackID;
};
```

The coordinate system

- In `trackerRecord`, we have a hybrid cylindrical/toroidal system
  - *r* and *z* should be obvious
- The angle ... well, not so much
  - The angle is defined as “downstream” from a convenient reference point
  - Almost all objects are located within vacuum chamber sections by relative measurements
  - Hence, the global angle is defined on the arc0/arc11 boundary ... slightly downstream of the nominal inflector aperture

To whit...


Inflector aperture position relative to 0 degree of arcSection 0
-5.587 degrees
0 degree of arcSection 0
Start of Q1 relative
to 0 degree of arcSection
0
16.323 degrees
#2

There's a pattern here...

- A `somethingRecord` is the unit of storage of a single particle `Step` in the `Event`
- `somethingRecords` are generally stored in a `std::vector<somethingRecord>`
- That vector is a leaf in the `somethingTree`
- `Entries` in parallel `somethingTrees` are all from the same simulation `Event`

trackerRecord

```
/** Provides a Root storable class to record in-ring beam tracking
    data.  Uses the data recorded by the trackerSD class. */
struct trackerRecord {

  /** Horizontal offset from the central orbit, mm. */
  Float_t rhat;
  /** Vertical offset from the central orbit, mm. */
  Float_t vhat;
  /** Global angular offset downstream of the ar0/arc11 boundary (NOT
      the inflection point!). */
  Float_t theta;
  /** Global event time, ns. */
  Float_t time;

  /** Total momentum, MeV. */
  Float_t p;
  /** Fraction of momentum along the rhat direction. */
  Float_t prhat;
  /** Fraction of momentum along the vhat direction. */
  Float_t pvhat;

  /** Current orbit number since injection. */
  Int_t turn;
  /** Unique volume ID of the current tracking volume; use with the
      g2UniqueObjectManager for volume identification. */
  Int_t volumeUID;
  /** Current track ID; used with the stored trackRecord for particle
      identification. */
  Int_t trackID;
};
```

Volume identifiers

- Between runs, volumes can be moved/added/removed!
- At `BeginOfRun` (such as `/run/beamOn`), the geometry is *frozen* and *voxelized* ... from then on, it can't change until EndOfRun
- Root files are stored per run, hence, a reference database of all volumes is built and stored *without work on your part*!
    - But!!! Physical Volume Names must be *unique* for this scheme to work!
- The DB is called `g2UniqueObjectManager` and provides a useful set of services

g2UniqueObjectManager

```
class g2UniqueObjectManager : public TObject {
public:

  /** Registers a volume with the UID store, mapping the physical
      volume pointer, \a ptr, to a unique integer ID, and associating
      that with the volume identity, it's \a name. */
  bool add(void* ptr, std::string name);

  /** Clears the UID store. */
  void clear();

  /** Looks up a volume name given its UID, \a uid. */
  std::string lookup(ULong64_t uid) const;

  /** Determines whether a given volume, \a uid, has a name that
      matches a given pattern, \a p. */
  bool re_match(ULong64_t uid, std::string p) const;

  /** Returns a list of all the volumes in the store whose names match
      the pattern \a p */
  std::vector<std::string> re_match_names(std::string p) const;

  /** Returns a list of the UIDs for volumes in teh store whose names
      match the patter \a p */
  std::vector<ULong64_t> re_match_uids(std::string) const;

  /** Counts the number of entries in the UID store. */
  int count() const;
};
```

g2UniqueObjectManager

```
User default configuration .g2MIGTRACE/default_user_config.migtrace not present.
         SVN Build Version 232



                      uuuuuuu
                   uuu       uuu
                 uu             uu
                u    UU     UU    u
               u   + UU     UU     u
               u   - UU     UU     u
               u     UU     UU     u
               u     UUU   UUU     u
               u     UU UUU UUU   u
               u    UU          uuu
                u  UU
                 uu                          u
                   uuu                    u  uu
                      uuuuuuuuuuuuuuuuuuuuuuuuuuuuu
                                          u  uu
                                             u

         ******* WELCOME TO THE g2MIGTRACE SIMULATION *******

g2MIGTRACE >> /run/beamOn 1
/run/beamOn 1
Entries in UOM: 228

  Muons injected : 1
  Muons stored : 0
  Capture Efficiency : (0 +/- 0)%

Elapsed time this run: 0.123990051sec
Unique Objects in Manager: 228
g2MIGTRACE >>
```

trackerRecord

```
/** Provides a Root storable class to record in-ring beam tracking
    data.  Uses the data recorded by the trackerSD class. */
struct trackerRecord {

  /** Horizontal offset from the central orbit, mm. */
  Float_t rhat;
  /** Vertical offset from the central orbit, mm. */
  Float_t vhat;
  /** Global angular offset downstream of the ar0/arc11 boundary (NOT
      the inflection point!). */
  Float_t theta;
  /** Global event time, ns. */
  Float_t time;

  /** Total momentum, MeV. */
  Float_t p;
  /** Fraction of momentum along the rhat direction. */
  Float_t prhat;
  /** Fraction of momentum along the vhat direction. */
  Float_t pvhat;

  /** Current orbit number since injection. */
  Int_t turn;
  /** Unique volume ID of the current tracking volume; use with the
      g2UniqueObjectManager for volume identification. */
  Int_t volumeUID;
  /** Current track ID; used with the stored trackRecord for particle
      identification. */
  Int_t trackID;
};
```

Track Identifiers

- In every Event, every the birth of every particle is recorded
- `trackRecord` -> `std::vector<trackRecord>` -> `trackTree`

trackRecord

```
struct trackRecord {

  /** Usually the particle name. */
  std::string trackType;
  /** The Geant track ID of the current particle, which is stored in
      some other Record types. */
  Int_t trackID;
  /** The Geant track ID of this particle's parent.  This equals
      itself for the primary. */
  Int_t parentTrackID;
  /** The current orbit number at particle birth. */
  Int_t turn;
  /** The current physical volume UID the track was born in. */
  Int_t volumeUID;
  /** The radial offset from the nominal storage orbit at the
      particle's birth. */
  Float_t rhat;
  /** The vertical offset from the nominal storage orbit at the
      particle's birth. */
  Float_t vhat;
  /** The azimuthal angle downstream from the global zero at the
      particle's birth. This is a few degrees downstream of the
      inflection point; see the documentation directory. */
  Float_t theta;
  /** The global time at the particle's birth. */
  Float_t time;
  /** The total momentum given the particle at birth. */
  Float_t p;
  /** The fraction of the particle's momentum which is oriented
      radially at birth. */
  Float_t prhat;
  /** The fraction of the particles's momentum which is oriented
      vertically at birth. */
  Float_t pvhat;
};
```

Doing something useful

- Enable what you want
- Run
- Write some analysis code

Writing some analysis code

- Currently, you'll have to do a manual build/link step on your analysis code ... the build system provides you no assistance.
  - You'll need to augment your `include` path so the headers in `g2MIGTRACE/trunk/include` are found
  - You'll need to link against `$G4WORKDIR/tmp/$G4SYSTEM/libROOTRecords.so`
  - Then you can open the `TFile` and analyze away!
- There's no code in the repository, but some can be provided on request.

For developers

- How it all works
- How to add output

How it all works

- The runtime component
  - `rootStorageManager`
  - `g2UniqueObjectManager`
  - Sensitive Detectors and the `TTrees`
- The build component
  - Dictionaries
  - File naming conventions

rootStorageManager

- A singleton esponsible for all Root specific operations
  - Activate/Deactivate sensitive detectors associated with data types to be stored
  - Opening `TFiles`
  - Storing Metadata
  - Booking/branching/writing `TTrees`
  - Converting from Geant4 implementations to Root storable types
  - Writing and closing `TFiles`

g2UniqueObjectManager

- Bidirectionally maps the Physical Volume Name to a (much much!) shorter UUID (the 64bit linear address of the instantiation)
- UUIDs are stored in various places in lieu of Volume Names
- Provides lookup services
    - By name (regular expressions!)
    - By UUID

Sensitive Detectors and the Trees

- All step-by-step data collection is done within Sensitive Detectors
- SDs are `Activated` by the same code within the `rootStorageManager` that books the Trees
- They are also Deactivated if the trees aren't booked!
- Trees are sorted, translated, and written to the Root file by `rootStorageManager` when `EventAction::EndOfEvent` fires

SD Translation

- The Geant4 classes traffic in Geant4 classes (duh)
- The Root persistence framework traffics in Root persistable classes (duh)
- These are not the same code!
    - You can't easily store Geant4 data in Root classes
- `rootStorageManager` provides a translation layer ... you write a converter, and the manager does the rest
    - `trackerHit` -> `trackerRecord`

The build component

- Standard set of makefiles
  - DAGs! Learn to do it right!
- Persistable types must follow these rules to produce a working dictionary:
  - Class declaration in `include/newRecord.rhh`
  - Class definition in `src/newRecord.rcc`
    - Even if “trivial”/empty!
  - LinkDef header in `include/newLinkDef.h`
    - Again, even if empty ... which it probably shouldn't be
- New Sensitive Detector hit types should be called `newHit.{hh,cc}`, and a convert function should be written as in `src/rootStorageManager.cc`