The Bayeux library and the SuperNEMO software

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supernemo
collaboration

Overview

- Introduction
- **Bayeux**

  a fundation library for data processing, geometry, computing, simulation... and all that sort of thing !
- **Falaise**

  a few words about the SuperNEMO software framework.
- Perspectives and conclusion

supernemo collaboration

The origins of the SuperNEMO software framework

The SuperNEMO R&D started in 2004 (LPC Caen and LAL) :

- 2004 : MC study for a Selenium-Xenon TPC [a],
- 2005+ : BiPo1 and BiPo2 prototype detectors [b] : DAQ, MC, data analysis, visualization software
- 2005+ : NAT++ (a C++ based data analysis alternative framework for NEMO3) [c]
- 2006+ : SuperNEMO preliminary MC tools

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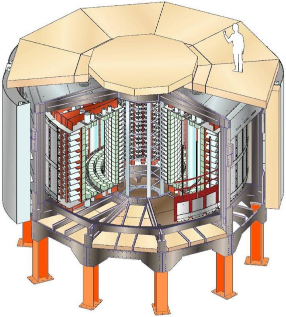
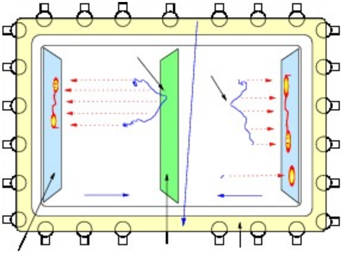
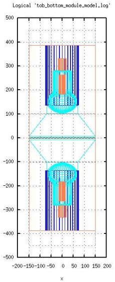
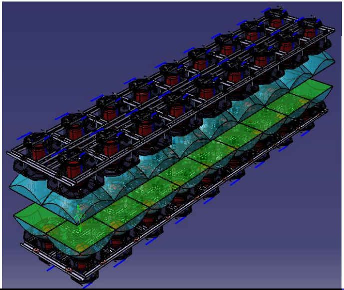
a. F. Mauger, Simulation of DBD in the SeXe TPC, TPC 2006, Paris
b. arxiv-1005.0343
c. PhD : Y. Lemière, M. Bongrand, A. Chapon, S. Blondel, C. Hugon, B. Soulé...

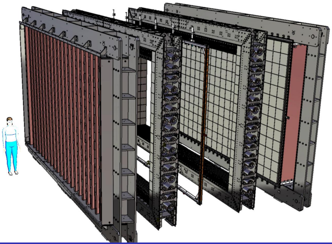
Introduction











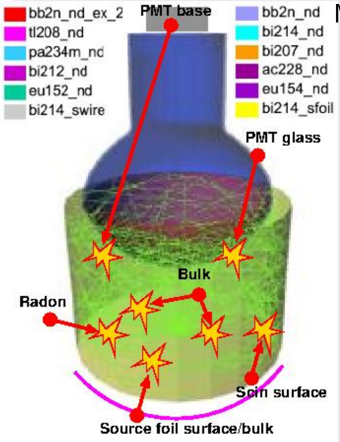
What about existing third party software...

- BiPo, NEMO3, SuperNEMO : many needs to address in parallel for MC, data analysis, for various prototype setups with very different geometries and various data models and processing approaches,
- Existing tools (a.k.a. *Third party software* : Root, Geant4...) have nice features but do not share an unified interface with other tools unless we painfully hardcode software bridges,
- Geometry modelling : Geant4 and Root have their own system (two distincts sets of C++ classes), with some recovery but far to be fully compatible, and without interoperability,
- More, they usually force users to *put all one's eggs in one basket*,
- No existing unique SW tool (Root, Geant4...) able to address all these topics in an unified framework unless one hardcodes lots of things, repeat plenty of tedious coding, investigate sparse/obsolete documentation, finally read the source code... then go mad !

Missing features. . .

- Some scalable data models that are not fully designed during the R&D stages, still efficient for production, handled through versatile data processing tools,
- An *agnostic* portable I/O system able to serialize plain C++ data structure, STL, smart pointers, crossed referenced objects. . .
- Unified geometry modelling system with smart associated tools : factories of geometry patterns, volume identification/numbering scheme, locator mechanisms. . .
- Missing a scalable and unified configuration system with support of system of units, traceability, reuseability, self documentation, integrability in a larger software environment, versionning and configuration variants. . .
- Good support of (or compatibility with) standard features of the C++ langage (templates, STL, Boost),

Problems specific to the SuperNEMO $\beta\beta$ project



Monte-Carlo tools :

- Need for simulation of many different hypothesis (elaborate background models) : a lot of radioactive processes ($\beta\beta$ decays, radioactivity generators), vertexes at many different locations/identifiers of the geometry,
- Some similar tools are used for BiPo, SuperNEMO, shielding studies, HPGe : low radioactivity and low energy physics, shared technologies and geometry, signal processing. . .
  $\rightsquigarrow$ avoid to replicate the code.

The basics of the SuperNEMO software (1)

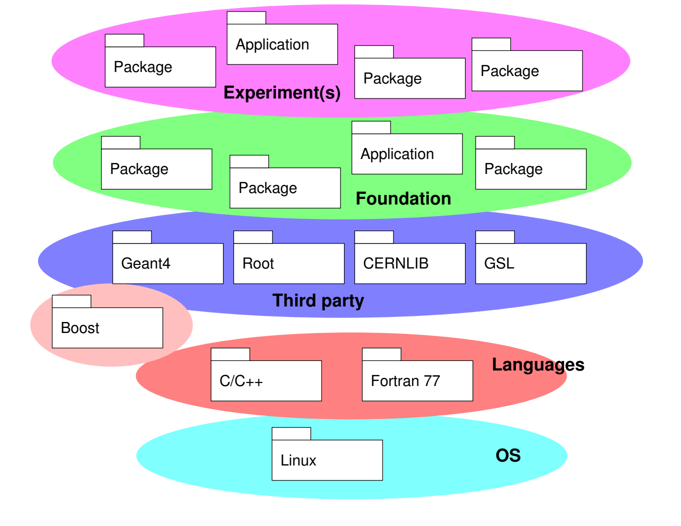
... designed from original works on NAT++ and BiPo1 SW :

- Use plain C++ and standard features of the langage (STL, Boost),
- Use and wrap existing features from *third party software* (TP) whenever it makes sense :
  - do not reinvent the wheel, but hide implementation details from TP and propose an unique user interface,
  - limit to really useful things for the project(s),
  - introduce new features when needed,
  - easier to maintain $\mathcal{O}(10\text{ y})$ and adapt to future TP interface changes,
- Make things as generic as possible (in the limits of our activities),
- Plugin mechanisms and object factories to support user extensions,

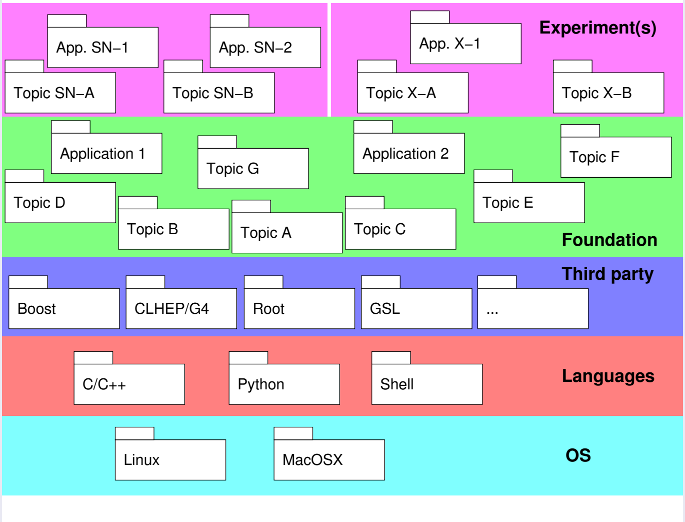
The basics of the SuperNEMO software (2)

- Use the *divide to rule* strategy : implement software modules for well confined independant tasks with a clear interface,
- Minimize coding : scripting facilities through human friendly configuration files, dynamic management of object through manager classes and object factories,
- Integration : distribute a standard and consistent software framework for all activities in the collaboration,
- Open source (GPL), Subversion, CMake.
- Do not strive for perfection, try to be useful, do our best. . .

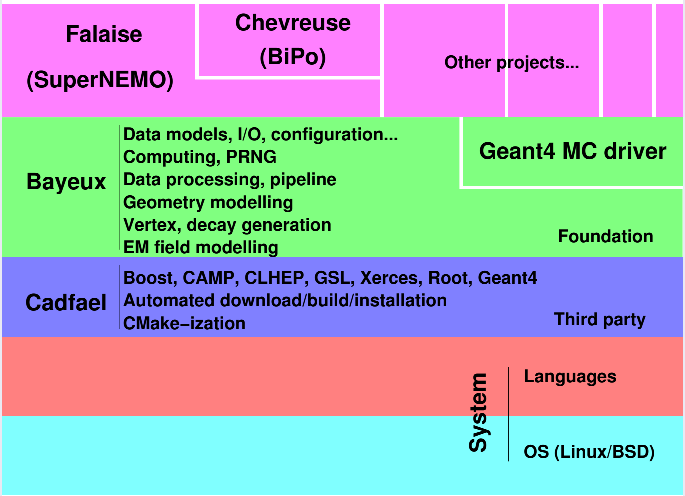
Historical architecture : prototype for NEMO3, BiPo1



Current architecture : production/development for SuperNEMO/BiPo3



Current SW blocks



Overview

- About Bayeux. . .
- Configuration tools
- Data model(s) and I/O
- Geometry
- Simulation
- Data processing pipeline
- Conclusion

What is Bayeux and what's in it ?

- A collection of C++ classes and functions designed for the simulation, recording and analysis of data for experimental particle and nuclear physics projects.
- Split into several specialized submodules :
  - `datatools` : Serializable data structures based on Boost and core utilities (object factories, services, configuration...).
  - `brio` : A Boost over ROOT I/O serialization system (extends `datatools` I/O).
  - `cuts` : Generic tools for making arbitrary data selections.
  - `materials` : Description of isotopes, elements and materials plus tools for input to simulation applications (i.e. GDML@Geant4/Root).
  - `mygsl` : C++ wrappers and extensions to the GNU Scientific Library (C).

What is Bayeux and what's in it ?

- A collection of C++ classes and functions designed for the simulation, recording and analysis of data for experimental particle and nuclear physics projects.
- Split into several specialized submodules :
  - `geomtools` : Generic modelling tools for working with experiment geometries and provide input to simulation and visualization tools (i.e. GDML for Geant4/Root).
  - `emfield` : Electromagnetic field modelling and management.
  - `dpp` : A basic data processing pipeline API.
  - `genbb_help` : C++ port and extensions to the Decay0/GENBB program by Vladimir Tretyak, for input to simulation libraries and applications.
  - `genvtx` : Vertex random generator tools for input to simulation libraries and applications.
  - `mctools` : Utilities for particle and nuclear physics simulation with a Geant4 interface.

Bayeux

Those who make Bayeux. . .

- François Mauger (NEMO3, SuperNEMO, LPCTrap. . .), LPC Caen,
- Benoît Guillon (SuperNEMO, SoLid), LPC Caen,
- Xavier Garrido (SuperNEMO), LAL,
- Benjamin Morgan (SuperNEMO, Geant4. . .), Warwick University,
- Other contributors.

Why Bayeux ?

Provide tools to describe and use an experimental setup in terms of :

- Geometry (for MC and visualization),
- Data models, I/O, services,
- Data processing for real or MC data : digitization, reconstruction, analysis,
- Monte-Carlo studies and production (using Geant4).

Configuration with Bayeux/datatools

The `datatools::properties` class

- A generic store for configuration parameters or versatile data
- Dictionary of key/value entries
- Types : boolean, integer & real numbers, character strings and arrays of that types
- Description embedded in the parameters' entries
- Serializable through the `datatools` I/O system
- Loadable from/storable to ASCII files through a dedicated parser/writer
- Support a large set of units (ala CLHEP) : time, length, mass...
- Other features...

Example : configure an algorithm object (1)

C++

```
#include <datatools/properties.h>
#include <datatools/clhep_units.h>
class my_analysis {
public:
  void initialize(const datatools::properties & setup_) { /* ... */ }
  void run() { /* ... */ }
  void reset() { /* ... */ }
};
int main(void) {
  datatools::properties setup;
  setup.set_description("Configuration parameters for my data analysis");
  setup.store_flag("debug", "Debug mode activation");
  setup.store("number_of_threads", 4, "For multi-core host");
  setup.store("tolerance", 1.0 * CLHEP::mm, "Length tolerance");
  setup.store("histograms.mode", "1d+2d", "Generation of histograms");
  std::vector<double> fdims;
    fdims.push_back(1.2 * CLHEP::cm);
    fdims.push_back(3.6 * CLHEP::cm);
  setup.store("fiducial.dimensions", fdims);
  std::vector<std::string> ifiles;
    ifiles.push_back("${DATA_DIR}/data/run_1.data.gz");
    ifiles.push_back("${DATA_DIR}/data/run_2.data.gz");
  setup.store("files.input", ifiles, "Input data files");
  setup.tree_dump(std::clog, "The configuration parameters: ");
  my_analysis my_ana;
  my_ana.initialize(setup);
  my_ana.run();
  my_ana.reset();
  return 0;
}
```

Example : configure an algorithm object (2)

```
The configuration parameters:
|-- Description  : 'Configuration parameters for my data analysis'
|-- Name : "debug"
|   |-- Description  : Debug mode activation
|   |-- Type  : boolean (scalar)
|   `-- Value : 1
|-- Name : "fiducial.dimensions"
|   |-- Type  : real[2] (vector)
|   |-- Value[0] : 12
|   `-- Value[1] : 36
|-- Name : "files.input"
|   |-- Description  : Input data files
|   |-- Type  : string[2] (vector)
|   |-- Value[0] : "${DATA_DIR}/data/run_1.data.gz"
|   `-- Value[1] : "${DATA_DIR}/data/run_2.data.gz"
|-- Name : "histograms.mode"
|   |-- Description  : Generation of histograms
|   |-- Type  : string (scalar)
|   `-- Value : "1d+2d"
|-- Name : "number_of_threads"
|   |-- Description  : For multi-core host
|   |-- Type  : integer (scalar)
|   `-- Value : 4
`-- Name : "tolerance"
    |-- Description  : Length tolerance
    |-- Type  : real (scalar)
    `-- Value : 1
```

Configuration with Bayeux/datatools

Example : configure an algorithm object (3)

C++

```
void my_analysis::initialize(const datatools::properties & setup_) {
  bool debug = false;
  bool h1d = false;
  bool h2d = false;
  double tolerance = 0.5 * CLHEP::mm;

  if (setup_.has_flag("debug")) debug = true;

  if (setup_.has_key("histograms.mode")) {
    const std::string & hmode = setup_.fetch_string("histograms.mode");
    h1d = (hmode.find("1d") != hmode.npos);
    h2d = (hmode.find("2d") != hmode.npos);
  }

  if (setup_.has_key("tolerance")) {
    tolerance = setup_.fetch_real("tolerance");
    if (! setup_.has_explicit_unit("tolerance")) {
      tolerance *= CLHEP::mm;
    }
  }

  /* ... */
}
```

Example : configure an algorithm object (4)

From a ASCII configuration file :

my_ana.conf

```
#config Configuration parameters for my data analysis
#description Debug mode activation
debug : boolean = 1
#description For multi-core host
number_of_threads : integer = 4
#description Length tolerance
tolerance : real as length = 1 mm
#description Generation of histograms
histograms.mode : string = "1d+2d"
fiducial.dimensions : real[2] in cm =   1.2   3.6
#description Input data files
files.input : string[2] as path = \
 "$DATA_DIR/data/run_1.data.gz" \
 "$DATA_DIR/data/run_1.data.gz"
```

Example : configure an algorithm object (5)

Use the configuration file from C++ :

C++

```
#include <datatools/properties.h>
#include <datatools/clhep_units.h>
class my_analysis {
public:
  void initialize(const datatools::properties & setup_) { /* ... */ }
  void run() { /* ... */ }
  void reset() { /* ... */ }
};
int main(void) {
  datatools::properties setup;
  datatools::properties::read_config("my_ana.conf", setup);
  if (setup.has_key("histograms.mode")) {
    std::clog << "About to run the histogram mode: '"
              << setup.fetch_string("histograms.mode") << "'" << std::endl;
  }
  if (setup.has_key("tolerance")) {
    std::clog << "... with tolerance: "
              << setup.fetch_real("tolerance") / CLHEP::um << std::endl;
  }
  my_analysis my_ana;
  my_ana.initialize(setup);
  my_ana.run();
  my_ana.reset();
  return 0;
}
```

The datatools::multi_properties class (1)

- A store of stores for configuration parameters (ala .ini format)
- A dictionary of datatools::properties objects (*configuration sections*)

my_processing_chain.conf

```
#description Parameters for a processing chain
#key_label  "name"
#meta_label "type"
[name="calib.calo" type="processing::calibration"]
#config Configuration parameters for the calorimeter calibration
#description Activatation of the debug mode
debug : boolean = 0
#description Calibration mode
mode : string = "calorimeter"

[name="calib.tracker" type="processing::calibration"]
#config Configuration parameters for the tracker calibration
#description Calibration mode
mode : string = "tracker"
#description Tracker calibration algorithm
tracker.algo : string = "cellular_automaton"
#description Tolerance for the tracker calibration algorithm
tracker.tolerance : real as length = 1.3 mm

[name="rec" type="processing::reconstruction"]
#config Configuration parameters for the reconstruction
mode : string = "vertex+pretracks"
```

The `datatools::multi_properties` class (2)

- Used with object factories within a dedicated *manager* object,
- Allow dynamic instantiation of a collection of objects that are configured on-the-fly and then used by a client application,
- Such a mechanism is used in many places in Bayeux :
  - `Bayeux/datatools` : a manager of *service* objects
  - `Bayeux/cuts` : a manager of *data selector* objects
  - `Bayeux/geomtools` : a manager of *geometry models* objects (factory of *logical/physical volumes*)
  - `Bayeux/genvtx` : a manager of *vertex generator* objects
  - `Bayeux/genbb_help` : a manager of *decay generator* objects
  - `Bayeux/emfield` : a manager of *electromagnetic field* objects
  - `Bayeux/dpp` : a manager of *data processing module* objects

Configuration with Bayeux/datatools

The `datatools::multi_properties` class (3)

- All stages of the simulation, data processing, analysis can be addressed/configured using this mechanism,
- We can publish *official* configuration files as well as use ones provided by users (and mix them),
- Flexible and scalable configuration system,
- Human friendly : any configurable object/class is associated to its setup file in a comprehensive format, possibly with support for explicit physical units,
- The setup objects (`datatools::properties` and `datatools::multi_properties`) are transient and serializable,
- They can be stored in some run header, database...
- Traceability, versioning, reusability, expandable.
- The `datatools` *Object Configuration Description* (OCD) mechanism provides documentation for such configurable objects (ReST, HTML...).

The Boost/Serialization library

- A tool to store and load arbitrary objects and data structures,
- Separate the format in flavored *archives* (Input/Output, ASCII/XML/binary) and the medium (files, memory buffers. . .),
- Based on template methods/functions and a few utility macros,
- Powerful features : support natively STL containers, memory tracking, smart pointers, versioning, portability,
- Used as the base of the Bayeux I/O system.

C++

```
struct hit {
  int32_t   id;
  uint16_t  tdc;
  uint16_t  qdc;
  template<class Archive>
  void serialization(Archive ar, unsigned int version) {
    ar & boost::serialization::make_nvp("id",  id);
    ar & boost::serialization::make_nvp("tdc", tdc);
    ar & boost::serialization::make_nvp("qdc", qdc);
  }
};
```

The datatools I/O system

- An interface for all serializable objects (`datatools::i_serializable`),
- Generic I/O reader/writer classes : `datatools::data_reader`, `datatools::data_writer`,
- Support crossed references objects through the `datatools::handle` template class (wrapper for `boost::shared_ptr`),
- Sequential storage of objects in archive, or archives in files,
- Mechanism to *register* classes for the I/O system (macros),
- Storage strategies :
  - Store several objects (possibly of different types) in one archive (needed for cross-references between objects),
  - Store one object per archive (memory tracking confinement),
- Note : the `brio` module extends the `datatools` I/O tools with random access to data files (using low level I/O system from Root).

Serialize a datatools::properties object

C++

```
#include <datatools/properties.h>
#include <datatools/io_factory.h>
int main(void) {
  {
    datatools::properties setup;
    setup.store_flag("debug", "Debug mode activation");
    setup.store("number_of_threads", 4, "For multi-core host");
    setup.store("tolerance", 1.0, "Length tolerance");
    setup.store("histograms.mode", "1d+2d", "Generation of histograms");

    datatools::data_writer out("setup.xml"); // XML
    out.store(setup);
    datatools::data_writer out2("setup.txt"); // bzip2-compressed portable ASCII
    out2.store(setup);
    datatools::data_writer out3("setup.data.gz"); // gzip-compressed portable binary
    out3.store(setup);
  }
  {
    datatools::properties setup;

    datatools::data_reader in("setup.xml");
    in.load(setup);

    setup.tree_dump(std::cout, "My setup parameters:");
  }
  return 0;
}
```

Serialization with Bayeux/datatools

XML format : very useful for debug

XML archive format


```
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<!DOCTYPE boost_serialization>
<boost_serialization signature="serialization::archive" version="10">
<record>datatools::properties</record>
<record class_id="0" tracking_level="1" version="0" object_id="_0">
        <description></description>
        <properties class_id="1" tracking_level="0" version="0">
                <count>4</count>
                <item_version>0</item_version>
                <item class_id="2" tracking_level="0" version="0">
                        <first>debug</first>
                        <second class_id="3" tracking_level="0" version="0">
                                <description>Debug mode activation</description>
                                <flags>1</flags>
                                <boolean_values>
                                        <count>1</count>
                                        <item>1</item>
                                </boolean_values>
                        </second>
                </item>
                <item>
                        <first>histograms.mode</first>
                        <second>
                                <description>Generation of histograms</description>
...
```

Serialization with Bayeux/datatools

Portable ASCII format : more compact

Portable ASCII archive format


```
22 serialization::archive 10 21 datatools::properties 1 0
0 0  0 0 4 0 0 0 5 debug 0 0 21 Debug mode activation 1 1 1
15 histograms.mode 24 Generation of histograms 4 0 0 1 0 5 1d+2d
17 number_of_threads 19 For multi-core host 2 1 0 4
9 tolerance 16 Length tolerance 3 1 0 1
```


Portable binary format (compressed) or `brio`

Hum ! Not human friendly display.
However the best for production runs (storage/CPU).

Feedback from a real use case

Have been used for BiPo data storage (real, MC, reconstructed, analysis) and processing for $\simeq$8 years ($\mathcal{O}$(10 TB)).

A geometry manager class which provides

- Description of a hierarchical setup of geometry volumes with standard shapes, materials and arbitrary list of additional properties,
- Support for arbitrary materials and compounds (through Bayeux/materials),
- ASCII files : text based description of the geometry (no coding) thanks to registered factories of *geometry models*,
- Primitives for basic shapes : box, cylinder... tesselated...,
- Models with automated placement algorithms : linear and circular replicated, gridded, stacked, surrounded volumes,
- The *GID manager* : apply rules for the absolute identification of (all) geometry volumes using unique *geometry identifiers* (GID) (`geomtools::geom_id` class), taking into account their hierarchy (mother/daughter relationship),
- *geometry mapping* : automated construction of lookup tables of GIDs,

A geometry manager class which provides

- A *plugin system* : adding EM field manager (through Bayeux/emfields), specialized mapping and/or *locators* (GID↔placement),
- Embeddable in a *geometry service* reusable anywhere along the data processing chain : MC, reconstruction, analysis, visualization,
- Export to GDML for G4 and/or Root if needed,
- Standalone debugging and visualization tool (Gnuplot-based *geometry inspector*).

Main configuration (datatools::properties format)

```
#@description The label identifying the virtual geometry setup
setup_label : string = "MyNeutrinoExperiment"
#@description The version string of the virtual geometry setup
setup_version : string = "0.1"
#@description Files that contain geometry models' definitions
factory.geom_files : string[4] as path  =
  "$SETUP_CONFIG_DIR/geometry/models/sensors.geom"
  "$SETUP_CONFIG_DIR/geometry/models/detector.geom"
  "$SETUP_CONFIG_DIR/geometry/models/experimental_area.geom"
  "$SETUP_CONFIG_DIR/geometry/models/world.geom"
#@description The file defining geometry categories
id_mgr.categories_list : string as path =
  "$SETUP_CONFIG_DIR/geometry/categories.lis"
#@description Generation of a map of geometry IDs
build_mapping : boolean = 1
#@description Files containing geometry plugins' definitions
plugins.configuration_files : string[1] as path =
  "$SETUP_CONFIG_DIR/geometry/plugins/materials.conf"
```

Geometry ID mapping

The *GID manager* knowns the hierarchical rules for *categories* of geometry volumes :

```
#@description A  list of geometry ID categories/types
#@key_label  "category"
#@meta_label "type"

[category="detector.gc"   type="400"]
addresses : string[1] = "unit"    # GID=[400:0] ... [400:7]

[category="electrode.gc"  type="410"]
inherits : string = "detector.gc" # GID=[410:0] ... [410:7]

[category="sensor.gc"     type="420"]
extends  : string = "detector.gc"
by       : string[1] = "position"  # GID=[420:0.0], [420:0.1] ...
```

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Materials plugin

Provides informations about the materials used within the geometry setup :

```
#@description Material geometry plugin
#@key_label  "name"
#@meta_label "type"

[name="materials_driver" type="geomtools::materials_plugin"]
materials.alias_allow_overload : boolean = 1
materials.configuration_files : string[5] as path =
  "@materials:data/std_isotopes.def"  # Standard definitions
  "@materials:data/std_elements.def"  # Standard definitions
  "@materials:data/std_materials.def" # Standard definitions
  "$SETUP_CONFIG_DIR/geometry/my_materials.def"      # User
  "$SETUP_CONFIG_DIR/geometry/material_aliases.def" # User
```

Definitions of isotopes, elements, materials and material aliases

```
#@description Syntax for isotopes, elements...
#@key_label  "name"
#@meta_label "type"
[name="H" type="isotope"]
z : integer = 1
a : integer = 1
[name="Hydrogen" type="element"]
z               : integer   = 1
isotope.names   : string[2] = "H"      "D"
isotope.weights : real[2]   =  99.9885  0.0115
[name="std::air" type="material"]
density                    : real      = 1.2931 mg/cm3
state                      : string    = "gas"
temperature                : real      = 300. kelvin
pressure                   : real      = 1.0 bar
composition.mode           : string    = "fraction_mass"
composition.names          : string[2] = "Nitrogen" "Oxygen"
composition.fraction_mass  : real[2]   =  0.8        0.2
```

Definitions of the geometry models : *world*

```
#@description The geometry model of the world volume
#@key_label  "name"
#@meta_label "type"
[name="world" type="geomtools::simple_shaped_model"]
shape_type : string = "box"
x           : real as length =  8.0 m
y           : real as length =  8.0 m
z           : real as length = 20.0 m
material.ref : string = "rock" # That's underground physics!
internal_item.labels : string[1] = "area"
internal_item.model.area : string = "exp_area.model"
internal_item.placement.area : string = "0 0 0 (cm) "
```

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Add daughter volumes

```
#@key_label  "name"
#@meta_label "type"
[name="exp_area.model" type="geomtools::simple_shaped_model"]
shape_type : string = "box"
x          : real as length = 5.0 m
y          : real as length = 5.0 m
z          : real as length = 9.0 m
material.ref : string = "low_pressure_air"
internal_item.labels : string[3] = "det0" "det1" "Gladys"
internal_item.model.det0 : string  = "detector.model"
internal_item.placement.det0 : string =
                            "2 0 -100 (m) / y 90 (degree)"
internal_item.model.det1 : string  = "detector.model"
internal_item.placement.det1 : string =
                            "-2 0 -100 (m) / y 90 (degree)"
internal_item.model.Gladys : string  = "miss_jones.model"
internal_item.placement.Gladys : string  =
                            "0 100 -200 (cm) / z +45 (degree)"
```

Add *mapping* rules

We set some specific rules that enable the GID manager to automatically build the list of unique GIDs associated to some volumes :

```
# Automatically generate the GID [400:0] for this volume
mapping.daughter_id.det0 : string  = "[detector.gc:unit=0]"

# Automatically generate the GID [400:1] for this volume
mapping.daughter_id.det1 : string  = "[detector.gc:unit=1]"
```

Add auxiliary parameters for client application

By convention, properties starting with the `visibility.` prefix are related to visualization tools :

```
#@description The recommended color for rendering the volume
visibility.color  : string  = "cyan"

#@description The visibility hidden flag for rendering
visibility.hidden : boolean = 0

#@description Another rendering hint
visibility.texture : string = "foggy_atmosphere"
```

By default, all *properties* starting with `visibility.`, `mapping.`, `material.` and `sensitive.` are preserved and stored in the *logical geometry volume* it is associated to.
Can be extended on user request, allow *plugins* and *client applications* to fetch any parameters they may need from any geometry hierarchy node.

Set of simple configuration files :

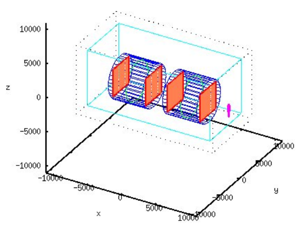
```
|-- manager.conf    # The main configuration file
|-- categories.conf # The definition of geometry categories
|-- models # Here we put geometry models definition files
|    |-- misc.geom  # Gladys' geometry model is here !
|    |-- sensor.geom
|    |-- detector.geom
|    |-- experimental_area.geom
|    `-- world.geom
`-- plugins # Here we put plugins definition files
     |-- materials.conf # The plugin for materials
     `-- material_aliases.def # Definition of materials' aliases
```

The geomtools' inspector : a dedicated shell

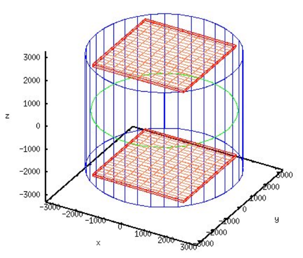
```
shell$ bxgeomtools_inspector -c manager.conf

        G E O M T O O L S   I N S P E C T O R
        Version 4.0.0

        Copyright (C) 2009-2013
        Francois Mauger, Xavier Garrido, Benoit Guillon
                                         and Ben Morgan

        immediate help: type "help"
        quit:           type "quit"
        support:        Gnuplot display
        support:        Root display from GDML

geomtools> help
...
```

The geomtools' inspector : setup display

```
geomtools> display -3d
Press [Enter] to continue...
```

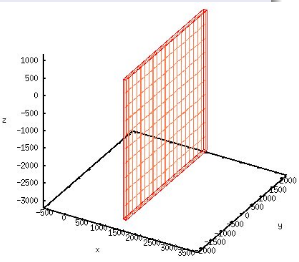



```
geomtools> display -3d detector.model
Press [Enter] to continue...
```



The geomtools' inspector : browse the hierarchy

```
geomtools> list_of_gids --with-type 420
List of available GIDs :
 [420:0.0] as 'sensor.gc' [420:0.1] as 'sensor
 [420:1.0] as 'sensor.gc' [420:1.1] as 'sensor
geomtools> display -3d [420:0.1]
Press [Enter] to continue...
```

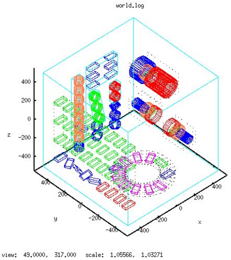


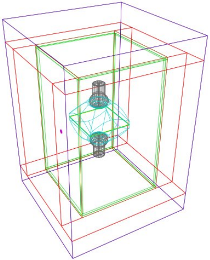
The geomtools' inspector : GDML export

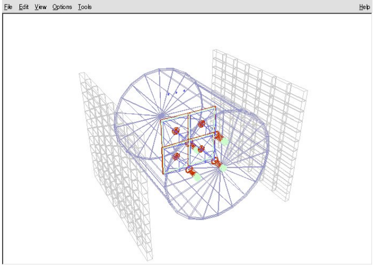
```
geomtools> export_gdml
GDML file 'MyNeutrinoExperiment-0.1.gdml' has been generated !
geomtools> quit
```

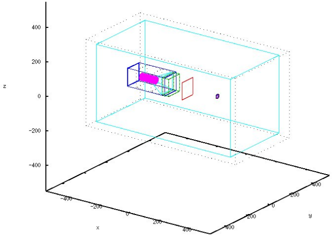
```
shell$ cat MyNeutrinoExperiment-0.1.gdml
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<gdml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="gdml.xsd"  >
<define>
<position name="miss_jones.model.log.stacked__0__.phys.pos"
          x="0" y="0" z="-512.5" unit="mm" />
...
<volume name="world.log" >
  <materialref ref="rock" />
  <solidref    ref="world.log.solid" />
  <physvol>
    <volumeref   ref="exp_area.model.log" />
    <positionref ref="world.log.area.phys.pos" />
  </physvol>
</volume>
</structure>
<setup name="Setup" version="1.0" >
  <world ref="world.log" />
</setup>
</gdml>
```

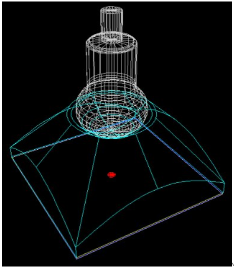
Geometry with Bayeux/geomtools

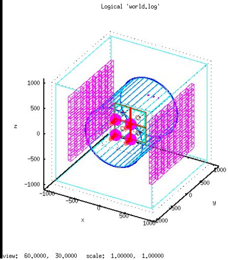






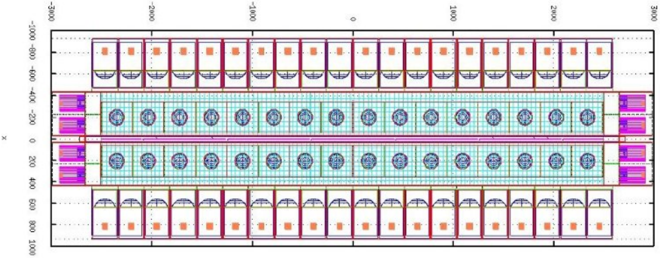






Do more with `geomtools` :

- SuperNEMO demonstrator's virtual geometry :

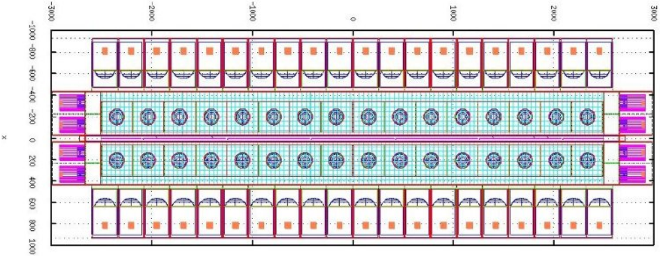


- $\simeq \mathcal{O}(10^5)$ volumes, each with its unique GID (mapping, on user request),
- use mainly generic primitives and only a few hardcoded geometry models for complex shapes (example : OM's extructed light guides),
- used as Geant4 geometry input through the GDML automated interface,
- used by the SuperNEMO event visualization program (see Falaise),

Geometry with Bayeux/geomtools

Do more with `geomtools` :

- SuperNEMO demonstrator's virtual geometry :



- used by the vertex generation manager : because in DBD physics, all elements in the geometry are susceptible to host radioactivity ($\beta\beta$ source foil strips, tracker field wires, scintillator block wrapper films, screws, bolts. . .) and thus generate background,
- used by event reconstruction and analysis processing modules through a dedicated geometry service.

supernemo collaboration

Simulation with Bayeux

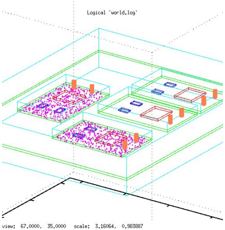
What modules are involved ?

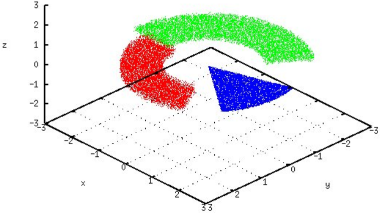
- To build a simulation framework :
  - g) geomtools : geometry modelling,
  - v) genvtx : generation of primary vertex,
  - k) genbb_help : generation of the primary decay/kinematics,
  - s) mctools and its Geant4 plugin : a simulation driver that integrates the functionalities found in g), v) and k).
- Design, implementation, tests and validation of g), v) and k) are done independantly of Geant4,
- Flexible (friendly ASCII config files using the datatools configuration interface), expandable (support for user plugin at every levels),
- In principle reusable in other context (another MC framework ?).

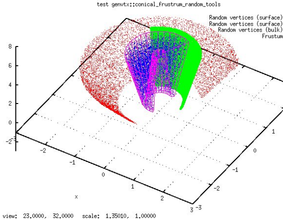
Vertex generation with genvtx

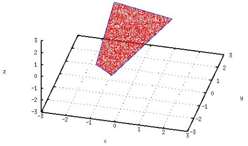
- *Primitives for vertex generation* from usual shapes of interest : boxes, cylinders, tubes, polycones... in bulk volume, on surfaces, with arbitrary shift and skin thickness,
- A *vertex generation manager* interfaced with the *geometry manager* for automated instantiation of vertex generators addressed by the *geometry mapping* mechanism,
- Configured with simple ASCII files (datatools : :multi_properties) : no C++ coding is needed for common shapes (primitives already available),
- Specific needs can be addressed with *vertex generator plugins* using the `genvtx` API (class registration, factories).
  This plugin may be hardcoded or, better, use special primitives for vertex generation and geometry modelling,
- Possibilities to *combine weighted vertex generators* with their own activities (absolute, surface, volume) expressed in common units (Bq/m^2, Bq/m^3, mBq/kg...).

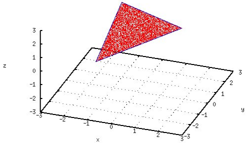
Simulation with Bayeux

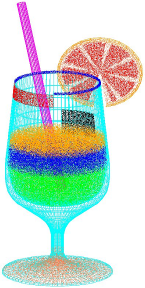












supernemo
collaboration

Typical configuration file for automated vertex generators

```
#@description Definitions of some vertex generators
#@key_label  "name"
#@meta_label "type"
[name="from_the_outside.vg" type="genvtx::box_model_vg"]
origin : string  = " category='world' " # This rule matches the world volume
mode   : string  = "surface"
mode.surface.back   : boolean = 1
mode.surface.front  : boolean = 1
mode.surface.bottom : boolean = 1
mode.surface.top    : boolean = 1
mode.surface.left   : boolean = 1
mode.surface.right  : boolean = 1
[name="electrode_det0_bulk.vg" type="genvtx::cylinder_model_vg"]
# The following rule matches the electrode of detector number 0
origin : string  = " category='electrode.gc' unit=0"
mode   : string  = "bulk"
[name="pixels_det0_row1_surface.vg" type="genvtx::box_model_vg"]
# The following rule matches the pixels in rows 1 of
# detector number 0 for sensors on both sides
origin : string  = " category='pixel.gc' unit=1 position=* column=* row=1 "
mode   : string  = "surface"
mode.surface.top : boolean = 1
[name="pixels_det1_pos0_col3_bulk.vg" type="genvtx::box_model_vg"]
# The following rule matches the pixels in column 3 of
# detector number 1 for sensors on side 0
origin : string  = " category='pixel.gc' unit=1 position=0 column=3 row=* "
mode   : string  = "bulk"
```

Generation of particles/decays with genbb_help

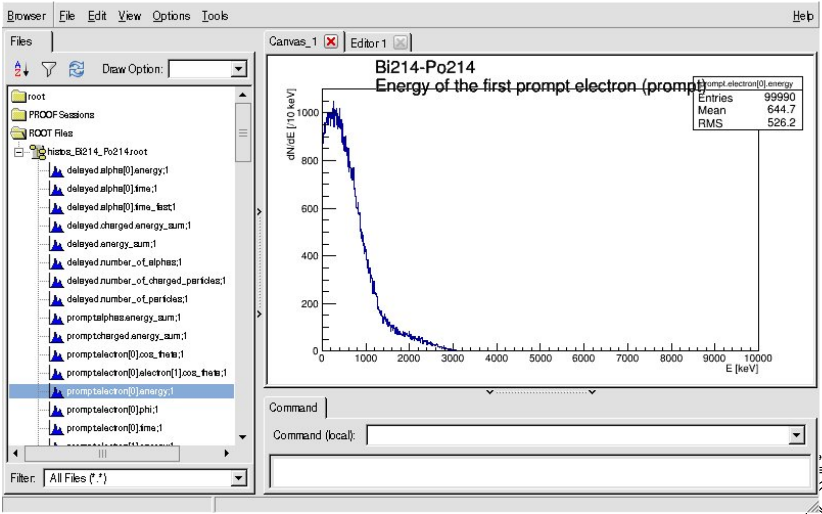
- A C++ port of the well known Decay0/Genbb Fortran program by Vladimir Tretiak,
- Implement 18 $\beta\beta$ processes for 38 isotopes of interest from ^{48}Ca to ^{198}Pt,
- Implement 60 instable radionucleides (with delayed decay cascades) from ^{14}C to ^{241}Am (background, calibration sources),
- Generic data model : serializable `genbb::primary_particle` and `genbb::primary_event` classes,
- An API for extensions with additional generators (plugins, factories).
- Possibilities to *combine weighted event generators* (example : elaborate a *background model* for a given material),
- A *manager* class with ASCII files : again, no C++ coding in most use cases.

The bxgenbb_inspector tool

- An application to generate and browse the output from event generators,
- Generate multiplicity and energy histograms for generated particles,
- Example :

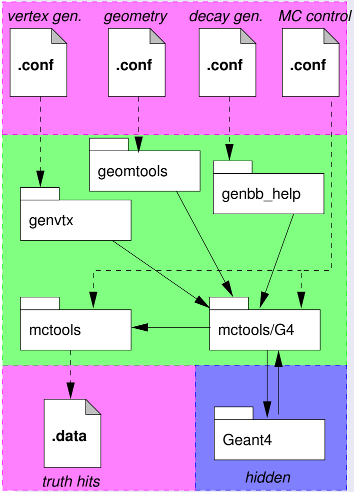
```
shell$ bxgenbb_inspector  \
  --configuration "@genbb_help:manager/config/pro-1.0/manager.conf" \
  --action "shoot"  \
  --generator "Bi214_Po214" \
  --prng-seed 314159 \
  --number-of-events 100000 \
  --modulo 1000 \
  --histo-def "@genbb_help:inspector/config/le_nuphy-1.0/inspector_histos_prompt.conf" \
  --histo-def "@genbb_help:inspector/config/le_nuphy-1.0/inspector_histos_delayed.conf" \
  --prompt-time-limit 1 \
  --prompt \
  --delayed \
  --title-prefix "Bi214-Po214" \
  --output-file "histos_Bi214_Po214.root"
[notice:void genbb::inspector::_run_batch():1620] Generated event #1
[notice:void genbb::inspector::_run_batch():1620] Generated event #1000
[notice:void genbb::inspector::_run_batch():1620] Generated event #2000
...
[notice:void genbb::inspector::_run_batch():1620] Generated event #100000
```

Simulation with Bayeux



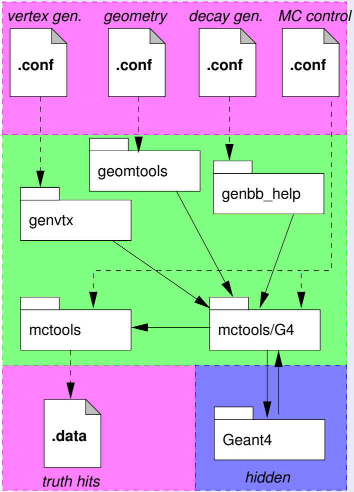
Musical interlude : Xavier Garrido singing his favorite song. . .

Now we are ready for the simulation !



- A MC driver wrapping a full Geant4 session manager, with many supported G4 features (GDML, visualization, physics lists, regions, user limits, secondary particle handling)
- Running mode : batch, interactive, pipeline (parallel MC thread). . .
- Automated instantiation of *sensitive volumes* on user request (factories),
- Provides an API for *truth hits post-processing* : pre-digitization and data storage reduction,
- Provides a few useful *truth hits post-processors* algorithms : calorimetry, garbage, visualization,

Now we are ready for the simulation !



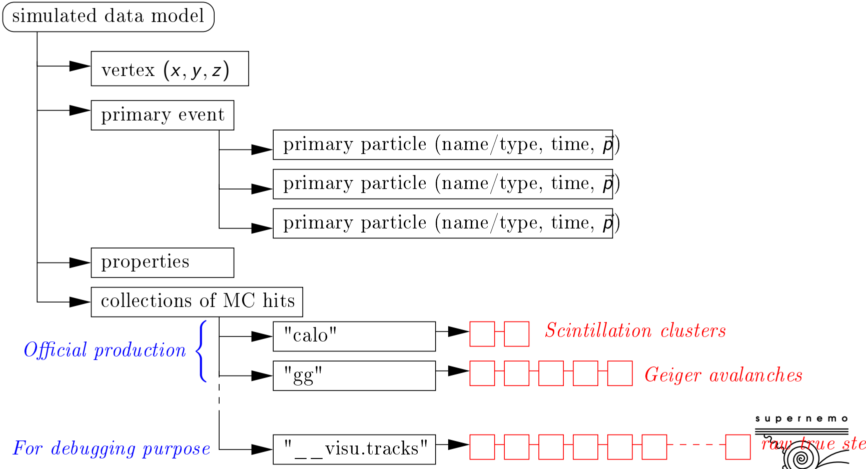
- Generic ouput data models : mctools::base_step_hit (truth hits from G4) and mctools::simulated_data serializable classes,
- Generate collections of truth hits for each sensitive part of the detector :
  - *Official* MC hits from real sensitive detectors (calorimeter, tracking fiducial volume)
  - Debug/visualization MC hits from non-sensitive detectors (ex : mechanics structures that are not sensors)
- Choose the level of details of the truth data output : realistic (production), truth hits (≡G4Step) from everywhere (debug) at the price of more CPU and storage.

Simulation with Bayeux

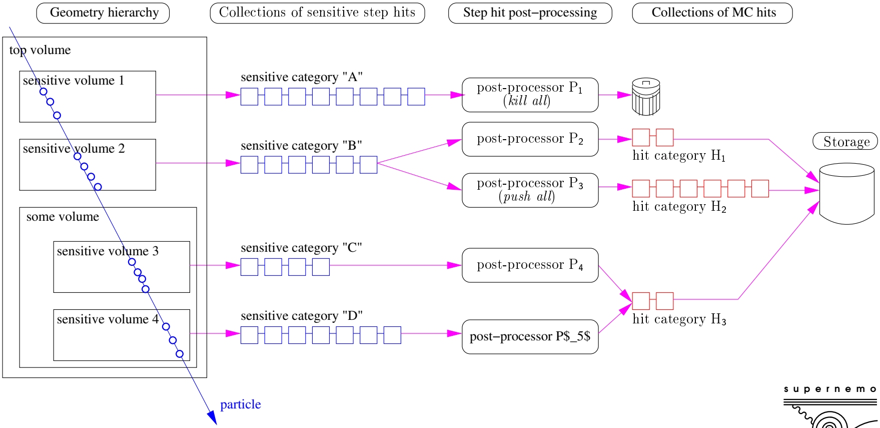
- Use the Bayeux's text-based UI interface : no C++ coding unless we must add specialized user plugins using the API and its factory registration mechanism.
- The simulated output, whatever the simulated experiment is, always uses the same data model and `datatools` I/O system,
- Easy to read the output file and process the objects in it (digitization, calibration...), easy to translate in some other formats,
- Provide the `bxg4_production` program to run any MC sessions, whatever the experiment is (SuperNEMO demonstrator, BiPo3, HPGe...).
- Provide a *simulation module* compatible with the processing pipeline implemented in the `dpp` library.

Simulation with Bayeux

The output we want :



How we build the output :

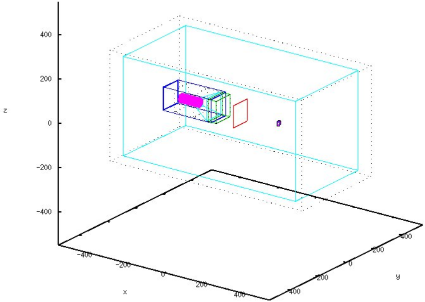


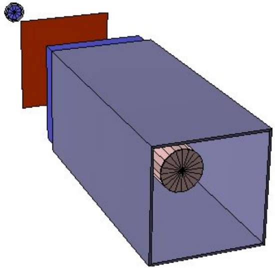
A full configuration setup for a simulation :

```
MyNeutrinoExperiment/ # A typical configuration tree
|-- geometry
|   `-- 0.1
|       |-- manager.conf   # Setup the geometry
|       |-- categories.lis # Define the geometry categories of volumes
|       |-- models
|       |   |-- source.geom   # The decription of the source
|       |   |-- detector.geom # The decription of the detector
|       |   `-- world.geom    # The top volume
|       `-- plugins
|           |-- mappings.conf         # Mapping plugin
|           |-- materials.conf        # Materials plugin
|           `-- material_aliases.def  # Definition of materials' aliases
`-- simulation
    |-- geant4_control
    |   `-- 0.1
    |       |-- manager.conf # Setup the G4 driver
    |       |-- processes
    |       |   |-- em.conf              # Electromagnetic processes
    |       |   `-- particles.conf       # List of particles
    |       `-- step_hit_processors.conf # Post-processing of true hits
    |-- primary_events
    |   `-- 0.1
    |       |-- manager.conf    # Setup the vertex generation
    |       |-- dbd.def         # Definitions of DBD decay generators
    |       `-- background.def  # Definitions of background decay generators
    `-- vertexes
        `-- 0.1
            |-- manager.conf    # Setup the vertex generation
            `-- generators.def  # Definitions of vertex generators
```

mctools' example ex00

A simple geometry : an optical module ala BiPo/SuperNEMO





mctools' example ex00

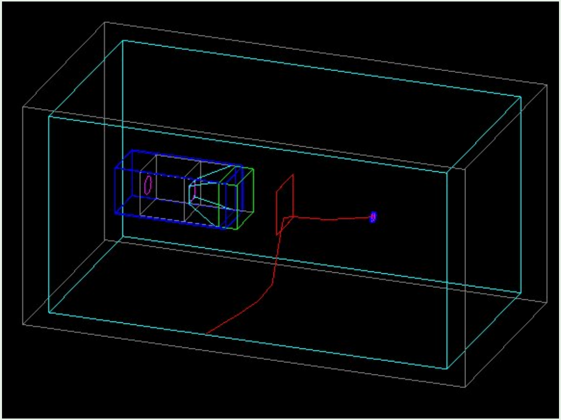
Running Geant4 in interactive mode :

Shell

```
$ bxg4_production \                          # Standalone unique G4 session application
   --logging-priority "warning" \
   --number-of-events-modulo 1 \
   --interactive \
   --g4-visu \
   --config "manager.conf" \                        # Setup the simulation manager
   --vertex-generator-name "source_bulk.vg" \       # Choose the vertex generator from a list
   --vertex-generator-seed 0 \
   --event-generator-name "electron_1MeV_cone" \    # Choose the decay generator from a list
   --event-generator-seed 0 \
   --shpf-seed 0 \
   --g4-manager-seed 0 \
   --output-prng-seeds-file "prng_seeds.save" \
   --output-prng-states-file "prng_states.save" \
   --output-profiles "all_details" \                # Choose the detail level of the output
   --output-data-file "mctools_ex00_electron_1MeV_source_bulk.xml" \
   --g4-macro "geant4_visualization.mac"
...
$Idle> /run/beamOn 1          # Fire the G4 gun
...
```

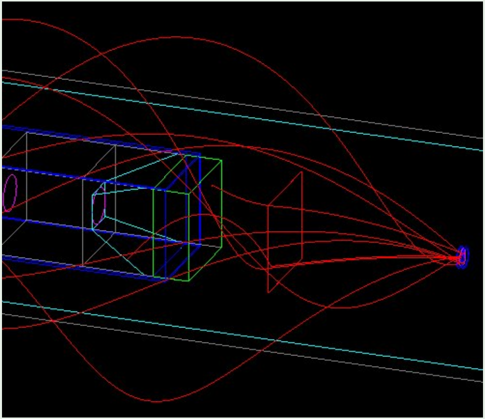
mctools' example ex00

Geant4 display : a low-energy electron from the source film, backscattered on the attenuator plate in front of the scintillator block, and finally leaving the *world* volume



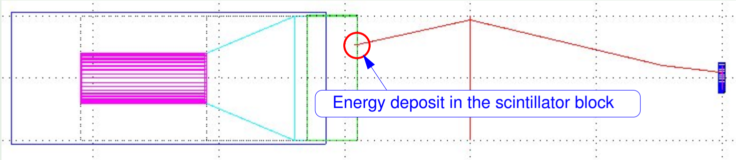
mctools' example ex00

Geant4 display : many electrons with some magnetic field activated



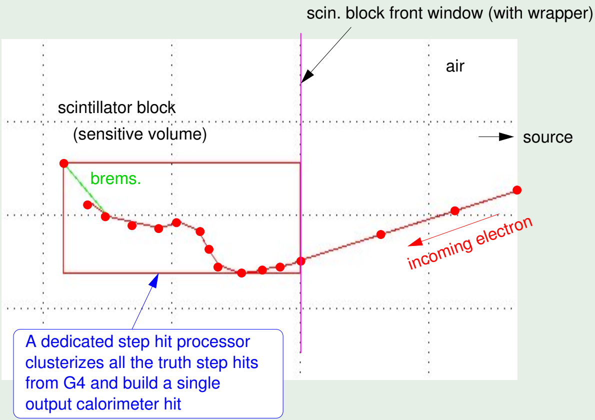
mctools' example ex00

Off-line display : *sensitive hits* in the scintillator block



mctools' example ex00

Post-processing of *truth sensitive hits* to build an *output hit* of the "scin" category : reduce to useful information for further digitization processing



mctools' example ex00

Output data model : use plain C++ classes with serialization support

```
Simulated data :
|-- Properties : <empty>
|   `-- <no property>
|-- Collection type : 1
|-- Collections of step hit handles :
|   |-- Category '__visu.tracks' has 75 hit(s) [capacity=75]
|   `-- Category 'scin' has 1 hit(s) [capacity=1]
|-- Primary event :
|   |-- Valid: 1
|   |-- Label : ''
|   |-- Time  : 0 s
|   |-- Particles: [1]
|   |   `-- Particle #0 :
|   |       |-- Type           : 3 (e-)
|   |       |-- Particle label : 'e-'
|   |       |-- Time           : 0 ns
|   |       |-- Kinetic energy : 1 MeV
|   |       |-- Momentum       : (-1.41112,0.0107192,0.174975) MeV
|   |       `-- Vertex         : <no vertex>
|   |-- GENBB weight : 1
|   `-- Classification : '1e0p0g0a0X'
`-- Vertex : (199.999,-4.92332,-6.91926) mm
```

emo collaboration

mctools' example ex00

Raw truth hits of the "__visu.track" category

```
Truth '__visu.tracks' hit :
|-- Store          : (11001111111)
|-- Hit ID         : 23
|-- Geometry ID    : [2030:0]
|-- Auxiliaries :
|    |-- Name : "track.id"
|    |    |-- Type  : integer (scalar)
|    |    `-- Value : 1
|    |-- Name : "track.parent_id"
|    |    |-- Type  : integer (scalar)
|    |    `-- Value : 0
|    `-- Name : "track.primary"
|         |-- Type  : boolean (scalar)
|         `-- Value : 1
|-- Position start : (-90.8437,-1.53469,-24.7307) mm
|-- Position stop  : (-90.8669,-1.57955,-24.6445) mm
|-- Time start     : 1.06084 ns
|-- Time stop      : 1.06122 ns
|-- Momentum start : (nan,nan,nan) keV
|-- Momentum stop  : (nan,nan,nan) keV
|-- Energy deposit : 14.4153 keV
`-- Particle name  : `e-'
```

Official calorimeter truth hits of the "scin" category

```
Truth 'scin' hit :
|-- Store          : (11001111111)
|-- Hit ID         : 0
|-- Geometry ID    : [2030:0]
|-- Auxiliaries :
|    `-- Name : "track.primary"
|         |-- Type  : boolean (scalar)
|         `-- Value : 1
|-- Position start : (-91.3098,-10.1873,38.0118) mm
|-- Position stop  : (-90,-8.27668,38.2714) mm
|-- Time start     : 1.04847 ns
|-- Time stop      : 1.06046 ns
|-- Momentum start : (nan,nan,nan) keV
|-- Momentum stop  : (nan,nan,nan) keV
|-- Energy deposit : 896.2 keV
`-- Particle name  : `e-'
```

mctools' example ex00

- Dedicated configuration parameters for each sensitive detector,
- Ability to choose the volumes from where we'd like to record truth hits and G4 tracking informations (by names, by materials, by geometry categories),
- Ability to choose the level of details (G4 tracking informations) to be saved in a truth hits from within a given sensitive category,
- The truth hit data model uses a versatile/generic container embedded in the object : `datatools::properties`

```
Truth '__visu.tracks' hit :
|-- Store          : (11001111101)
|-- Hit ID         : 1
|-- Geometry ID : No
|-- Auxiliaries :
|     |-- Name : "g4_volume.copy_number"
|     |     |-- Type  : integer (scalar)
|     |     `-- Value : 0
|     |-- Name : "g4_volume.name"
|     |     |-- Type  : string (scalar)
|     |     `-- Value : "source.model.log_PV"
|     |-- Name : "material.ref"
|     |     |-- Type  : string (scalar)
|     |     `-- Value : "lab_medium"
|     |-- Name : "sensitive.category"
|     |     |-- Type  : string (scalar)
|     |     `-- Value : "__source.sd"
|     |-- Name : "track.id"
|     |     |-- Type  : integer (scalar)
|     |     `-- Value : 1
|     |-- Name : "track.parent_id"
|     |     |-- Type  : integer (scalar)
|     |     `-- Value : 0
|     `-- Name : "track.primary"
|           |-- Type  : boolean (scalar)
|           `-- Value : 1
|-- Position start : (199.998,2.70044,-8.70333) mm
|-- Position stop  : (197.5,2.38021,-8.98234) mm
|-- Time start     : 8.28555e-06 ns
|-- Time stop      : 0.00898817 ns
|-- Momentum start : (nan,nan,nan) keV
|-- Momentum stop  : (nan,nan,nan) keV
|-- Energy deposit : 0.776159 keV
`-- Particle name  : `e-'
```

Simulation with Bayeux

Conclusion

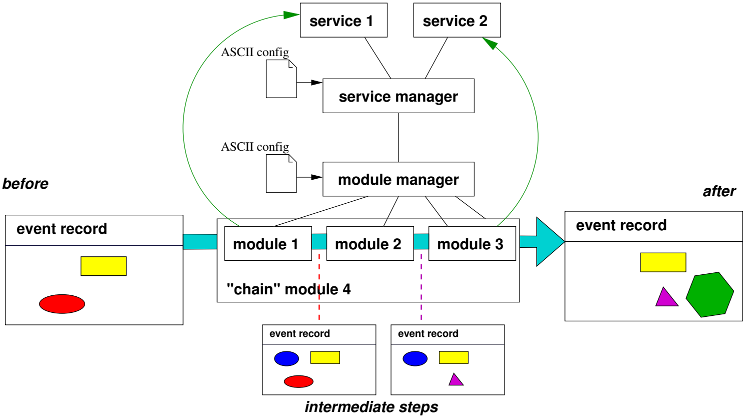
- Not a full featured Geant4 driver, however it has fulfilled all our needs so far,
- Simplify/fasten the making of an simulation environment,
- We can add new functionalities when needed,
- Fully integrated in the Bayeux framework : UI, configuration, data model and I/O, so our users are familiar with the approach,
- These tools has been used for years for SuperNEMO activities.

Data processing with Bayeux/dpp

A generic data processing pipeline

- Based on data processing modules,
- Can chain them and organize them along a data pipeline,
- A manager class, module class registration and factories,
- Configuration as usual (see Bayeux/`datatools::multi_properties`),
- Provides primitive modules : chain, conditional module, I/O modules...
- Interfaced with the datatools support for services.
- Ability to distribute an official chain of data processing steps through a set of blessed configuration files and modules,
- User can develop and insert their own algorithms along the pipeline,
- An unique program to address any processing chain : `bxdpp_processing`

Data processing with Bayeux/dpp



Data processing with Bayeux/dpp

The datatools::things class

- A container able to store arbitrary *serializable objects of any type* : data banks,
- Used template, RTTI, registered factories,
- Used as a dictionary with unique string keys to access the data banks,
- Data banks can be added, removed, transformed,
- Can store several versions of a type of objects : `"CD1"` : calibrated data method 1, `"CD2"` : calibrated data method 2, both of type `myexperiment::calibrated_data`
- Support cross-referenced data structures in different data banks (example : the *digitized tracker hits* in the *calibrated data bank* point to some of the *raw MC truth hits* in some *simulated data bank*)
- Ideal candidate class to be used as the data record processed by the data processing pipeline,
- I/O (load/store from Boost archives) is supported by Bayeux serialization system (standard reader/writer classes).

Data processing with Bayeux/dpp

How is organized the data processing

1. Decide for a set of registered data processing modules (eventually load some dedicated plugins for that),
2. Provide the configuration parameters for each of them,
3. Ask the `bxdpp_processing` program (or some `dpp::manager object`) to run and loop on some collection of data records (`datatools::things`),
4. Enjoy the output !

Conclusion

- Bayeux provides an unique framework for various activities within the collaboration,
- Bayeux is built on top of standard features of the C++ language and uses some third party software (automatically managed by the Cadfael aggregator package),
- Has solved many SW technical issues and provides generic tools,
- Bayeux (prototype&beta) has been successfully used during the last 5 years,
- It is now ready for a production release : version 1.0, next week,
- A living project : additional features are planed for future releases,

Conclusion

- Other projects are now starting to use it :
  - Studies at LPC : nuclear safety and radiation protection (under industrial contract),
  - LPCTrap experiment and collaborators : search for weak exotic coupling in β decay,
  - Effects of radiation in semiconductor chip structures (SINUS group, with IM2NP Marseille),
- Probably of educational interest : for nuclear/particle physics lab teaching,
- Feel free to make a try !

Dedicated to SuperNEMO

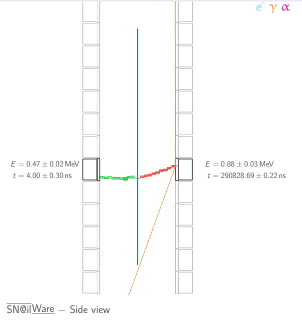
- Built on top of Bayeux (also use SVN, CMake),
- Implement a dedicated C++ library for simulation, data models, data processing,
- Published versioned resource files : configuration for geometry, MC... keep track of former MC/processing setup through ASCII files,
- `flsimulate` application for MC production :
    - SuperNEMO demonstrator,
    - Tracker commissioning,
    - BiPo3.
- `flreconstruct` application for pipelined data reconstruction :
    - blessed modules and algorithms,
    - plugin system for user contribution.
- SuperNEMO and BiPo event browsers.

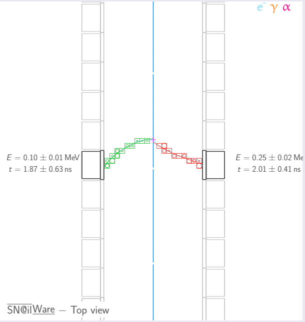
What we have now

- Simulation module,
- Mock digitization/calibration module,
- Tracker clustering module,
- Track fitting module,
- Track reconstruction module,
- Geometry and event visualization,
- Ready for analysis and studies. . .

Snapshots

MC background from the source foils (^{214}Bi, ^{40}K) :





Conclusion

- Falaise relies on generic functionalities provided by the Bayeux library,
- Concentrate on specific problems for the SuperNEMO experiment,
- Falaise 1.0 will be released end of June,
- Will be improved in the future :
  - Final geometry design : final layout of the calorimeter, shielding,
  - Realistic modelling of the magnetic field,
  - Final raw data model(s) and realistic digitization (waiting for the finalization of the front end electronics design, trigger strategies and DAQ system...)
  - More data reconstruction and analysis tools,
  - Interface to a database system and the control and monitoring system.

General conclusion

- A quick tour of the SW tools used by the SuperNEMO collaboration,
- Based on Cadfael/Bayeux/Falaise packages,
- We can now investigate a lot of physics cases with these tools,
- Bayeux could be useful for many other projects,
- Contact us to investigate/use these tools.

General conclusion

Thanks to

- Core SW : X. Garrido, B. Morgan, B. Guillon, M. Bongrand...
- SN plugins : X. Garrido, F.Nova, S.Calvez...
- Visualization : X. Garrido.
- Songs (particularly confined in a bus) : X. Garrido

supernemo collaboration