REST v2.2 Introduction

1 Introduction
2 Installing REST
3 Try Some Examples
  3.1 Generate a readout file
  3.2 Process a raw data file
4 The REST Framework
  4.1 TRestMetadata : basic functionality of REST
  4.2 TRestManager : managing REST applications
  4.3 TRestRun : operating files and managing metadata
  4.4 TRestEvent & TRestEventProcess : data and analysis
  4.5 TRestProcessRunner : running analysis in an efficient way
5 Using REST
  5.1 Running with a ROOT script
  5.2 Rml introduction
  5.3 Writing an rml
  5.4 During processing
  5.4 REST data format
  5.5 Browsing and viewing events
  5.6 Plot the analysis result
6 Some Metadata Classes
  6.1 TRestGas
  6.2 TRestReadout
  6.3 TRestG4Metadata
7 Base Class Interface Reference
  7.1 TRestEvent
  7.2 TRestMetadata
  7.3 TRestEventProcess
8 Start Your Own Analysis with REST
  8.1 Adding a class to souce code
  8.2 Referring to REST library in another project
  8.3 Example : restG4
Appendix
  List of REST processes
  List of REST macros
  REST pre-definition data

Introduction

REST is an event-oriented analysis framework. Based on ROOT, it defines specific classes to keep data, read config, and run processes. Most of these classes are designed for gas detectors with micropatterned readout.

REST does analysis through some modular process classes. They in chain convertes raw data to the final analysis result. One can easily modify the process chain in the config file and do his own analysis. We will frequently introduce new or update the old processes as the analysis work of PandaX-III requires. The user can also write his own processes at any time.

(we need to add some development history here)

We made many changes since then, and up to now REST is still under development. The latest version is V2.2, which is the basis of this guide.

Installing REST

We first start with the installation of REST. First check the environment. Following are some necessary development tools on linux.

- unzip
- cmake
- g++
- gcc
- python
- git
- subversion

Most of the Linux distributions should already contain these softwares. One can check if they are installed by typing their name directly in bash(for subversion type "svn"). If not installed, use `sudo apt-get install ...` or `sudo yum install ...` to install them.

In addition, we need to install the following packages referred to by REST.

- ROOT6 or higher
- tinyxml

REST's gas functionality also relies on library "garfield" (compiled with ROOT6). This can be switched on/off by setting cmake flags. Note that geant4 is not required by REST mainbody. It is the package "restG4" that uses both geant4 and REST library.

We have some shell scripts to install these packages. One can find them in ./scripts/installation.

After finishing installing these packages, we are able to install REST mainbody. There are some python scripts in the directory ./scripts. The script "scriptsInterface.py" provides a wizard for installation (requires package "python-tk"). Change to that directory and call the script by typing `python scriptsInterface.py`. Updating for REST is also available in it.

One can also choose to manually install REST. For example, we first make a directory "build" in REST directory and enter it. Then type `cmake ..` followed by `make install`, and if all proceed normally, REST will be installed in the directory ./install. We have several Cmake flags listed below:

-DINSTALL_PREFIX=(install path) : change the installation path of REST
-DREST_GARFIELD=(ON/OFF) : switch on/off the garfield dependence. Methods in gas classes will return default value with a warning message when garfield is off.
-DREST_WELCOME=(ON/OFF) : switch on/off the welcome message when logging in. The message contains information about the versions, install path, install date, etc.

Finally the user needs to source the shell script before using REST software. The shell script is in the installation path named "thisREST.sh". It is recommended to add a line "source .../thisREST.sh" in users .bashrc file.

Check if REST is successfully installed by typing `rest-config --welcome` in the command line. A welcome message should show up. Then type `restManager` to check if the exectuable can normally run. The usage of restManager will be shown.

Try Some Examples

The main executable of REST is restManager and restRoot. By typing directly `restManager` it will show its usage. By typing restRoot the user can access to REST libraries and macros inside ROOT prompt. We have some example files for restManager in the directory ./examples/restManager. We first switch to that directory.

Generate a readout file

We first try to generate a readout file. A readout file saves the definition of the detector's readout system, including geometry, daq channel mapping, strip gain, etc. This file very important for the processes. Generate it by typing :

`restManager --c generateReadoutFile.rml --o readouts.root`

This command will make REST to save readout definition to a file "readouts.root", which can be used in the later data analysis work. The readout definition is all in the rml file. Later we will explain what it did.

A readout figure will showup after the generation. The user can also view the figure later on by typing `restViewReadout readouts.root PandaReadout_MxM`. Here "PandaReadout_MxM" is the name of the readout definition.

Process a raw data file

If you are in pandax-iii daq server, you can try to process some raw data file with the readout file we just generated. For example, to process a 7MM run data file, we can type the command:

`restManager --c multiCoboAnalysis.rml --i /data2/7MM/graw/CoBo_AsAd0_2017-12-23T17\:24\:04.657_0000.graw --o abc.root`

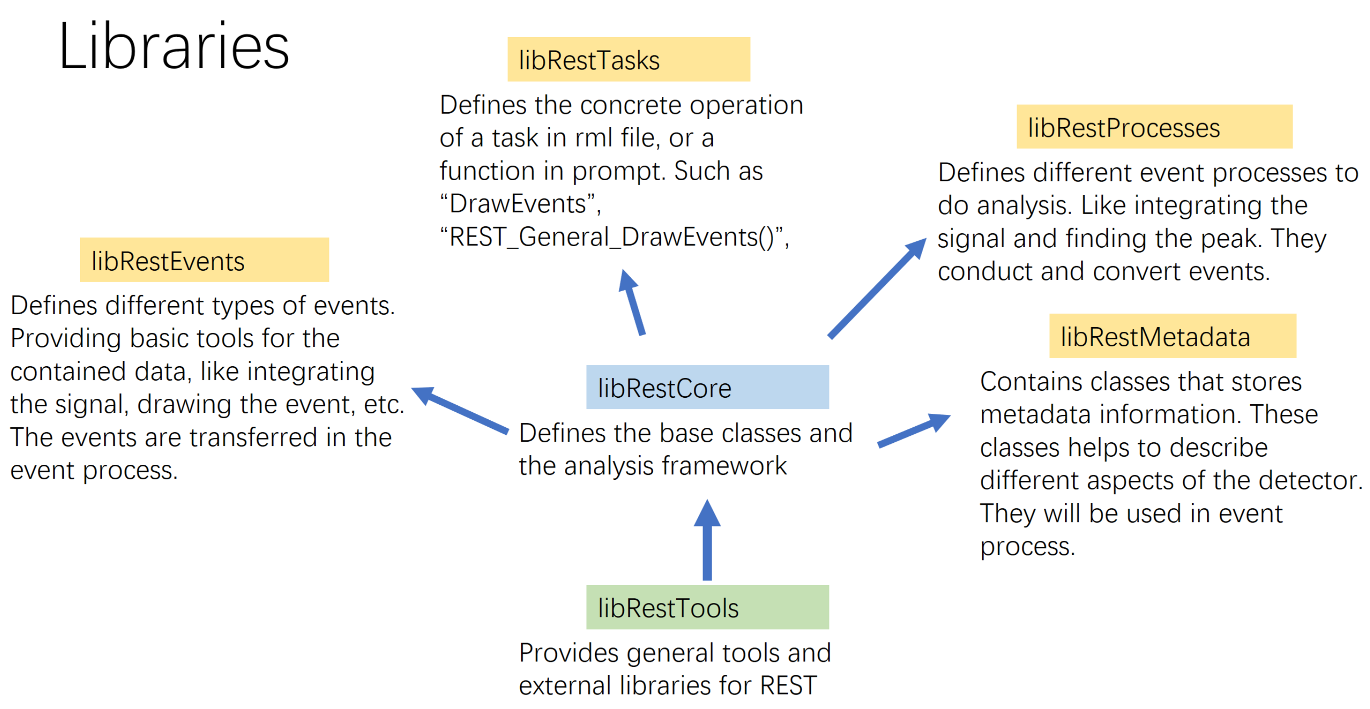
This gives REST names of the config file, input file and output file. If works smoothly, you can see numbers of processed events increasing.

When it is done, use command: `restRoot abc.root` to see the content of generated ROOT file. The file should contain two trees and some saved classes. We will talk it later.

The REST Framework

REST is developed based on ROOT. It provides additional classes for the data analysis. The property of REST's analysis lies in its the event-orientation. An event is the collection of all physical existence due to one incident particle. Events are independent from each other, while their content is from a same random process in a same run. In REST we define several types of events, such as RawSignalEvent, SignalEvent, HitEvent and TrackEvent. We also define process classes to deal with these events, to make analysis for them or to change types between them. Some configuration and definitions are needed to make a process, so we define metadata classes to read config file with specific format, or to save/load the object into/from a ROOT file.

REST is organized with several libraries. The center of them is libRestCore. Inside this library we have several base classes which builds up the whole framework of REST. libRestCore relies on the library libRestTools, which provide some basic tools(string tools, output tools, units tools) and some external codes. Up on libRestCore, other REST libraries such as libRestProcesses, libRestMetadata, libRestEvents and libRestTasks are built.


Libraries
libRestTasks
Defines the concrete operation of a task in rml file, or a function in prompt. Such as "DrawEvents", "REST_General_DrawEvents()",
libRestProcesses
Defines different event processes to do analysis. Like integrating the signal and finding the peak. They conduct and convert events.
libRestEvents
Defines different types of events. Providing basic tools for the contained data, like integrating the signal, drawing the event, etc. The events are transferred in the event process.
libRestCore
Defines the base classes and the analysis framework
libRestMetadata
Contains classes that stores metadata information. These classes helps to describe different aspects of the detector. They will be used in event process.
libRestTools
Provides general tools and external libraries for REST

Here we will talk about some important classes in libRestCore. The methods in these class will only get their names mentioned. One can find their detailed usage in REST class reference.

TRestMetadata : basic functionality of REST

We first talk about the most important class - TRestMetadata. This abstract class brings basic funcitionality to REST, and is the base class of many REST classes. Data member of a TRestMetadata-inherted class is defined inside an rml file, an xml encoded configuration file. With this configuration file the inherted class can be initialized. The concrete operation of its initialization is defined in the method InitFromConfigFile() by the inherted class. This method is called during start up of the class by another method LoadConfigFromFile(), which parses the rml file or section as preparation.

TRestMetadata itself is inherted from the class TNamed. It allows the save/load functionality into/from a ROOT file. In many cases loading from ROOT file will be much quicker than reading and parsing an rml file.

TRestMetadata inherted class should have a name and a title. They are from TNamed class. In addition, we also define two basic attritubes: verbose level and storage. They controls the amount of words printed on screen and whether the class should be saved. All those will automatically be set from the rml config file.

One major type of the inherted class is called "metadata". They contain data of, for example, the geometry of a simulation, the properties of a gas, the readout pattern used to "pixelize" data, etc. Usually we will first instantiate and save a metadata class with an rml file. In pratical use, we can just read it from the saved ROOT file.

Another family of TRestMetadata inherted class is called "application". Their rml file gives, for example, the parameters of an analysis, the targets of a plot, the processes to load of an analysis, etc. Currently, REST cannot load application classes from saved ROOT file.

TRestMetadata also provides some utilities for the inherted class. The most commonly used methods are: GetParameter(), GetElement(), GetChar(), GetDataMemberWithName(), etc. It also defines leveled string output tools: fout, essential, info, debug, etc. See them in the REST class reference page.

TRestManager : managing REST applications

This class, as its name suggests, manages all other REST applications, including TRestRun, TRestProcessRunner, and so on. A REST application has a poniter to its manager, thus it can easily get access to its sibling applications. For example, a process class can get access to its sibling TRestRun, and acquires matadata in it.

TRestManager performs initialization for its managed applications by a strategy called sequential start up. For example, inside the rml configuration file, there is a section declared as "TRestManager". And in this section there is some child sections declared by different application names(here we have "TRestRun", "TRestProcessRunner"). TRestManager will try to instantiate objects of corresponding applications by calling the method TClass::GetClass(). Then it call the applications' LoadConfigFromFile() method giving them the defined child sections. If the application also contains TRestMetadata-inherted class which can be initialized through rml file/sections, its section will have its own child section(here we have "TRestReadout"). And this grandchild section is given to the grand-resident class in that application. This is sequential startup.

```
<TRestManager ... >
  <TRestRun ... >
    <TRestReadout ... >
      ...
    </TRestReadout>
  </TRestRun>
  <TRestProcessRunner ...>
    ...
  </TRestProcessRunner>
  <addTask .../>
  <globals>
    ...
  </globals>
</TRestManager>
```

In short, we perform sequential startup by constructing a same hierarchy in rml file with REST classes. This helps to make the code and conifig file easier to read.

An xml section declared as "globals" is also in the TRestManager section, the content of it will be expanded into all other sections in the same level. They will not override the one which are already defined.

There is also an xml section declared as "addTask". This line actually tells TRestManager the real work with those initialized applications. "addTask" section can either call a TRestTask type application which has a default behavior after initialization(talked later), or be a C++ style command for TRestManager to execute. For example, we can use:

`<addTask command="TemplateEventProcess->RunProcess()" value="ON"/>` ,

and TRestManager will invoke the method "RunProcess()" in the application named "TemplateEventProcess". This application should be defined in previous sections.

TRestRun : operating files and handling data

TRestRun is an application class hosting REST metadata classes and operating files. Usually, when REST is running, an instantiated TRestRun object opens a saved ROOT file to provides the metadata and eventdata. When the framework finishes its run, this object in turn helps to create output file and save the result data. As a result, TRestRun is a data handler among the whole framework, which is very important.

Some methods are frequently called by other classes to get event/meta data: GetNextEvent(), GetEntry(), ImportMetadata(), GetMetadata(), etc. There are also some methods for file operation: OpenInputFile(), FormFormat(), MergeProcessFile(), CloseFile(), FormOutputFile(), etc.

Usually there is a "TRestRun" section inside the "TRestManager" section in the rml file. We use lines like:

`<addMetadata name="PandaReadout_MxM" file="readouts.root"/>`

to import a metadata object from saved ROOT file.

TRestEvent & TRestEventProcess : data and analysis

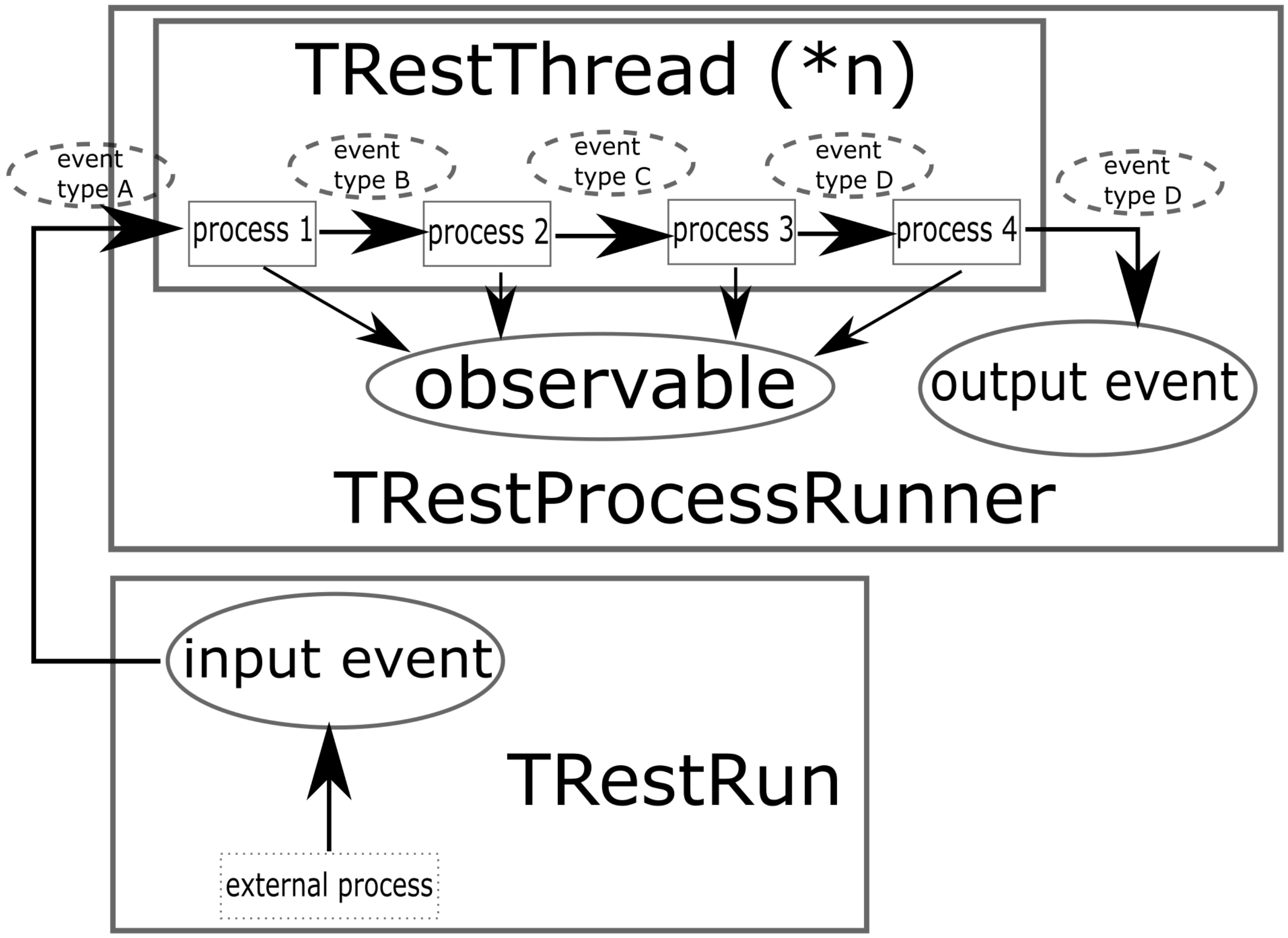
TRestEventProcess is another important application class. It is a base class for all REST pre-defined processes. TRestEvent is directly inherted from TObject. It is a base class for all REST pre-defined event types.

Besides the functionality of reading configuration from file, TRestEventProcess defines extra interfaces for its inherted class to do the job. The method InitProcess() and EndProcess() are used as preparation/completion steps before/after the process loop. The method ProcessEvent() is the main method of the loop. It receives an input TRestEvent and returns a new output TRestEvent. The input and output events are in concrete type inherted from TRestEvent.

TRestEventProcess can also output analysis result to a tree. This kind of analysis result is called "observable". For example, TRestRawSignalAnalysisProcess will add a branch in the output tree called "BaseLineSigmaMean". This observable is the value of average baseline RMS of the input TRestRawSignalEvent. By switching on/off the observable in the config file, user can change the output of this process. Observbles can only be double type, and the user must call the method TRestAnalysisTree::SetObservableValue() during the process.

A special kind of TRestEventProcess is called ExternalProcess. They usually open a/several raw data files (e.g. binary signal readout file) and directly generate output event. Their input event is null and they cannot save any observables in the tree.

REST uses chained process to do anslysis. For exapmle, In a practical detection run we get the raw readout waveform. The data file is first converted into type TRestRawSignalEvent by some processes. Then we go forward with the envolution of event type. The defined process TRestSignalZeroSuppresionProcess converts the type TRestRawSignalEvent into TRestSignalEvent type (cutting out the baseline and extracting the pulse). We redord the observables(baseline level, rms, etc) during the process. To go further we also have TRestSignalToHitProcess, which maps the channel id with their physical location according to an external readout file. The signal will be convered into 3D hit points. Finally we are able to draw a hit map or an energy spectrum with spacial cut.



In this way, an event is conducted and analized by a chain of processes. It is conducted with the changing representation of TRestEvent. During the process, we extract its information, mix our definition, and change its representation into the very processed type. We could finally get a close reconstruction to the event's physical truth.

TRestProcessRunner : running analysis in an efficient way

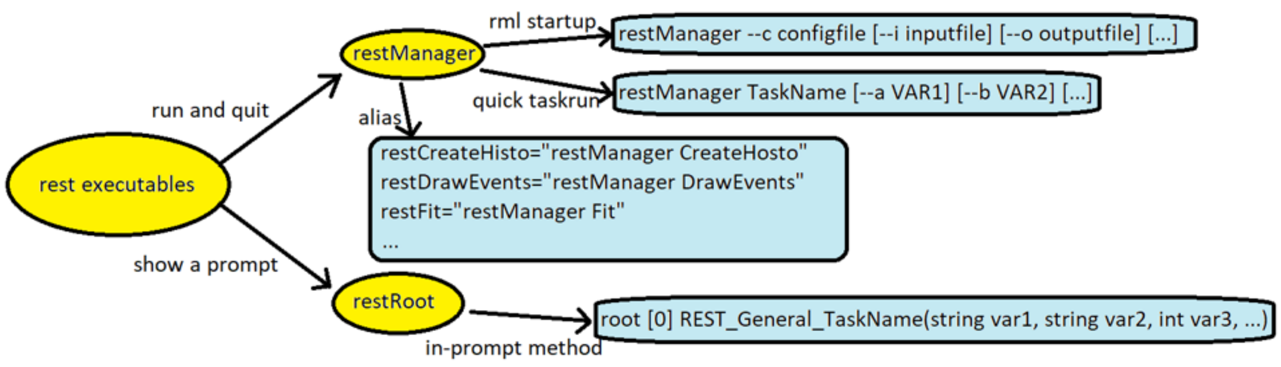
All TRestEventProcess objects are managed by TRestProcessRunner, which enables multi-threading, chain validation, output handling, etc. This application class makes several copies of the process chain and keeps each of them in a thread. Any number of threads are supported with siginificant improvement of process efficiency. During the event process, the thread first asks TRestProcessRunner for an input event, which in term asks its sibling TRestRun object for the next event from input file. After processing, the thread will ask TRestProcessRunner to make a save for its output event. The runner copies the thread's tree's branch address to its own tree, and call TTree::Fill() afterwards. However, REST deals with data files with usually very large size, so heavy IO stress are exerted on disk. As a result, too much threads will not be helpful to the higher efficiency.

TRestProcessRunner is able to save a snapshot of the values of the class members for each managed TRestEventProcess objects in a corresponding branch. This is regarded as an alternative of saving observables as analysis result. The user can switch off the saving by using an annotation like `//!` at the end of the class member definition. This saving supports not only double type, but also int, vector, map, etc., which makes the analysis more flexible.

We also implemented a test run functionality in the runner. It tries to give an input event to the process chain and receives the output event. It will then know the memory address of the output event and therefor be able to config the output tree. In old times we must instantiate a TRestEvent object for the output of an event process, and copy the data from input event(if the process dosen't change the event type). Now we can simply copy the address of the input event and directly operate it. This will also improve the efficiency and simplify the code.

Using REST

REST in all provides two main executables, several ROOT scripts, several alias calling the scripts, plus a shell script containing REST system infomation.


rest executables
run and quit
show a prompt
restManager
rml startup
restManager --c configfile [--i inputfile] [--o outputfile] [...]
quick taskrun
restManager TaskName [--a VAR1] [--b VAR2] [...]
alias
restCreateHisto="restManager CreateHosto"
restDrawEvents="restManager DrawEvents"
restFit="restManager Fit"
...
restRoot
in-prompt method
root [0] REST_General_TaskName(string var1, string var2, int var3, ...)

`restManager` is the main program of REST. It runs with the first argument specifying the rml config file or ROOT script name. And with the following arguments giving some parameters. In rml config mode, the usage is like:

`restManager --c CONFIG_FILE [--i INPUT_FILE] [--o OUTPUT_FILE] [--j THREADS] [--e EVENTS_TO_PROCESS] [--v VERBOSELEVEL]`.

Here we must give the rml config file to the program. Other arguments with squared brackets are optional. If given, they will overwrite the corresponding parameters in rml config file. "restManager" calls TRestManager object to parse rml config file and handle the objects and tasks defined in the xml section.

In scripts executing mode, the usage is: `restManager TASK_NAME ARG1 ARG2 ARG3`. User just needs to specify the script name and REST will automatically find and run it from the "macro" directory in installation path. Alias are set together with those ROOT scripts. The commands `restXXX` is actually an alias of the command "restManager XXX", which also executes a script. The usage is like:

`restViewEvents abc.root TRestRawSignalEvent` or `restManager ViewEvents abc.root TRestRawSignalEvent`

Several pre-defined ROOT scripts are already installed there. We have a list of them in the appendix. The arguments are auto detected from the definition of the C++ function in script. REST also provides a default help message for the function is wrong number of input argumets are given.

The program "restManager" runs once and quits after finish. On the other hand, `restRoot` will not quit but provide a prompt after finish. "restRoot" is identically ROOT with additional REST libraries and ROOT scripts loaded. As a result, it can not only operate REST objects or data trees saved in TFile, but also run the methods in pre-defined ROOT scripts like "REST_Printer_SignalEvent()". For example, in prompt, calling `TASK_NAME(ARG1,ARG2,ARG3)` will be equal to the previous call: `restManager TASK_NAME ARG1 ARG2 ARG3`.

Finally we have a shell script `rest-config`. It provides some basic infomation of REST, including installation date/directories, branch, commit id, compilation flags, etc.

Running with a ROOT script

Pre-defined ROOT scripts are also called REST macros. They can be found in ./macros directory. In a ROOT script we define a C++ function. The function can be used at both bash, ROOT prompt, and rml file. We have an application "TRestTask" which can be instantiated from that script. TRestTask first calls gInterpreter to load the file, and then forms a ROOT command calling the function in file.

TRestTask provides basic functionalities of helping message and rml parsing for traditional ROOT scripts. If that's not enough, we can define TRestTask-inherted class ourselves inside the scripts, and override the helping or rml parsing methods in it.

When using `restRoot`, the program will load all the ROOT scripts and user can get access to all the defined C++ function in prompt. When using `restManager`, without rml file, REST will try to instantiate a TRestTask class either from REST library(if this TRestTask-inherted class is defined manually) or by loading the file. If it is with rml file, The instantiated TRestTask object will also perform an rml parsing afterwards. This makes different callings resulting the same, as they both referrs to a same ROOT script. It also saves a lot of time for developer adapting these different usage.

For example, we can write a ROOT script named "REST_ViewEvents.hh" in the directory ./macros. Inside the script we define a C++ function "REST_Viewer_GenericEvents()" and a class "REST_ViewEvents". When we use the line `<addTask type="ViewEvents" filename="abc.root" value="ON"/>` in an rml file, TRestManager will try to instantiate a TRestTask-inherted class with class name "REST_ViewEvents". The class will set its datamember "filename" to the value "abc.root", and then do the task of showing an event. It calls the defined function "REST_Viewer_GenericEvents()" in file, giving the argument of the input file name. This is equivelent to the call `REST_Viewer_GenericEvents("abc.root")` inside restRoot prompt, and the call `restManager ViewEvents abc.root` at bash.

Rml introduction

Though encoded in standard xml format, all REST config files use .rml extension to identify themselves. rml file makes a clear hierarchy of C++ objects used during analysis. This kind of configuration file not only tells the newcomer the job it is carrying, but also gives him a good view of the entire REST framework.

Firstly, the user needs to study a little xml stuff. We start with a template rml file.

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<A_ROOT_SECTION>
  <ClassName name="userGivenName" title="User given title" >
    <parameter name="parName" value="parVal" />       <SomeCommand field1="value1" field2="value2"/>
    <ContainedClassName field1="value1" field2="value2" ... >
      <SomeCommand field1="value1" field2="value2" />
      comments or words
    </ContainedClassName>
  </ClassName>
  <AnotherClass ...>
    ...
  </AnotherClass>
  <SomeCommand field1="value1" field2="value2"/>
</A_ROOT_SECTION>
```

The first line is universal, telling the text viewer this file is xml encoded. Then here comes a **section**. An xml section is a sealed text structure starting with `<decalre` and ending with `</decalre>` or `/>`. Sections in an xml file usually have multiple nesting relationship. Here as the indentation suggests, we have a root section decalred "A_ROOT_SECTION". It has three child sections "ClassName", "AnotherClass", "SomeCommand". In tinyxml xml sections are also called **element**, and the declaration are also called "value". In old version xml sections are also called **KeyDefinition** or **KeyStructure**.

Xml sections can also have some **field values** (also called xml **attributes**), like in the template `field1="value1"` or `name="userGivenName"`. In REST these attributes can also be written in a child section declared with **parameter**. In the template if we add an attribute `parName="parVal"` in the thrid line, this is equivalent to the forth line: `<parameter name="parName" value="parVal" />`.

The symbol `<`, `>`, `&`, `"` shall appear in the main text of xml encoded file. Use escape string `&lt;`, `&gt;`, `&amp;`, `&quot;` respectively.

In REST, the section decalration `include`, `for`, `variable` and `myParameter` and the symbols `{`, `}`, `[`, `]` are reserved for the software. They will be preprocessed by the software before the method "InitFromConfigFile()" in matadata classes.

variable and myParameter

The xml sections "variable" and "myParameter" are for the keyword replacement. They are defined with a line like: `<variable name="PITCH" value="3" overwrite="false" />`. xml sections with same or lower hierarchy than this definition section will have its attributes replaced. If this definition section is in the "globals" section, then all xml sections in the file can see it.

To replace "variables", we must mark the corresponding keyword, while to replace "myParameter" we need not. Both the following symbols can mark the keyword: `{}`, `[]` an `${}`. For example, we add a line after the previous "variable" definition: `<myParameter name="pitch" value="{PITCH}" />`. This marks out the keyword "PITCH" and it will be replaced by the word "3". Now we defined a "myParameter" with name "pitch" and value "3". Then we add another line: `<addPixel id="0" origin="(pitch,pitch/4+pitch)" size="(20,20)" rotation="45" />`. In this line all the apperrance of "pitch" will be replced by the word "3". The expression will be executed.

REST works together with system environmental variable. By switching true or false for the "overwrite" attribute, a variable definition will use the text defined vale or the system environmental variable. By marking the keyword with `$ENV{}` REST will search for system environmental variable to replace it.

include definition

It is possible to link to other rml files in any section. The included file must also be xml encoded. REST will open the file and searches for the section with the same declaration(or type attribute) and name attribute as the current section. If found, the external section will be expanded into the current section. Variable in that file will be imported together.

There are two ways to make a include definition. One can either specify the external file in the element attribute:
`<addProcess type="TRestRawSignalAnalysisProcess" name="sAna" value="ON" file="processes.rml"/>`
or in the element's child:
`<addProcess type="TRestRawSignalAnalysisProcess" name="sAna" value="ON">`
`&emsp;<include file = "processes.rml" />`
`</addProcess>`

These two include definitions will order REST to find a section in the file process.rml declared as "addProcess" or "TRestRawSignalAnalysisProcess" and named with "sAna". The section can both be a root element or a child element of root element(cannot be grand-child element). If found, REST will expand its attributes and child elements to the element "addProcess".

for loop expansion

The definition of FOR loop is implemented in RML in order to allow extense definitions, where many elements may need to be added to an existing array in our metadata structure. The use of FOR loops allows to introduce more versatil and extense definitions. Its implementation was fundamentally triggered by its use in the construction of complex, multi-channel generic readouts by TRestReadout.

The for loop definition is as follows, where *pitch* and *nChannels* are previously defined myParameters, and *nCh* and *nPix* are the *for* loop iteration variables.

```
<for variable = "nCh" from = "0" to = "nChannels-2" step = "1" >
  <readoutChannel id = "{nCh}" >
    <for variable = "nPix" from = "0" to = "nChannels-1" step = "1" >
      <addPixel id = "{nPix}" origin = "((1+{nCh})*pitch,pitch/4+{nPix}*pitch)" size = "(pixelSize,pixelSize)" rotation = "45" />
    </for>
    <addPixel id = "nChannels" origin = "({nCh}*pitch,pitch/4+(nChannels-1)*pitch+pitch/2)" size = "(pitch+pitch/2,pitch/2)" rotation = "0" />
  </readoutChannel>
</for>
```

REST will recongize the fields "variable", "from", "to", "step" in the header of the for loop definition. The variable "nCh", definded at the header of the for loop definition, will be updated in each loop and be used to replace values of the loop content. During the loop, REST will add the new content element at the front of the for loop element(add a new sibling). After the loop, REST will delete the for loop element, leaving purely the loop content.

an example

We used generateReadoutFile.rml in the ./example directory to generate a readout file. We now open it and see what it did.

```
... <TRestManager ...>
  <globals>...</globals>
  <TRestRun>...</TRestRun>
  <addTask .../>
  <addTask .../>
</TRestManager>
```

The root section is declared "TRestManager". It contains a scetion declared "globals", a scetion declared "TRestRun" and two sections declared "addTask". This section has a corresponding class in REST with same class name.

In the "TRestManager" section, obviously, the "globals" section are providing some global setting for others. The "TRestRun" section has also a corresponding class in REST. This class mainly deals with file IO and data transmission. So we are adding TRestRun class inside TRestManager class. Lets see what's in it.

```
<TRestRun ...>
  <TRestReadout ...>
    <readoutModule .../>
    <readoutPlane ...>
      <addReadoutModule .../>
      <addReadoutModule .../>
      <addReadoutModule .../>
      ...
    </readoutPlane ...>
  </TRestReadout>
</TRestRun>
```

Its easy guess that we are adding a TRestReadout class inside TRestRun class. This class is what contains real readout definition. Inside its section, there are several operations. First we define a readout module, which in our experiment is the MicroMegas. And then we define a readoutplane, adding several of this kind of readout module in it, giving their physical position and some other infomation. All together they form an one-plane readout system. This TRestReadout class is now saved inside TRestRun class.

Previous work is done within the initialization of these classes. Now these classes are ready and we need to tell REST what to do. So finally, in "addTask" section, we give the command readoutrun->FormOutputFile(). and readoutrun->CloseFile(). Here "readoutrun" is the name(not class name) of the previously defind TRestRun class. Obviously here we are telling REST to "save file and close". The two lines of command are actually a method in the class TRestRun which TRestManager will invoke.

Writing an rml

Here we will talk about the detailed options of rml config file when using REST. We usually have a "TRestRun" section, a "TRestProcessRunner" section, a "globals" section and some "addTask" section under the root section "TRestManager" in an rml file to be loaded by `restManager`. "TRestRun" section and "TRestProcessRunner" section corresponds to the two REST application objects managed by TRestManager. They cooperate with each other.

name, title and verbose level

TNamed class introduces name and title as datamembers for the objects of its inherted class. In addition, TRestMetadata introduces verbose level option. We need to set all three of them as basic information for any TRestMetadata inherted class objects. Use xml attributes or child sections "parameter" to set them. For example:

```
<TRestProcessRunner name="TemplateEventProcess" verboseLevel="info">   <parameter name="title" value="A Template of REST Analysis" />
  ...  </TRestProcessRunner>
```

There are five verbose levels one can choose, and the parameter "verboseLevel" can either be a number value or a string value.

level	number	string	Description
REST_Silent	0	silent	show minimized information of the software, as well as error messages
REST_Essential	1	essential	+show some essential information, as well as warnings
REST_Info	2	info	+show most of the infomation
REST_Debug	3	debug	+show the debug messages, pause at each processes to show the details
REST_Extreme	4	extreme	show everything

The default verbose level for a TRestMetadata inherted class is silent/info before/after loading the rml file(calling the method "LoadConfigFromFile()").

setting run information

Physically, a "run" is a continuous data taking during which all the detector's configuration maintains a constant. We can set run information in "TRestRun" section and they can be saved in output file.

Below is a list of run info datamember in the class TRestRun. They can be set with a line like: `<parameter name="experiment" value="PandaX-III"/>` under the section "TRestRun".

item	type	rml parameter name	Description
fRunNumber	int	runNumber	first identificative number
fParentRunNumber	int	~~~~	~~~~
fRunClassName	TString	~~~~	~~~~
fRunType	TString	runType	Stores bit by bit the type of run. e.g. calibration, background, pedestal, simulation, datataking
fRunUser	TString	user	To identify the author it has created the run. It might be also a word describing the origin of the run (I.e. REST_Prototype, T-REX, etc)
fRunTag	TString	runTag	A tag to be written to the output file
fRunDescription	TString	runDescription	A word or sentence describing the run (I.e. Fe55 calibration, cosmics, etc)
fExperimentName	TString	experiment	The experiment name

adding metadata

REST metadata objects is managed by TRestRun. They provides, for example, gas definition or readout definition to the processes to use. So inside the "TRestRun" section we need to add metadata. It is possible to either import them from a ROOT file or to generate new.

To import them from file we need to use a line like:
`<TRestRun ...>`
  `<addMetadata name="PandaReadout_MxM" file="readouts.root"/>` ,
`</TRestRun ...>`
where we input the name of the matadata object and the name of the file. This is a recommended way to add metadata as it is faster. One can spend some time generate definition files for the detector, then other users need not to do it again.

To generate a new instance, we need to add a full definition of the class. The section declaration must be the metadata class name. The content of the section should follow the rule of the class. For example:

```
<TRestRun ...>
  <TRestReadout ...>
    <readoutModule .../>
    <readoutPlane ...>
      <addReadoutModule .../>
      <addReadoutModule .../>
      <addReadoutModule .../>
      ...
    </readoutPlane ...>
  </TRestReadout>
</TRestRun>
```

adding process and its observables

Now we are going to add processes and define the needed output observables. In the section "TRestProcessRunner" we add sections like `<addProcess type="TRestRawSignalAnalysisProcess" name="sAna" value="ON" file="processes.rml"/>` . We have to specify the type and name. In addition, we can use the option "value" to switch on/off the process in the analysis chain.

To add observables or to set parameters, we need to write lines like: `<observable name="FirstX" value="ON" />` or `<parameter name="resolutionReference" value="1.0" />` inside the "addProcess" section (as a child section of it). In case there are too many observables and parameter to define, which may cause a mess in the rml file, we can use an include definition here. REST already defines some useful observable/parameter sets for its process. For example for TRestSmearingProcess we have two parameter sets defined in the file "processes.rml", their names are "smear_1FWHM" and "smear_3FWHM" respectively. Use an attribute like: `file="processes.rml` to include and expand this rml file. To change the parameter set just change the "name" attribute.

input file and external process

The input file must be given to TRestRun to run an analysis. If the input file has .root extension, then it will be regarded as REST data file and will be directly opened. If not, we must have an external process in TRestRun to extract events from it. The "addProcess" section for external file processes can both be in section "TRestRun" and section "TRestProcessRunner". There can only be one external process added, and it is running under single threaded mode.

changing saved branches

Some parameters in section "TRestProcessRunner" changes the branches to save in the two output trees. They are:
`<parameter name="inputAnalysis" value="on"/>`
`<parameter name="inputEvent" value="on"/>`
`<parameter name="outputEvent" value="on"/>`

Output analysis is saved in whatever settings. If the user turns on "outputEvent", then the output event will be saved. It is by default on. If the user turns on "inputEvent", then "outputEvent" will be automatically turned on. All the events with different types will be saved. If the user turns on "inputAnalysis", then when the input file is a root file, tree observables in it will be copied to the output file.

Events may have overlaps. For example, the output events of two processes are of the same type when a process is a pure anslysis process. In this situation, only the later one will be saved.

By default all these three settings are on in REST. If the user wants to save some disk space, he can choose to save analysis items only(turn off events). Or if he only wants a view of the last processed event, he can choose to save output event only.

changing event region

Three parameters in section "TRestProcessRunner" changes the region of events to process. They are: "firstEntry", "lastEntry" and "eventsToProcess". If they are all zero, then the input file will have its all events processed. If the parameter "eventsToProcess" is non-zero, then the process will be stopped after it reaches the number. The parameter "firstEntry" and "lastEntry" is only effective when the input file is a REST data file. They determines the entry region in the tree to extract events to process. "lastEntry" will be overwritten by a non-zero "eventsToProcess".

REST counts processed events number by the number of saved events. If there is a cut in some process and the event is not saved, we need to read more events than the given number. If there is many threads working together, the actual saved event number will be silghtly bigger than required.

search path for definition files

Usually we put include rml files and pre-defined root files in a same directory as the main rml file. This makes it simple to specify the file name. On the other hand, when the target file is in a remote directory and we don't want to input a long absolute path in rml, we can add additional paths for REST to find files. The following is an example:
`<globals>`
  `<parameter name="addonFilePath" value="$ENV{REST_PATH}/inputData/definitions/:$ENV{REST_PATH}/inputData/gasFiles/"/>`
`</globals>`

Putting the parameter in "globals" section will make it visible for all the sections in rml. The value is in linux env style with ":" separating multiple paths. User can also set the env "myREST_addonFilePath" in his .bashrc, and directly use $ENV{myREST_addonFilePath} as value.

The directry "inputData" is where REST saves its universal reference files. For example here in the directoty "definitions" REST saves many pre-defined rml files for readout, processes and gases. The detailed organization of the directory "inputdata" can be found in the appendix. REST pre-definition data

output file: naming and saving

REST also enables auto-naming of the output file. By using square brackets in the "outputFile" parameter in TRestRun section, the user can have REST trying to replace the strings. For example, we can have a the parameter written like:

`<parameter name="outputFile" value="RUN[RunNumber]_[Time]_[LastProcess].root" />`

The replace work is done as follows:

1. replace with system environmental variable(done in rml parsing step)
2. replace with the file info
3. replace with the process info
4. replace with the run info

There are some public keywords for replacement in REST:

source	item	Description
file info	Time	The last write time of the input file
file info	Date	The last write date of the input file
file info	Size	The size of input file
file info	Entries	The total entries of input file (if is REST data file, otherwise = 2e9)
process info	FirstProcess	The name of first event process
process info	LastProcess	The name of last event process
process info	ProcNumber	The number of processes
run info	see the table above	~~~~

In future we may add more keywords. The user can also add his own file info keywords from the input file name. What he needs is to add another parameter line like:
`<parameter name="inputFormat" value="run[RunNumber]_cobo[CoBoId]_[Fragment].graw"/>`
Therefore REST will match the input file name with the given format. For example, when file name is: "run00042_cobo1_0000.graw", then item "RunNumber" with value "00042", item "CoBoId" with value "1", and item "Fragment" with value "0000" will be added into file info.

Let's assume that the graw file is created in 2018-01-30 16:30, and the last event process is a TRestRawSignalAnalysisProcess with a name "sAna", then the output file name will be: "RUN00042_16:42_sAna.root".

Another parameter "mainDataPath" defines the path of saving output file. By default REST saves the output file at current directory. When "mainDataPath" is specified, the output file is saved in this directory. We can set it in "globals" section. For example:

```
<globals>
  <parameter name="mainDataPath" value="../" />
</globals>
```

then all the output file will be saved in the parent directory.

the "addTask" command

Don't forget to add an "addTask" section after all the sections are completed. We invoke the method RunProcess() in TRestProcessRunner to run the analysis. Here we need a line in "TRestManager" section like:
`<addTask command="TemplateEventProcess->RunProcess()" value="ON"/>`.
Here "TemplateEventProcess" is the name of the TRestProcessRunner object defined previously.

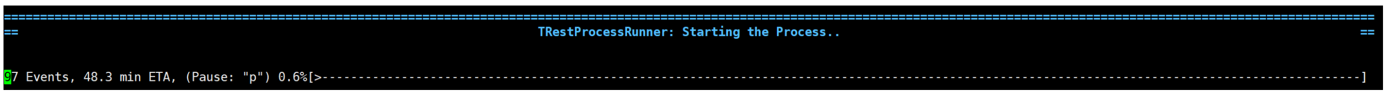
It is also possible to directly use a line:
`<addTask type="processEvents" value="ON" />`.
This asks TRestManager to directly call start of TRestProcessRunner object.

During processing

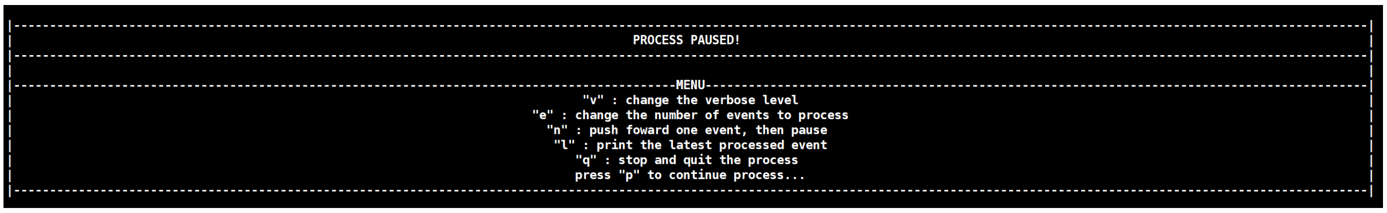
When we have prepared the rml file, we can start the process! The command is like following:

```
restManager --c multiCoboAnalysis.rml --i /data2/7MM/graw/CoBo_AsAd0_2017-12-23T17\:24\:04.657_0000.graw --o abc.root
```

REST provides a progress bar and a pause menu during the process. Pressing "p" and then "enter" will pause the process and a pause menu will be shown. Functionalities like changing verbose level, printing current event or exiting with saving, etc. is provided in the menu. As shown in the following figures.



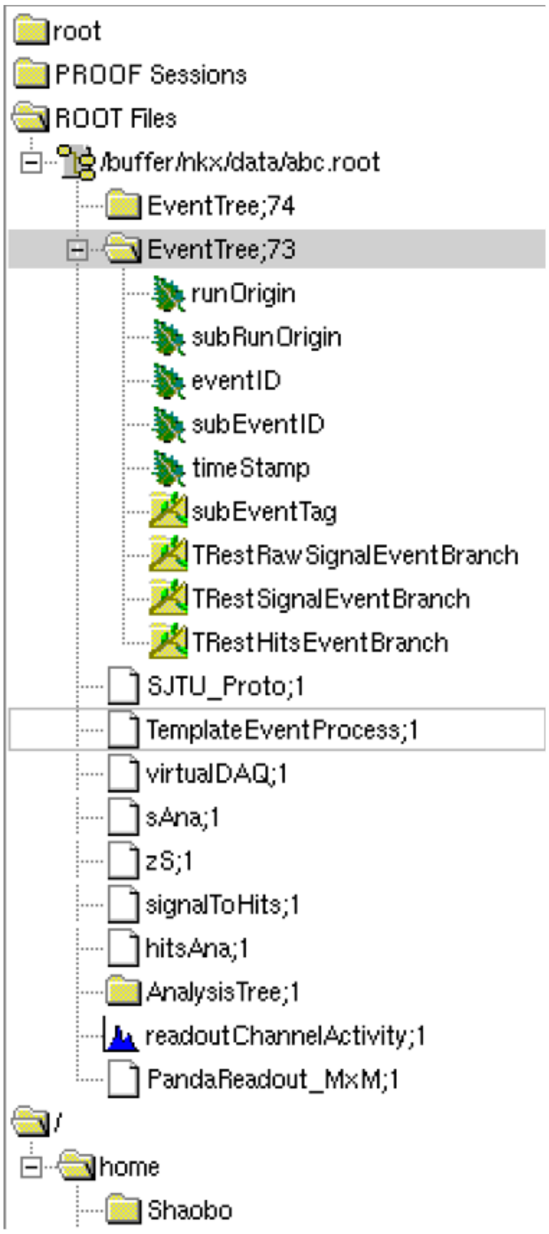
```
================================================================================================================================================
==                                                TRestProcessRunner: Starting the Process..                                                  ==

g7 Events, 48.3 min ETA, (Pause: "p") 0.6%[>------------------------------------------------------------------------------------------------------]
```

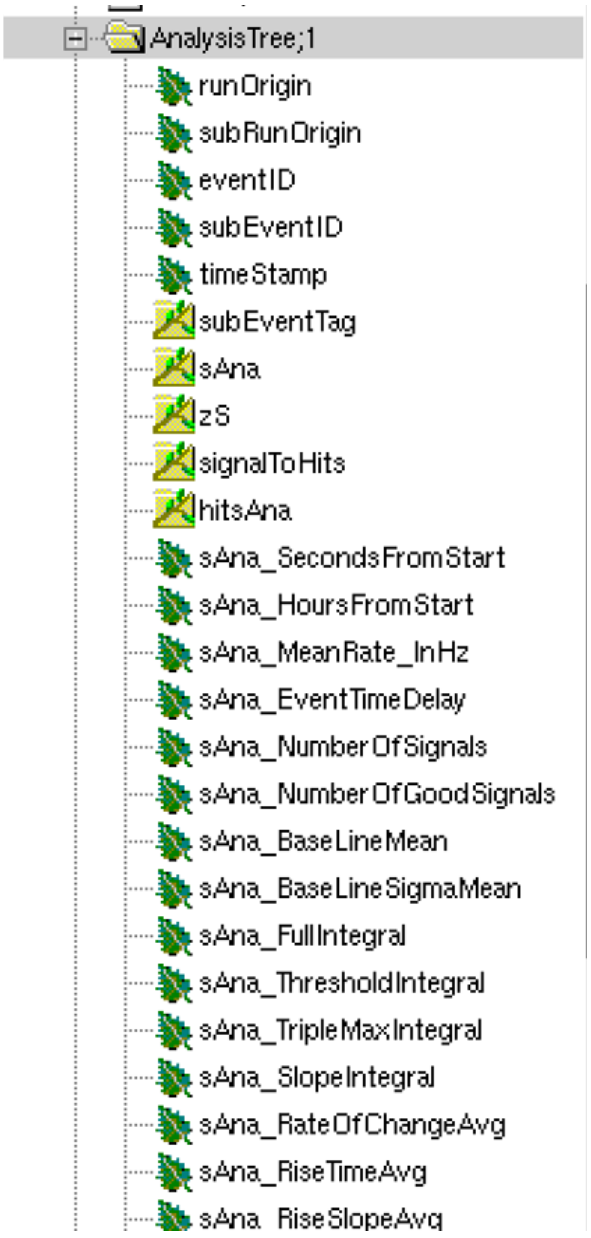


```
|----------------------------------------------------------------------------------------------------------------------------------------------|
|                                                          PROCESS PAUSED!                                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                              |
|-----------------------------------------------------------------------MENU-------------------------------------------------------------------|
|                                                    "v" : change the verbose level                                                            |
|                                               "e" : change the number of events to process                                                   |
|                                                "n" : push foward one event, then pause                                                       |
|                                                 "l" : print the latest processed event                                                       |
|                                                    "q" : stop and quit the process                                                           |
|                                                    press "p" to continue process...                                                          |
|----------------------------------------------------------------------------------------------------------------------------------------------|
```

REST data format

REST saves an event tree, an analysis tree, some metadata or application objects, and some ROOT analysis objects in a same output file of the analysis run, as shown in the figure.





The trees are of the type TRestAnalysisTree, which is typically a ROOT tree plus a list of observables. Inside these trees there are six branches saving some basic information of the event, including run ID, event ID, event time, event tag, etc.

For the event tree, we also save the output event of each process in sequence. The event branches are C++ object branches with a same structure as the class definition. Here in the figure we can see three event branches are saved: A TRestRawSignalEventBranch, a TRestSignalEventBranch, and TRestHitsEventBranch.

For the analysis tree, we also save the observables as well as a snapshot of each processes. In the figure there are four process branches called "sAna", "zS", "signalToHits" and "hitsAna". If we open them, we can see some leaves inside corresponding to the processes' class member. Analysis tree is separated from the event tree for the convenience of drawing. Usually event tree contains large amount of data and makes it slow to draw some thing, which needs to go through all the entries of the tree.

Several metadata and application objects are also saved in file. They are used for recovering the setup of that analysis run. For example, REST can read the saved TRestRawSignalAnalysis object (here named "sAna") and get the parameters used at that time. For metadata objects, REST can directly use them again in the next run.

In addition, REST allows processes to save some ROOT analysis objects in the file. Here the TH1D "readoutChannelActivity" is saved by the process "sAna" (of type TRestRawSignalAnalysisProcess). We can directly draw it.

Browsing and viewing events

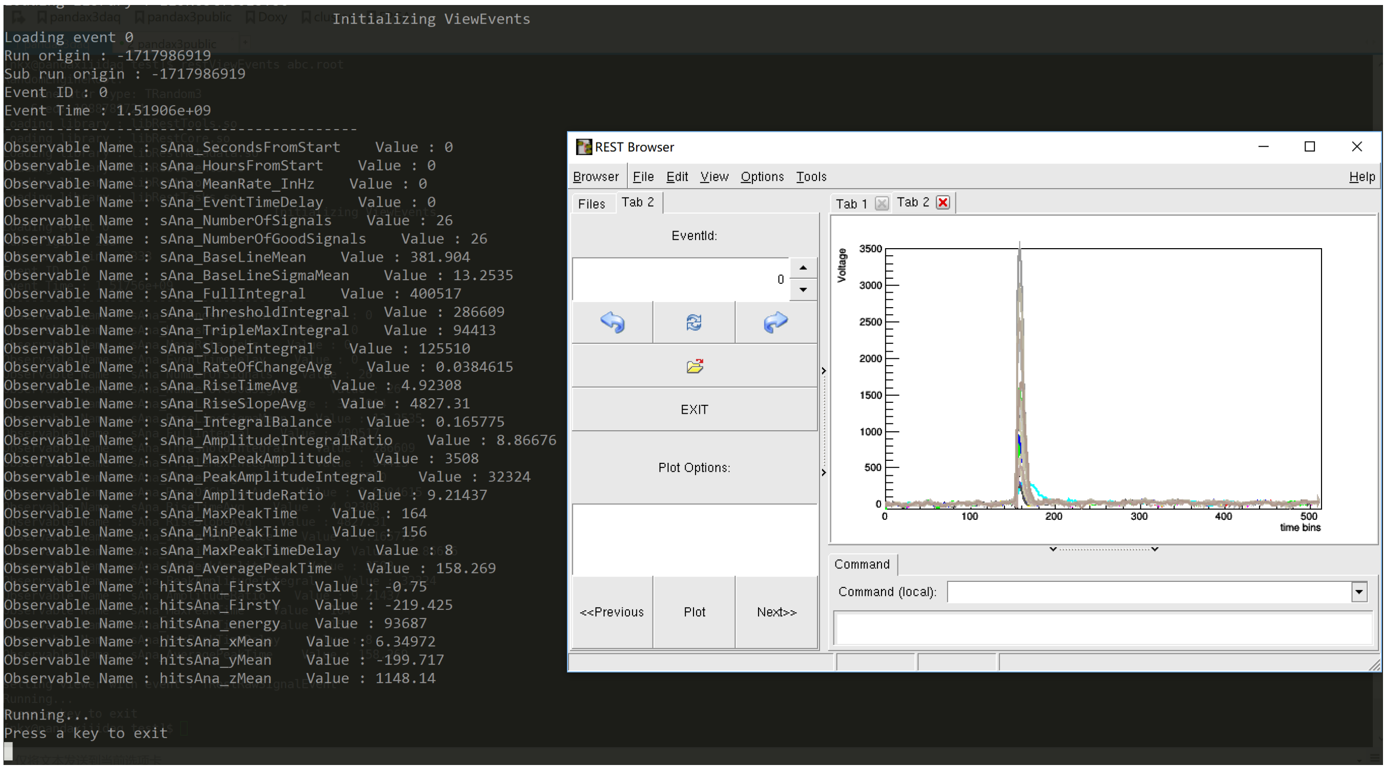
Events in REST data files are managed by TRestRun, whose graphical interface, in turn, is shown by by TRestBrowser. This class shows a TBrowser window during initialization. In the window there is a canvas showing the current event, and a control panel to switch between events.

In restRoot prompt, by using TRestBrowser, one can easily get accsess to the file's events, and don't need to manually instantiate a TRestEvent object and set the tree's branch address. He just needs to type:
`restRoot abc.root`
`TRestBrowser a`

`TRestxxxEvent*eve=(TRestxxxEvent*)a.GetInputEvent()` ,
and will be free to operate this event.

By default TRestBrowser extracts the last event in file, and draws it in the canvas by using the viewer class TRestGenericEventViewer. This viewer just calls the default method TRestEvent::Draw(). Other viewers like TRestHitsEventViewer or TRestG4EventViewer are also available. Some pre-defined ROOT scripts can be used to draw these events in differently. The commands like: "restViewEvents abc.root", "restManager ViewHitsEvents hits.root", "REST_Viewer_LinearTrackEvent("track.root")" and "restManager --c Viewabc.rml" shall all work.

Here for example, we use the generated file in example, and call the command `restViewEvents abc.root` . The last event is TRestRawSignalEvent type in this file, and a TRestBrowser window will show up with some observable values on prompt.



```
                                         Initializing ViewEvents
Loading event 0
Run origin : -1717986919
Sub run origin : -1717986919
Event ID : 0
Event Time : 1.51906e+09
-----------------------------------------
Observable Name : sAna_SecondsFromStart    Value : 0
Observable Name : sAna_HoursFromStart    Value : 0
Observable Name : sAna_MeanRate_InHz    Value : 0
Observable Name : sAna_EventTimeDelay    Value : 0
Observable Name : sAna_NumberOfSignals    Value : 26
Observable Name : sAna_NumberOfGoodSignals    Value : 26
Observable Name : sAna_BaseLineMean    Value : 381.904
Observable Name : sAna_BaseLineSigmaMean    Value : 13.2535
Observable Name : sAna_FullIntegral    Value : 400517
Observable Name : sAna_ThresholdIntegral    Value : 286609
Observable Name : sAna_TripleMaxIntegral    Value : 94413
Observable Name : sAna_SlopeIntegral    Value : 125510
Observable Name : sAna_RateOfChangeAvg    Value : 0.0384615
Observable Name : sAna_RiseTimeAvg    Value : 4.92308
Observable Name : sAna_RiseSlopeAvg    Value : 4827.31
Observable Name : sAna_IntegralBalance    Value : 0.165775
Observable Name : sAna_AmplitudeIntegralRatio    Value : 8.86676
Observable Name : sAna_MaxPeakAmplitude    Value : 3508
Observable Name : sAna_PeakAmplitudeIntegral    Value : 32324
Observable Name : sAna_AmplitudeRatio    Value : 9.21437
Observable Name : sAna_MaxPeakTime    Value : 164
Observable Name : sAna_MinPeakTime    Value : 156
Observable Name : sAna_MaxPeakTimeDelay    Value : 8
Observable Name : sAna_AveragePeakTime    Value : 158.269
Observable Name : hitsAna_FirstX    Value : -0.75
Observable Name : hitsAna_FirstY    Value : -219.425
Observable Name : hitsAna_energy    Value : 93687
Observable Name : hitsAna_xMean    Value : 6.34972
Observable Name : hitsAna_yMean    Value : -199.717
Observable Name : hitsAna_zMean    Value : 1148.14

Running...
Press a key to exit
```

In the right side it shows a combined plot of the event, which consists from many individual signals. In the left side we have a control panel which helps to switch next/previous/specific event/signal and open a new file. Different event viewers will define different interfaces of the control panel and the plot window.

Some viewer processes are also available in REST. The user can have a view of the events during the process. All the viewer processes are single thread only, and TRestProcessRunner will automatically roll back to single thread mode with a viewer process in process chain.

Plot the analysis result

It is also allowed to plot histograms for observables in output file. REST has an application class called TRestAnalysisPlot. It generates plot string according to an rml config file and calls the TTree::Draw() method to draw the histogram. It can also save the plots to a pdf file or ROOT file afterwards.

To use it, a "TRestAnalysisPlot" section is needed in "TRestManager" section. The template of rml config file for TRestAnalysisPlot can also be found in ./examples. It shall follow the rules below. The command calling it is like:
`restManager --c plots.rml --i abc.root --p ouput.pdf`

add input file and set plot mode

To add input files just use a section like: `<addFile name="filename.root" />` in the "TRestAnalysisPlot" section. Multiple input file is allowed. If the "addFile" section does not exist, TRestAnalysisPlot will ask the sibling TRestRun object for its output or input file as the input file.

In most cases REST saves a single output file in an analysis run. So these multiple files are from different runs, or analysis with different configurations. Usually we are interested in the difference of one observable between different runs. In this case we just set the plot mode to "compare" with section:
`<parameter name="plotMode" value="compare" />` . Then REST will plot these same-observable-from-different-file in a same figure with different color. The "compare" plot mode is also the default plot mode.

In rare cases the multiple files are from a same run with same analysis configuration, then we need to set plot mode to "add". This will make REST plot the observables into a single histogram.

define a canvas

It is needed to define a canvas for TRestAnalysisPlot. Use a section like:
`<canvas size="(1000,800)" divide="(2,2)" save="plot.pdf" />`
to define it. The canvas can be devided into several sub-canvas and each of them will contain a plot figure. It can also be saved into a file. Most of the common figure formats are supported, as REST calls TCanvas::Print() method to make the save. The list of supported file formats shall be found in ROOT website.

add a plot with cut

Now we define and add a plot in "TRestAnalysis" plot section.

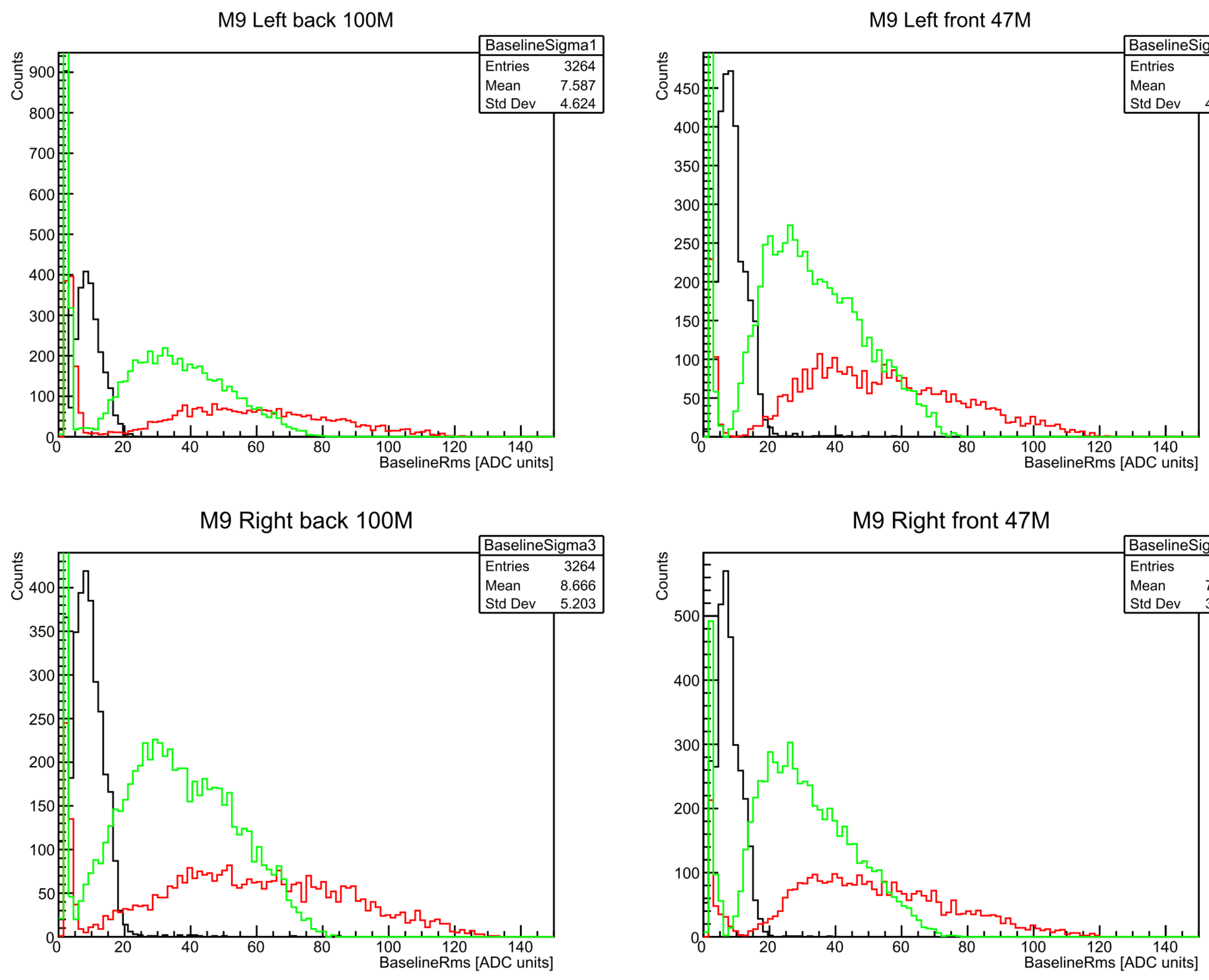
```
<plot name="Baseline" title="Baseline average" value="ON" >
  <parameter name="xlabel" value="BaselineRms [ADC units]" />
  <parameter name="ylabel" value="Counts" />
  <parameter name="logscale" value="false" />
  <parameter name="option" value="" />
  <source name="sAna_BaseLineSigmaMean" range="(0,1000)" nbins="100" />
  <cut source="sAna_NumberOfGoodSignals" condition="&gt;1" value="ON" />  </plot>
```

Here we can set xlabel, ylabel and logscale with corresponding parameters. We can also add additional options with parameter "option".

Then we add the source of the plot. Its name is "sAna_BaseLineSigmaMean", which is an observable in the analysis tree. Here we got a TH1 histogram of this observable. We can also define the region of this histogram, just as the template shows. TH2 and TH3 are also supported, by adding more lines of this kind of "source" section.

We also add cut for the plot. Here in the "plot" section we add a cut that the observable "sAna_NumberOfGoodSignals" should be greater than 1. Note that standard xml needs escape string to express the symbol `>`. Though this symbol still works out of some reason, we suggest using `&gt;` instead of `>` for a good habit.

Finally with an "addTask" section in "TRestManager" section, we can make a plot like below



Some Metadata Classes

In this section we will talk about the usage of REST metadata classes. They load useful information about the experiment setup from rml config file. How to write those files is what the user should know.

TRestGas

The TRestGas metadata members description can be found detailed in the TRestGas class documentation. Here we provide few commands to show how to generate a new gas mixture and access its basic properties, as drift velocity, electron diffusion, and typical gas coefficients.

We start by definning a standalone TRestGas section inside our RML file. Our configuration file could be something like this.

(File : argonMixture.rml)

```
<TRestGas name="Argon-Isobutane 4Pct 10-10E3V/cm" title="Argon-Isobutane Mixture (4Pct Isobutane)">
  <parameter name="pressure" value="1" />
  <parameter name="temperature" value="293.15" />
  <parameter name="maxElectronEnergy" value="400" />
  <parameter name="W_value" value="26.145" />
  <parameter name="nCollisions" value="10" />
  <eField Emin="10" Emax="1000." nodes="20" />
  <gasComponent name="ar" fraction="0.96" />
  <gasComponent name="iC4H10" fraction="0.04" />
</TRestGas>
```

The *gasDataPath* defines the path where our gas file will be generated. In this case the file will be generated at the same location where we launch our program.

We can generate the gas file by specifying the full path to our configuration file and providing the name of the gas we want to use. In this case we will assume that we are launching the commands from the same directory where *argonMixture.rml* is found. We first start *ROOT* interpreter using *restRoot* to load all the REST libraries in the ROOT environment.

```
:~$ restRoot
```

```
[0] TRestGas *gas = new TRestGas( "argonMixture.rml", "Argon-Isobutane 4Pct 10-10E3V/cm", true )
```

This should start the generation of the gas file, the calculation will be running for a few hours. When it is finished a new .gas file will have been created at *gasDataPath*. The filename format defines in a unique way the parameters used in the TRestGas section. In this way, it is used by TRestGas to determine if the gas mixture we want to use is already existing as a .gas file.

If the gas file exists TRestGas will directly load the gas file. After the previous command is finished you can verify it by closing the session and starting again.

```
[1] .q
```

```
:~$ restRoot
```

```
[0] TRestGas *gas = new TRestGas( "argonMixture.rml", "Argon-Isobutane 4Pct 10-10E3V/cm", true )
```

This time the recently generated gas file will be loaded and no long calculation will be required.

We can now access the members of TRestGas to obtain the values for the drift velocity or the tranversal electron diffusion. The following command will print on screen the drift velocity.

```
[1] cout << "The drift velocity at 100 V/cm is : " << gas->GetDriftVelocity( 100 ) << endl
```

You can also find the information of the gas you are using by calling PrintMetadata().

```
[2] gas->PrintMetadata()
```

Although one must be careful with the definition range of the electric field and the pressure, we can retrieve the gas properties at different gas conditions. This code changes the value of the pressure to 10 atm and prints the drift velocity at that pressure value.

```
[3] gas->SetPressure( 10 )
```

```
[4] cout << "The drift velocity at 100V/cm at 10 bar is : " << gas->GetDriftVelocity( 100 ) << endl
```

Finally, we can quickly visualize the dependency of different gas properties as a function of the field. The following code will plot the drift velocity at 10 bar, for a field range between 1V/cm and 1000V/cm drawing 100 extrapolated points.

```
[5] gas->PlotDriftVelocity( 1, 1000, 100 )
```

Thats it. Other gas parameters and relevant information related to TRestGas can be found in the class documentation.

TRestReadout

We will address two different examples following basic readout topologies. You will find a variety of more complex examples at REST_v2/inputData/definitions/readouts.rml. More details about readout construction are available at the documentation of TRestReadout class. The class TRestMetadata describes detailed information on how to write RML files.

Example 1. A basic pixelated readout

In this example we generate a readout with a single readout plane, and one pixelated readout module placed inside. To achieve that each channel has a unique pixel definition.

// We define some environmental variables that we can later use as ${VARIABLE}
```
<globals>
```

```
  <variable name="PIX_SIZE" value="3" overwrite="true" />
  <variable name="CHANNELS" value="8" overwrite="true" />
</globals>

<TRestReadout name="pixelReadout" title="A basic pixel readout. ${CHANNELS}x${CHANNELS} channels. Pixel size : ${PIX_SIZE} mm" >

  // These parameters are later keywords inside the section
  // and will be substituted by their value.
  <myParameter name="nChannels" value="${CHANNELS}" />
  <myParameter name="pixelSize" value="${PIX_SIZE}" />

  // Mapping nodes is the number of nodes N, in a NxN grid.
  // This grid allows for faster channel/pixel finding algorithm.

  // If the mappingNodes value is 0. The value will be automatically assigned by REST.
  <parameter name="mappingNodes" value="0" />

  // This is just the module definition.
  <readoutModule name="pixelModule" size="(nChannels*pixelSize, nChannels*pixelSize)" tolerance="1.e-4" >

    // We use for loops to generate any number of channels given by the CHANNELS variable.
    // The loop variable must be placed between [] in order to be evaluated.
    <for variable="nChX" from="0" to="nChannels-1" step="1" />
      <for variable="nChY" from="0" to="nChannels-1" step="1" />

        // The readout channel id will be used to identify the channel and associate it to a daq id
        <readoutChannel id="[nChX]*nChannels+[nChY]" >
          // In this example we define one pixel per channel.
          // But we can define any number of pixels inside a channel
          <addPixel id="0" origin="([nChX]*pixelSize, [nChY]*pixelSize)" size="(${PIX_SIZE},${PIX_SIZE})" rotation="0" />
        </readoutChannel>

      </for>
    </for>

  </readoutModule>

  // The real readout implementation is done inside the readout plane.
  // The readout plane parameters define the active volume.
  <readoutPlane position="(0,0,-990)" units="mm" planeVector="(0,0,1)" chargeCollection="1" cathodePosition="(0,0,0)" units="mm" >

    // We can add any number of modules
    // name="pixelModule" is the name defined at the "readoutModule" section.
    // We define the module position inside the readout plane
    <addReadoutModule id="0" name="pixelModule"origin="(-nChannels*pixelSize/2,-nChannels*pixelSize/2)" rotation="0" />

  </readoutPlane>

</TRestReadout>
```

By using restRoot one can manually instantiate this TRestReadout object and save it. By using restManager to directly generate the ROOT file, one needs to add these sections in TRestRun and TRestManager section, and provide an "addTask" section.

Example 2. A multilayer stripped readout

In this example we define a stripped readout using single pixels with y-dimension much longer than x-dimension. We create two readout module definitions, one for each axis, and place each readout module at a different readout planes.

```
<globals>
  <variable name="PIX_SIZE" value="3" overwrite="true" />
  <variable name="CHANNELS" value="8" overwrite="true" />
</globals>

<TRestReadout name="strippedReadout" title="A basic pixel readout. ${CHANNELS}+${CHANNELS} channels. Pitch size : ${PIX_SIZE} mm" >
  <myParameter name="nChannels" value="${CHANNELS}" />
  <myParameter name="pixelSize" value="${PIX_SIZE}" />

  // In case of errors during the readout generation you might need to
  // define this value manually in the mapping nodes parameter.
  <parameter name="mappingNodes" value="nChannels" />

  // X-strips readout module definition
  <readoutModule name="stripsX" size="(nChannels*pixelSize, nChannels*pixelSize)" tolerance="1.e-4" >
```

```
    <for variable="nChX" from="0" to="nChannels-1" step="1" />
      <readoutChannel id="[nChX]" >
        <addPixel id="0" origin="([nChX]*pixelSize, 0)" size="(${PIX_SIZE},${PIX_SIZE}*nChannels)" rotation="0" />
      </readoutChannel>
    </for>

  </readoutModule>
```

// Y-strips readout module definition

```
  <readoutModule name="stripsY" size="(nChannels*pixelSize, nChannels*pixelSize)" tolerance="1.e-4" >

    <for variable="nChY" from="0" to="nChannels-1" step="1" />
      <readoutChannel id="[nChY]" >
        <addPixel id="0" origin="(0, [nChY]*pixelSize)" size="(${PIX_SIZE}*nChannels,${PIX_SIZE})" rotation="0" />
      </readoutChannel>
    </for>

  </readoutModule>
```

// We define a first readout plane

```
  <readoutPlane position="(0,0,-990)" units="mm" planeVector="(0,0,1)" chargeCollection="1" cathodePosition="(0,0,0)" units="mm" >
```

// This readout plane includes the readout with the strips along Y-axis (X-position)

```
    <addReadoutModule id="0" name="stripsX" origin="(-nChannels*pixelSize/2,-nChannels*pixelSize/2)" rotation="0" />

  </readoutPlane>
```

// We define a second readout plane covering the same active volume.

```
  <readoutPlane position="(0,0,-990)" units="mm" planeVector="(0,0,1)" chargeCollection="1" cathodePosition="(0,0,0)" units="mm" >
```

// This readout plane includes the readout with the strips along X-axis (Y-position)

```
    <addReadoutModule id="0" name="stripsY" origin="(-nChannels*pixelSize/2,-nChannels*pixelSize/2)" rotation="0" />

  </readoutPlane>

</TRestReadout>
```

For the moment, the process TRestHitsToSignalProcess is not able to process a multilayer readout plane, and/or charge collection sharing between different readout planes, covering the same active volume. Although few changes would be needed to adapt this process.

Readout generation and storage in a ROOT file

Here we assume the previous examples are defined in a file named *readouts.rml* and this file is found at the working directory.

The following code will instantiate the TRestReadout class using the pixelated and stripped definitions, and save them to a ROOT file.

// We start a ROOT session with REST libraries and scripts loaded by using restRoot
:~$ `restRoot`

// We give the filename and the readout names as arguments for the TRestReadout constructors
[0] `TRestReadout *pixRead = new TRestReadout( "readouts.rml", "pixelReadout");`

[1] `TRestReadout *stripRead = new TRestReadout( "readouts.rml", "strippedReadout");`

// We create a new ROOT file with "RECREATE" option or open an existing file with "UPDATE" option
[2] `TFile *f = new TFile( "readouts.root", "RECREATE" );`

[3] `pixRead->Write("pixel");`

[4] `stripRead->Write("strip");`

[5] `f->Close();`

// We exit from ROOT session
[6] `.q`

After executing this code we will have a *readouts.root* file with two different readouts, named *pixel* and *strip*.

The original readout name given at the RML file has been lost. And in order to reference it in ROOT or REST we will use the names given at write time, *pixel* and *strip*.

Recovering the TRestReadout saved on a ROOT file

We can easily recover the TRestReadout as any other ROOT structure. In order to quickly look inside a REST/ROOT file we can use the executable **restPrintFileContents** to check the existing objects (readouts) inside the file.

:~$ `restPrintFileContents readouts.root`

The following code recovers the TRestReadout structure

:~$ `restRoot`

[0] `TFile *f = new TFile( "readouts.root" );`

// We get a pointer to the pixelated readout
[1] `TRestReadout *r = f->Get("pixel");`

// We print the metadata information of this readout
[2] `r->PrintMetadata();`

// And we print it again with full detail, with info about channels and pixels positions.
[3] `r->PrintMetadata(1);`

[4] `.q`

Readout visualization

The readout visualization is still far from optimal, but a couple of ways are available in order to verify the task of readout design.

In a ROOT session we can call the method TRestReadoutPlane::GetReadoutHistogram to draw the pixel boundaries.

~$ `restRoot`

[0] `TFile *f = new TFile( "readouts.root" );`

// We get a pointer to the pixelated readout
[1] `TRestReadout *r = f->Get("strip");`

// We draw first the readout plane 0. A canvas inside ROOT is automatically generated
[2] `r->GetReadoutPlane(0)->GetReadoutHistogram()->Draw();`

// We can draw the other strips readout plane on top of the existing drawing
[3] `r->GetReadoutPlane(1)->GetReadoutHistogram()->Draw("same");`

[4] `.q`

Or, we can directly use the script *REST_Viewer_Readout* to draw one of the readout planes.

~$ `restRoot`

// By default the plane with index 0 will be drawn, if not specified
[0] `REST_Viewer_Readout( "readouts.root", "strip" );`

// We can also draw the other readut plane
[1] `REST_Viewer_Readout( "readouts.root", "strip", 1 );`

Readout validation

The construction of complex readouts requires to evaluate the proper channel spatial definition. Complex readouts will be composed of channels in which several pixels are combined and overlapped. The overlap between different pixels on the same readout channel will never suppose a problem. However, different channels overlap may affect the final response of the readout channels.

In order to test the readout we can produce a random virtual hit generation, with (x,y) coordinates inside the range of the readout modules in a given readout plane. We may then activate few test channels and draw only those hits which dropped in the activated channels. The script *REST_UTILS_CheckReadout* allows to perform this task. To produce a faster result we can focus in a small area of the readout, defined by the *region* parameter. We can activate the 128 first channels with a channel *mask* definition.

The following code shows the use of this script that works for any TRestReadout class stored previously in a ROOT file.

$~ `restRoot`

// We define the 128 bits mask to enable different channels
[0] `Int_t mask[4];`

[1] `mask[0] = 0x80000100;` // Channels 8 and 31 enabled

[2] `mask[1] = 0x000000FF;` // Channels from 32 to 47 enabled

[3] `mask[2] = 0x0;` // All channels disabled [From 64 to 95]

[4] `mask[3] = 0x0;` // All channels disabled [From 96 to 127]

// We define also a reduced region of the readout where we will launch random (x,y)
[5] `Double_t region[4];`

[6] `Double_t region[0] = 0.2;` // Xmin starts at 20% of full area

[7] `Double_t region[1] = 0.8;` // Xmax ends at 80% of full area

[8] `Double_t region[2] = 0.4;` // Ymin starts at 40% of full area

[9] `Double_t region[2] = 0.9;` // Ymax ends at 90% of full area

// The last two arguments, N and pId are optional.

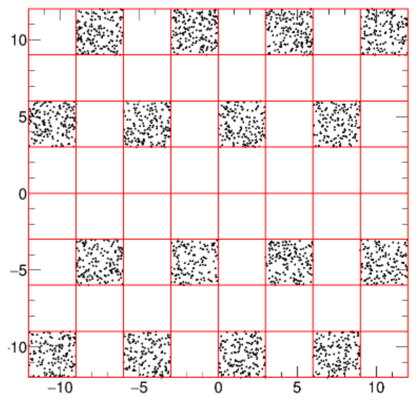
// The number of (x,y) coordinates to be generated.
Int_t N = 1E4;

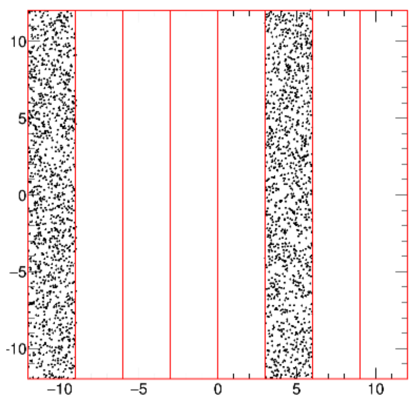
// The plane readout index to be checked
Int_t pId = 0;

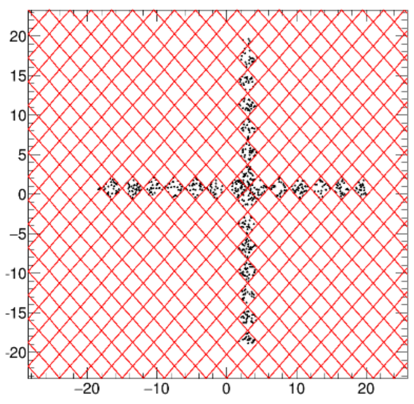
// This script will launch the generation of random (x,y) positions at the specified region,
// and it will draw only the hits on the activated channels (8, 31, 32-47).

[10] `REST_Tools_CheckReadout( "readouts.root", "pixel", region, mask, N, pId )`

These figures show the result of running the *REST_Tools_CheckReadout* script for different channels.







TRestG4Metadata

I don't know...

Base Class Interface Reference

In this section, we will talk about the interface of classes when one is going to write his own derived class from them. We will first cover some points of inherting the class TObject, which is the base class of many REST base classes. The users are welcomed to develop new classes based on them. There are three main base classes in REST, both of which are abstract class. The user needs to implement one or more methods in it.

TObject

Classes inherited from TObject can be saved in both TFiles and TTrees. If one wants to save his data in REST, it is recommended to write a data class inherited from TObject and save the class directly. Note that the name of the header file must be the same as the class defined in it. Otherwise CINT and TClass won't work for the class. For example, in file TRestHits.h, we write:

```
class TRestHits : public TObject{
public:
//some class members
//some methods
}
```

The source code will first get compiled with CINT. This compiler will generate an additional .cxx file implementing the Streamer() method. This method, provided by TObject, will help to save the class members. Both public, protected and private class members can be saved.

Sometimes it is not necessary to save all the class members in a class. Some class members may be too large, or contains temporary data. In this case we can turn them off by adding some annotations after their declaration in the header file. For example:

```
class TRestHits : public TObject{
public:
int a; //!
int b;
}
```

Then the class member “a” will not be saved when the class TRestHits gets saved in TFile/TTree.

If the class member is a pointer, we cannot save it directly. We need to either add “//->” annotation in the same line(not tested), or create and link an instance of the pointer, then save the instance, As shown in the code below.

```
1) TH1D* h; //->
2) TH1D* h; //!
TH1D _h;
//in some method before saving
_h=*h;
```

If one directly saves the pointer(adding no comments for CINT), he will get a memory leak problem when reading the saved file later on. This problem is fatal when the class is in a tree, and he is trying to loop all the entries to, e.g. draw something..

TRestEvent

class member

This is an abstract class inherted from TObject. We have some additional class members defined in it.

Type	Name	Description
Int_t	fRunOrigin;	Run ID number of the event
Int_t	fSubRunOrigin;	Sub-run ID number of the event
Int_t	fEventID;	Event identificative number. (Default: 0)
Int_t	fSubEventID;	Sub-Event identificative number. (Default: 0)
TString	fSubEventTag;	A short length label to identify the sub-Event. (Default: "")
TTimeStamp	fEventTime;	Absolute event time. (Default: 0)
Bool_t	fOk;	Flag to be used by processes to define an event status. (Default: true)

All of these class members are in hidden level "protected", which means we can directly use them in the inherted classes, while cannot access to them in the other classes. In other classes, we need to call getter and setter methods of TRestEvent. e.g. GetID(), GetSubEventTag(), SetTime(), etc.

These seven class members contains basic and universal infomation of an event. In the derived class, the user needs to add more class members to store event data. For example, in class TRestRawSignalEvent, we define a vector of TRestSignal object and store all the readout wave forms in it.

virtual methods

Initialize() is a pure virtual method in TRestEvent. So in derived classes the user **must** implement it. This method is used to reset data in the class. In the base class TRestEvent, this method resets values of: fEventID, fSubEventID, fSubEventTag, fEventTime and fOk (Note that run origin of the event won't be reset). When one is going to implement this method in derived class, he can first call TRestEvent::Initialize() and set these five universal class members, before reseting other defined class members. The followings are some example codes in TRestRawSignalEvent.

```
void TRestRawSignalEvent::Initialize(){
  TRestEvent::Initialize();
  fSignal.clear();
  fPad = NULL;
  gr = NULL;
  mg = NULL;
  fMinValue = 1E10;
  fMaxValue = -1E10;
  fMinTime = 1E10;
  fMaxTime = -1E10;
}
```

PrintEvent() is a virtual method used for printing data of the event. By default it prints only five universal class members of the event: fEventID, fSubEventID, fSubEventTag, fEventTime and fOk. To print more details, one needs to implement it in the derived class. For example, in TRestRawSignalEvent, we make a print of the value of waveforms of each signal.

DrawEvent() returns a TPad object containing the plot of the event. It is called in TRestGenericEventViewer. By default the method returns a blank pad. To enable the functionality of drawing, one needs to implement this.

useful methods and tools

The virtual method CloneTo() defines how the data in an event is cloned to another existing event. This method by default calls ROOT streamer to do cloning. It is already functional for all the derived classes. However, one can still override this default behavior in the derived class. This may improve the efficiency in some cases. Also,when we hide some class members againist ROOT streamer, by overriding this method, we can still copy them if we want them.

PrintAddress() is used for debugging. It prints the address of this event together with the address of its class members.

SetEventInfo() copies only the universal information from the input event. It is used when we want to manually transfer an event and not to use CloneTo();

TRestMetadata

This is an abstract class inherted from TNamed (TNamed is inherted from TObject). To write a TRestMetadata inherted class, there is a pure virtual method InitFromConfigFile() which everyone needs to implement. This method defines how this class loads data from rml config file. As there is too many methods in the class, we just explain roughly its usage here. For detailed class reference, check the doxygen website.

startup of TRestMetadata

The method InitFromConfigFile() needs to be called manually in the derived class or in the external class. If we want to instantiate the class object directly from a config file, we can add a constructor calling the method LoadConfigFromFile() in our class. Like:

```
TRestReadout::TRestReadout( const char *cfgFileName, string name) : TRestMetadata (cfgFileName){
  cout << "Loading readout. This might take few seconds" << endl;
  Initialize();
  LoadConfigFromFile( fConfigFileName, name );
}
```

```
int main(){
  TRestReadout*readout=new TRestReadout("readout.rml");
  ...
}
```

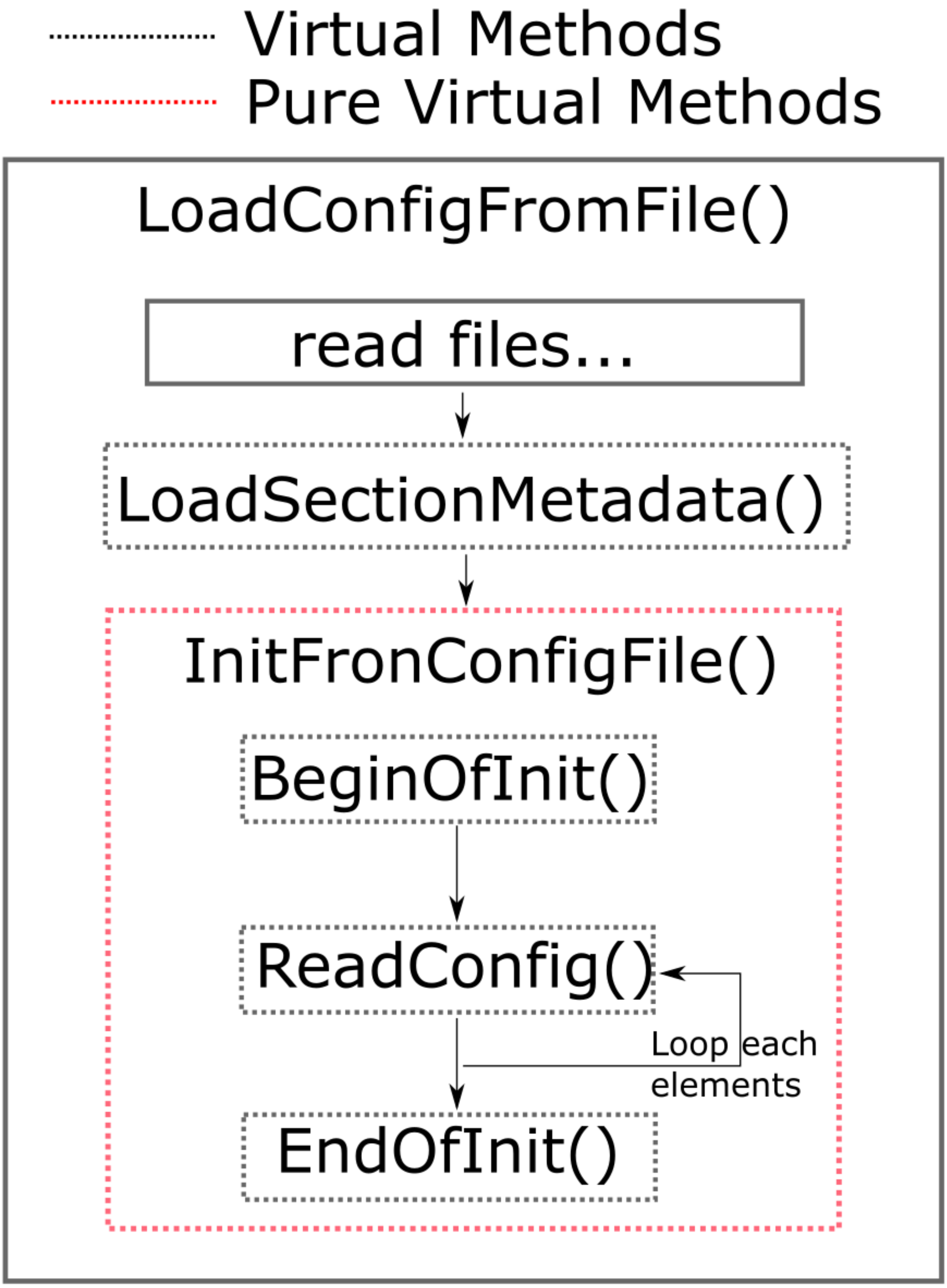
If we don't add this, we need to manually call the LoadConfigFromFile() method.

```
int main(){
  TRestReadout*readout=new TRestReadout();
  readout->LoadConfigFromFile("readout.rml");
  ...
}
```

In method LoadConfigFromFile(), we first open the given rml file and find the corresponding xml section in it. The xml section, wrapped by tinyxml class "TiXmlElement", is saved in the TRestMetadata class. Then the method LoadSectionMetadata() is called, which sets name, title and verboseLevel for the class. It also makes some parpration with config xml section (expand for loop, replave env, etc.). Then the method InitFromConfigFile() is called.

The method InitFromConfigFile() has default behavior which loops all the child elements in config xml section and calls the method ReadConfig() for each of them. In this case, ReadConfig() should be implemented. Sometimes we also override this default behavior if startup logic is simple. For example, in most of the process classes, we use overrided method to load config file, and call method GetParameter() to do parameter setting.

```
void TRestRawSignalTo2DHitsProcess::InitFromConfigFile(){
  fSelection = GetParameter("selection", "0");
  fBaseLineRange = StringTo2DVector(GetParameter("baseLineRange", "(5,55)"));
  fIntegralRange = StringTo2DVector(GetParameter("integralRange", "(10,500)"));
  fPointThreshold = StringToDouble(GetParameter("pointThreshold", "2"));
  fNPointsOverThreshold = StringToInteger(GetParameter("pointsOverThreshold", "5"));
  fSignalThreshold = StringToDouble(GetParameter("signalThreshold", "2.5"));
}
```



other virtual methods

The startup method LoadSectionMetadata(), ReadConfig() can be overriden. In addition, the method BeginOfInit(), EndOfInit() will also be helpful.

Another method is Initialize(), It resets the values in the class.

We also provide interface of printing in the method PrintMetadata(). REST macros like REST_PrintMetadata call this method and print the information on screen. The user needs to implement it in some times.

useful methods and tools

REST provides rml parsing methods, reflection methods and string output tools in TRestMetadata, as shown in the following. Inline methods from the class TRestStringHelper are also available. We will not talk about them here. Check in our doxygen website.

protected class members

Type	Name	Description
std::string	fConfigFileName	Full name of the rml config file
std::string	fSectionName	Section name given in the constructor of the derived metadata class
REST_Verbose_Level	fVerboseLevel	Verbose level used to print debug info. Won't save in file.
TRestManager*	fHostmgr	All metadata classes can be initialized and managed by TRestManager. We keep a pointer of TRestManager in all the classes. Won't save in file.
Bool_t	fStore	This variable is used to determine if the metadata structure should be stored in the ROOT file. Won't save in file.
TiXmlElement*	fElement	Saving the sectional element together with global element. Won't save in file.
TiXmlElement*	fElementGlobal	Saving the global element, to be passed to the resident class, if necessary. Won't save in file.
vector<TiXmlElement*>	fElementEnv	Saving a list of environmental variables. Won't save in file.
TRestLeveledOutput<REST_Silent>	fout	use this to display message when verbose level is >= REST_Silent. The message is in middle with color bold blue.
TRestLeveledOutput<REST_Essential>	essential	use this to display message when verbose level is >= REST_Essential. The message is in middle with color bold green.
TRestLeveledOutput<REST_Info>	info	use this to display message when verbose level is >= REST_Info. The message is in middle with color bold green.
TRestLeveledOutput<REST_Silent>	error	use this to display error messages. The message is left orientated with color bold red.
TRestLeveledOutput<REST_Essential>	warning	use this to display warning messages. The message is left orientated with color bold yellow.
TRestLeveledOutput<REST_Debug>	debug	use this to display debug messages. The message is left orientated with color white.
TRestLeveledOutput<REST_Extreme>	extreme	use this to display extreme debug messages. The message is left orientated with color white.

String output tools are as data member of TRestMetadata. The usage is very simple, just like cout:

```
fout << "hellow world" << endl;
debug << "Setting input event..." << endl;
```

Add the lines like this in your class' method functions. During running, when verbose level of this class is set to be higher than(or equal to) REST_Debug, the second message will automatically be shown. Otherwise there will only be the first message on screen.

TRestStringOutput allows the user to set output color, border, length and orientation. Check its usage here.

To set colors, use the method TRestStringOutput::setcolor(). For example:

```
fout.setcolor(COLOR_RED)
```

Here COLOR_RED is one of the pre-defined colors in REST, in the following list.

Name of Color	actual value(type: const char*)
COLOR_RESET	"\033[0m"
COLOR_BLACK	"\033[30m"
COLOR_RED	"\033[31m"
COLOR_GREEN	"\033[32m"
COLOR_YELLOW	"\033[33m"
COLOR_BLUE	"\033[34m"
COLOR_MAGENTA	"\033[35m"
COLOR_CYAN	"\033[36m"
COLOR_WHITE	"\033[37m"
COLOR_BOLDBLACK	"\033[1m\033[30m"
COLOR_BOLDRED	"\033[1m\033[31m"
COLOR_BOLDGREEN	"\033[1m\033[32m"
COLOR_BOLDYELLOW	"\033[1m\033[33m"
COLOR_BOLDBLUE	"\033[1m\033[34m"
COLOR_BOLDMAGENTA	"\033[1m\033[35m"
COLOR_BOLDCYAN	"\033[1m\033[36m"
COLOR_BOLDWHITE	"\033[1m\033[37m"
COLOR_BACKGROUNDBLACK	"\033[1m\033[40m"
COLOR_BACKGROUNDRED	"\033[1m\033[41m"
COLOR_BACKGROUNDGREEN	"\033[1m\033[42m"
COLOR_BACKGROUNDYELLOW	"\033[1m\033[43m"
COLOR_BACKGROUNDBLUE	"\033[1m\033[44m"
COLOR_BACKGROUNDMAGENTA	"\033[1m\033[45m"
COLOR_BACKGROUNDCYAN	"\033[1m\033[46m"
COLOR_BACKGROUNDWHITE	"\033[1m\033[47m"

rml methods

Here we list roughly the main rml methods in TRestMetadata. To look for more detail, check the doxygen website.

Return Type	Name	Number of Overloads	Description
std::string	GetParameter	3	Basic "GetParameter" functionality. Search in system env, section attribute value and "parameter" child section in sequence.
std::string	GetFieldValue	2	Basic "GetParameter" functionality. Search only in section attribute value.
double	GetDblParameterWithUnits	3	Basic "GetParameter" functionality. Search unit definition near the parameter, and convert the value to double automatically.
TVector2	Get2DVectorParameterWithUnits	3	Basic "GetParameter" functionality. Search unit definition near the parameter, and convert the value to TVector2 automatically.
TVector3	Get3DVectorParameterWithUnits	3	Basic "GetParameter" functionality. Search unit definition near the parameter, and convert the value to TVector3 automatically.
TiXmlElement*	GetRootElementFromFile	1	Tinyxml interface. Open an xml file and returns its root element.
TiXmlElement*	GetElement	3	Tinyxml interface. Finds the xml element with certain decalration, wraps it as class TiXmlElement.
TiXmlElement*	GetElementWithName	2	Tinyxml interface. Finds the xml element with certain decalration and name attribute, wraps it as class TiXmlElement.
TiXmlElement*	StringToElement	1	Old xml parser interface. Convert std::string to an xml element.
std::string	ElementToString	1	Old xml parser interface. Convert an xml element to string.
std::string	GetKEYStructure	5	Old xml parser interface. Get directly a string of xml section from either another string or TiXmlElement
std::string	GetKEYDefinition	4	Old xml parser interface. Get directly a string of xml section, exclude its child sections.

In most cases we just write a simple class with few class members to set from rml config file. We can simply use GetParameter() to do the setting.

reflection methods

Reflection means a mapping from string type class/classmember name to the actual address of the class/classmember. For example some times we need to write a config file to set values for a hundred of class members. The actual lines in the config file may be just several, but we need to parpare a hundred of lines like: "par1=GetParameter("par1")==""?0:StringToInteger(GetParameter("par1"));" in the code. Of course we don't want to write like this. In this case we need reflection.

Another example is that when we are writing a base class, we usually want to make it easier to inhert. We want to directly implement the InitFromConfigFile() method for all of the derived class. How can we set the class members' value event when we don't know them? We also need reflection.

The reflection methods are in the table below:

Return Type	Input Type	Name	Description
TStreamerElement*	string	GetDataMemberWithName	Get ROOT streamer class of the target class member with class member name
TStreamerElement*	int	GetDataMemberWithID	Get ROOT streamer class of the target class member with class member's streamer id(not real id)
int		GetNumberOfDataMember	Get total number of avaliable class members. Initialize the reflection functionality.
double	TStreamerElement*	GetDblDataMemberVal	Get the value of class member assume its type is double.
int	TStreamerElement*	GetIntDataMemberVal	Get the value of class member assume its type is int.
char*	TStreamerElement*	GetDataMemberRef	Get address of the given class member in type of char*
string	TStreamerElement*	GetDataMemberValString	Get the value of class member assume its type is string.
void	TStreamerElement*, char"	SetDataMemberVal	Set the value of class member with a pointer. Assume the pointer is of same type of the class member.
void	TStreamerElement*, string	SetDataMemberVal	Set the value of class member with a number string. Convert the string to certain value type(int, double, float).
void	TStreamerElement*	SetDataMemberValFromConfig	Autometically set the value of corresponding class member with the given xml section.

Note that if the class member has no ROOT streamer(with annotation //! after member definition), the reflection won't work for it.

TRestEventProcess

implementing

The most refquent case of developing REST is to write or modifiy an event process. TRestEventProcess is inherted from TRestMetadata, adding extra interfaces and tools to it. We need to implement/redefine additional methods/variables in TRestEventProcess. The followings are a list of them. The ones with a "★" mark ahead must be implemented/redefined by the user.

★TRestEvent* fInputEvent

★TRestEvent* fOutputEvent

virtual void InitProcess()

virtual void BeginOfEventProcess()

★virtual TRestEvent *ProcessEvent(TRestEvent* evInput) = 0

virtual void EndOfEventProcess()

virtual void EndProcess()

The variables "fInputEvent" and "fOutputEvent" defines the address of the process's input and output event. It is recommended to set them in the process's constructor. During launch, REST will check the input-output event type of each process to make sure the process chain is vailed. The following shows an example to write a constructor which sets input and output events.

```
class TRestRawSignalAnalysisProcess :public TRestEventProcess {
  private:
  //we define specific pointer of TRestEvent in class
  TRestRawSignalEvent *fSignalEvent;//!
  ...
}
```

```
TRestRawSignalAnalysisProcess::TRestRawSignalAnalysisProcess(){
  fSignalEvent = new TRestRawSignalEvent();//we instantiate specific TRestEvent object
  fOutputEvent = fSignalEvent;//and then sets fOutputEvent and fInputEvent to this pointer.
  fInputEvent = fSignalEvent;
  ...
}
```

After the input-output check, REST will call the method InitProcess() of each loaded process. Some values should be cleared/reset here in case the process needs to run again.

The three methods: BeginOfEventProcess(), ProcessEvent() and EndOfEventProcess() are called in sequence for one event. The most important one is the pure virtual method ProcessEvent(). It receives an input event and gives an output event, both in type TRestEvent. We need to force transform the pointer type inside the method.

```
TRestEvent* TRestRawSignalAnalysisProcess::ProcessEvent( TRestEvent *evInput ){
  fSignalEvent = (TRestRawSignalEvent *)evInput;
  fOutputEvent = fSignalEvent;
  fInputEvent = fSignalEvent;
  //some analysis for fSignalEvent
  ...
  return fSignalEvent;
}
```

Note that although ProcessEvent() seems to be independent on fInputEvent and fOutputEvent, we still need to set fOutputEvent/fInputEvent inside the method. Some times we may still want to access to input event and output event after the process.

REST allows event cut with TRestEventProcess. Simply return a NULL pointer inside the method, and this event will be skipped. Some times when the process cuts out event with too great the ratio, test run from TRestProcessRunner cannot determine the output event address for event tree to save. In this case we need to turn it off, and use the address from fOutputEvent. We cannot simply copy the pointer. We need a deep copy of input event.

```
TRestEvent* TRestRawSignalAnalysisProcess::ProcessEvent( TRestEvent *evInput ){
  //deep copy of the input event
  evInput->CloneTo(fSignalEvent);
  fOutputEvent = fSignalEvent;
  fInputEvent = fSignalEvent;
  //a large cut which selects event that have 10 or more signals
  if(fSignalEvent->GetNumberOfSignals()<10)return NULL;
  //some analysis for fSignalEvent
  ...
  return fSignalEvent;
}
```

The method EndProcess() is a method to be called after all the events are finished. Some additional jobs can be done here. For example, we can show a message about the process status in this method. Or, we can call saving for a TH1D object to the output file.

observable and internal variable

By default, we save process's internal variables in analysis tree's process branch, and save additional observables in observable branch. It is recommended to use observables to store important analysis result, because reading them would be faster. The observable can only be double type.

There are two ways to make an observable available in a process. We can directly call the method TRestAnalysisTree::SetObservableValue() inside the ProcessEvent() function. Each TRestEventProcess keeps a pointer to the analysis tree, we can call it like following:

```
//inside function ProcessEvent()(TRestRawSignalAnalysisProcess.cxx)
Double_t baseLineSigma = fSignalEvent->GetBaseLineSigmaAverage( fBaseLineRange.X(), fBaseLineRange.Y() );
fAnalysisTree->SetObservableValue( this, "baseLineSigmaMean", baseLineSigma );
```

Another way is to add the analysis result inside the process as a class member. And just change the value inside the ProcessEvent() function. After the function returns, REST will auto save this class member (of course NULL return will not be handled). The following is an example.

```
//inside class definition(TRestRawSignalAnalysisProcess.h)
Double_t baseLineSigmaMean;
```

```
//inside function ProcessEvent()(TRestRawSignalAnalysisProcess.cxx)
baseLineSigmaMean= fSignalEvent->GetBaseLineSigmaAverage( fBaseLineRange.X(), fBaseLineRange.Y() );
```

This kind of observable definition saves the amount of our code. We just need to focus on the analysis work, setting values of class members. However, changing class definition may cause the previous version unreadable, or even crash the program. The user also needs to reset the value of the class members if the method returns before value assignment.

After above, the observable is available. We need to add a line in rml config file to tell REST to save it. Note that the observable name should be same as the string argument in the former way.

```
<addProcess type="TRestRawSignalAnalysisProcess" name="sAna" value="ON">
  ...
  <observable name="baseLineSigmaMean" value="ON" />
</addProcess>
```

What if we want to save other types of analysis result? The only way is to save them as internal variable. For example, in TRestRawSignalAnalysisProcess, we want to save baseline sigma for each signal, not an average value. This time we are unable to use observable. We can add a vector<double> member inside the class definition. It will be auto saved in tree. Find it in the process branch.

single thread process

Processes can be set to single thread only by a bool value "fSingleThreadOnly". This option is for some special processes like external process and viewer process. The external processes read external data file, and the viewer process displays event figure. They cannot be executed in parallel. Set its value to true in the constructor.

REST will only activate one thread if a single thread process exists in the process chain. (note that external process will not be in the process chain.)

other class members

TRestEventProcess keeps the following pointers that may be useful:

Type	Name	Description
TRestAnalysisTree*	fAnalysisTree	The pointer to analysis tree, we usually call fAnalysisTree->SetObservableValue()
TRestRun*	fRunInfo	The pointer to TRestRun, which can provide the process with some metadata objects and run information in some cases.
vector<TRestEventProcess*>	fFriendlyProcesses	A list to all the friendly processes in the process chain. We may need to use the analysis result of other processes in some cases.
TCanvas*	fCanvas	A TCanvas object for drawing.

We also implemented a series of methods GetXXXMetadata(). For example to get the data of readout definition, we can simply use
`fReadout = (TRestReadout*)GetReadoutMetadata();`
in the class's method funciton. The alternative call is:
`fReadout = (TRestReadout*)fRunInfo->GetMetadata("TRestReadout")`

Start Your Own Analysis with REST

We may engage a new analysis request which REST is unable to handle. It is possible to modify/add processes to REST source code, or to develop a new project based on REST. The project can either be a program running separately, or a library added into REST libraries.

Modify an existing process

To customize our analysis, we start from modifing an existing TRestEventProcess class. We are going to add two new analysis items for baseline.

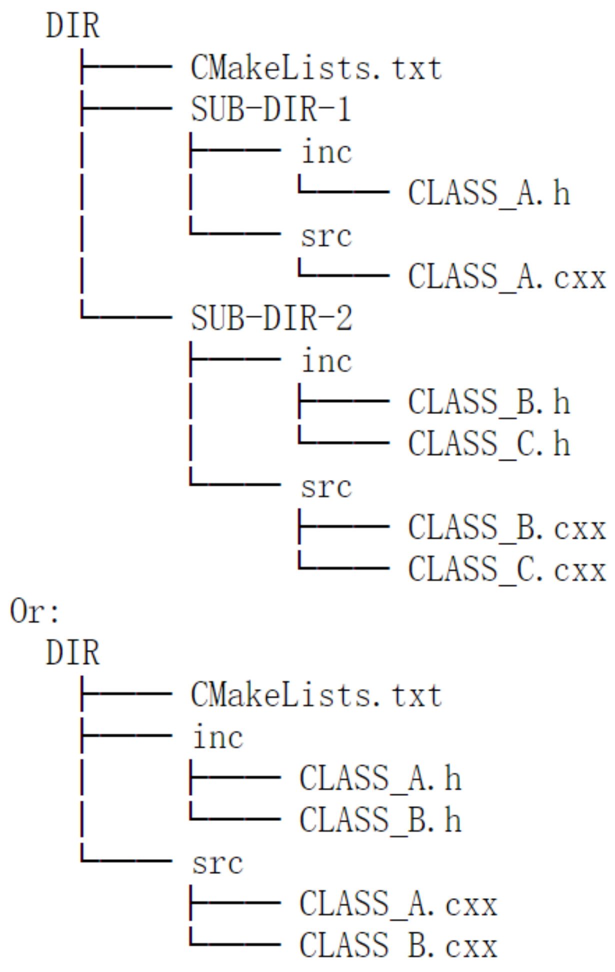
```
//inside class definition(TRestRawSignalAnalysisProcess.h)
...
vector<Double_t> baselinesigma;
Double_t baselinesigmamean;
...
```

```
//inside function ProcessEvent()(TRestRawSignalAnalysisProcess.cxx)
...
baselinesigmamean= fSignalEvent->GetBaseLineSigmaAverage( fBaseLineRange.X(), fBaseLineRange.Y() );
for (int s = 0; s < fSignalEvent->GetNumberOfSignals(); s++){
  TRestRawSignal *sgnl = fSignalEvent->GetSignal(s);
  Double_t _bslsigma = sgnl->GetBaseLineSigma(fBaseLineRange.X(), fBaseLineRange.Y(), _bslval);
  baselinesigma.push_back(_bslsigma);
}
...
```

After changing the source code, we need to switch to the build directory and type `make install` again. After this, TRestRawSignalAnalysisProcess should be working in the new way.

Adding a class to souce code

REST auto detectes source files in its directories. During the making, Cmake makes use of all the .h and .cxx files in the sub inc/src directories of each working directory. In concrete, the regular form of directory order is:



```
  DIR
   ├──── CMakeLists.txt
   ├──── SUB-DIR-1
   |      ├──── inc
   |      |      └──── CLASS_A.h
   |      └──── src
   |             └──── CLASS_A.cxx
   └──── SUB-DIR-2
          ├──── inc
          |      ├──── CLASS_B.h
          |      └──── CLASS_C.h
          └──── src
                 ├──── CLASS_B.cxx
                 └──── CLASS_C.cxx
Or:
  DIR
   ├──── CMakeLists.txt
   ├──── inc
   |      ├──── CLASS_A.h
   |      └──── CLASS_B.h
   └──── src
          ├──── CLASS_A.cxx
          └──── CLASS_B.cxx
```

Cmake first targets on a .cxx file. It regards the file name as the class name. Then it searches the .h file of this class. If found, it calls CINT to make a wrapper for the class with this .h file. ROOT CINT genertes a new .cxx file for the .h file, containing some streamer methods and reflection methods which overwrites those in TObject class. Each .h file can only contain one TObject inherted class whose name must be the same as the file name. Then Cmake includes that .h file and complies the two .cxx files calling gcc. This work is done for all .cxx files, after which CMake generates a library with the name of the directory.

As for the user, after adding a new class, he just needs to rerun the command `cmake PATH [options]` followed by `make install` in the build directory. Alternativelly he can switch to ./script directory and call `python scriptsInterface.py` .

To add a new process, we suggest copying the header file and the source file of our template dummy process. They are in the directory ./packages/userRESTLibrary, named "mySignalProcess". First rename the files and replace all the instance of "mySignalProcess" into your process name. Then add your class member and implement your InitFromConfigFile() method. It will be convenient to use GetParameter() and StringToDouble() methods to set configurations from rml file. Then define your input and output event type, by using code like: `fInputEvent = new TRestxxxEvent();`. Finally implement your ProcessEvent() method which is for the main analysis loop. A new process is ready!

Adding new event class or metadata class shall be similar.

Referring to REST library in another project

In the directory ./packages/userRESTLibrary, we have a library project which can directly be compiled. We did the same modification as above, creating a new utilized process and metadata class. Then we can use the following command:

~/REST_v2$ `cd packages/userRESTLibrary`

// We create the build directory and enter it
~/REST_v2/packages/userRESTLibrary$ `mkdir build`
~/REST_v2/packages/userRESTLibrary$ `cd build`

// We create the compilation environment, setting the library to be installed at the same example directory.
~/REST_v2/packages/userRESTLibrary/build$ `cmake -DINSTALL_PREFIX=../ ..`

// We compile and install the library
~/REST_v2/packages/userRESTLibrary/build$ `make install`

After following those steps, we should have a *lib* directory inside the *packages* directory, and inside a library named *libMyRESTLibrary.so*. In order to use the generated library the system needs to be able to find it looking at LD_LIBRARY_PATH.

Add the following line to your *.bashrc* file and launch a new terminal.

```
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:$HOME/REST_v2/packages/userRESTLibrary/lib
```

Now REST will always start up referring to this new library.

Example : restG4

To make a separate program based on REST we also have an example: restG4. It is in the directory ./packages/restG4. It provides an executable named restG4 which refers to both REST and geant4 library.

To install it use the similar command as above. By default restG4 is installed in REST executable directory (${REST_PATH}/bin/).

Appendix

List of REST processes

We list here the different event data processes implemented in REST together with a brief funcionality description.

Data transformation processes

These processes are in charged of transforming data between different basic data types in REST.

As soon as we transform one data type to another we can make use of the dedicated data type processes. For example, if we have a geant4 event (TRestG4Event), we may transform it to a basic hits event (TRestHitsEvent) and continue processing the event using the basic *hit processes*.

REST process	Input type	Output type	Description
TRestRawSignalToSignalProcess	TRestRawSignal	TRestSignalEvent	Transforms a rawsignal into a signal event.
TRestSignalToHitsProcess	TRestSignalEvent	TRestHitsEvent	Converts a signal event into a hits event using TRestReadout.
TRestHitsToSignalProcess	TRestHitsEvent	TRestSignalEvent	Transforms a HitsEvent into SignalEvent using TRestReadout.
TRestHitsToTrackProcess	TRestHitsEvent	TRestTrackEvent	Hit clusterization into tracks by proximity (Accurate).
TRestFastHitsToTrackProcess	TRestHitsEvent	TRestTrackEvent	Hit clusterization into tracks by proximity (Aproximation).
TRestG4toHitsProcess	TRestG4Event	TRestHitsEvent	Transforms a geant4 event into a hits event.

Analysis processes

These are pure analysis processes. They do not transform the event data itself but add new observables/branches to TRestAnalysisTree. They may apply cuts to the event data, somehow deciding if an event should continue being processed. Any process can decide to stop processing an event by just returning a NULL pointer. This should be documented in each process class.

REST process	Input type	Output type	Description
TRestRawSignalAnalysisProcess	TRestRawSignal	TRestRawSignal	Adds analysis observables from raw signal event.
TRestHitsAnalysisProcess	TRestHitsEvent	TRestHitsEvent	Adds analysis observables from hits event.
TRestGeant4AnalysisProcess	TRestG4Event	TRestG4Event	Adds analysis observables from a geant4 event.
TRestTrackAnalysisProcess	TRestTrackEvent	TRestTrackEvent	Adds analysis observables from a track event.
TRestTriggerAnalysisProcess	TRestSignalEvent	TRestSignalEvent	Applies cuts using time window and energy threshold trigger definition.
TRestFindG4BlobAnalysisProcess	TRestG4Event	TRestG4Event	Finds the electron end blobs in a TRestG4Event. For events with at least 2-electron tracks.

Signal processes

These processes just modify the data inside a signal event, returning again a signal event data type. These kind of processes add signal noise to simulated data, filter noise from rawdata, shape the input signal, or suppress signal data points which are under threshold.

REST process	Input type	Output type	Description
TRestAddSignalNoiseProcess	TRestSignalEvent	TRestSignalEvent	Adds random noise to a signal event.
TRestSignalDeconvolutionProcess	TRestSignalEvent	TRestSignalEvent	Deconvolutes a signal using a given input response signal.
TRestSignalGaussianConvolutionProcess	TRestSignalEvent	TRestSignalEvent	Convolutes the input signal with a gaussian.
TRestSignalShapingProcess	TRestSignalEvent	TRestSignalEvent	Shapes the input signal with a given input response signal.
TRestFindResponseSignalProcess	TRestSignalEvent	TRestSignalEvent	Selects clean signals from input to be used as response for deconvolution.
TRestSignalZeroSuppresionProcess	TRestRawSignalEvent	TRestSignalEvent	Keeps only points which are found over threshold.

Hit processes

These processes just modify the data inside a hits event, returning again a hits event data type. These kind of processes normalize hits energy, fiducialize hits in a given volume, drift and diffuse hits, or reduce the hit number using merging algorithms.

REST process	Input type	Output type	Description
TRestElectronDiffusionProcess	TRestHitsEvent	TRestHitsEvent	Spatially diffuses input hits using gas properties defined in TRestGas and the active TPC volume/geometry defined in TRestReadout.
TRestFiducializationProcess	TRestHitsEvent	TRestHitsEvent	Only hits inside readout active volume definition survive.
TRestAvalancheProcess	TRestHitsEvent	TRestHitsEvent	Statistical gain increase per hit.
TRestHitsNormalizationProcess	TRestHitsEvent	TRestHitsEvent	Re-scales the hits energy by a constant factor.
TRestHitsRotateAndTraslateProcess	TRestHitsEvent	TRestHitsEvent	Rotates and translates a hit distribution along its energy center.
TRestHitsReductionProcess	TRestHitsEvent	TRestHitsEvent	Merges hits by proximity reducing the effective number of hits.
TRestHitsShuffleProcess	TRestHitsEvent	TRestHitsEvent	Hits are disordered in the hits queue.
TRestSmearingProcess	TRestHitsEvent	TRestHitsEvent	Hits energy is re-scaled with a random factor by a given resolution.

Track processes

These processes operate over track event data, or a set of hits that have been grouped into tracks. We may find the minimum path between the hits inside each track, reduce the number of hits inside each track, find the track ends, or project the hits over the main trajectory effectively linearizing the track.

REST process	Input type	Output type	Description
TRestFindTrackBlobsProcess	TRestTrackEvent	TRestTrackEvent	Finds the track end blobs in a TrackEvent .Tracks should have been pre-processed with path minimization and reconnection processes.
TRestTrackLinearizationProcess	TRestTrackEvent	TRestLinearTrackEvent	Projects the hits into the track to get dE/dx profile.
TRestTrackPathMinimizationProcess	TRestTrackEvent	TRestTrackEvent	Finds the minimum path between hits inside each track.
TRestTrackReconnectionProcess	TRestTrackEvent	TRestTrackEvent	Improves physical track description after track minimization.
TRestTrackReductionProcess	TRestTrackEvent	TRestTrackEvent	Reduces the number of hits inside a track by merging closer hits.
TRestTrackToHitsProcess	TRestTrackEvent	TRestHitsEvent	It recovers back a track event into a hits event.

Rawdata processes

These processes read rawdata written in binary format and extract the signal event data to write it into a TRestRawSignalEvent.

REST process	Input type	Output type	Description
TRestRawToSignalProcess	rawdata	TRestRawSignalEvent	Used to encapsulate rawdata to signal processes.
TRestAFTERToSignalProcess	rawdata	TRestRawSignalEvent	Transforms AFTER data into raw signal event.
TRestCoBoAsAdToSignalProcess	rawdata	TRestRawSignalEvent	Transforms CoBoAsAd data into raw signal event.
TRestMultiCoBoAsAdToSignalProcess	rawdata	TRestRawSignalEvent	Transforms CoBoAsAd data into raw signal event. General version using several CoBoAsAd cards. Event data might be splitted between different data files. The process receives a list of all the files in a given run.
TRestFEMINOSToSignalProcess	rawdata	TRestRawSignalEvent	Transforms FEMINOS data into SignalEvent.
TRestMultiFEMINOSToSignalProcess	rawdata	TRestRawSignalEvent	Transforms FEMINOS data into SignalEvent. General version using several Feminos cards. Full event data is containned in one single file.

Viewer processes

These processes can be connected during intermediate event processes to visualize the input/output of different processes. Still many missing viewer processes should be developed in this section.

REST process	Input type	Output type	Description
TRestRawSignalViewerProcess	TRestRawSignalEvent	TRestRawSignalEvent	Visualizes a raw-signal event
TRestSignalViewerProcess	TRestSignalEvent	TRestSignalEvent	Visualizes a signal event

List of ROOT scripts

Call these macros directly in bash with "Command"; Call them in restRoot prompt by "Function name".

The macros could be changed frequently in future.

general macros

These macros provides basic data analysis functionality, including fit, integrate, etc, for observables in the anslysis tree

Command	Function name	Input arguments	Description
restCreateHisto	REST_General_CreateHisto()	TString varName TString rootFileName TString histoName int startVal = 0 int endVal = 1000 int bins = 1000 Double_t normFactor = 1	Creates and saves a histogram for a given observable in the data file.
restFit	REST_General_Fit()		Fits a given observable in the file and prints the result on screen.vis
restIntegrate	REST_General_Integrate()		Integrates a given observable in the file and prints the result on screen.
restIntegrateSmearing	REST_General_IntegrateSmearing()		Integrates with smearing a given observable in the file and prints the result on screen.

viewer macros

Command	Function name	Input arguments	Description
restViewEvents	REST_Viewer_GenericEvents()	TString fName TString EventType = ""	Shows a TRestBrowser which visualizes events in file by calling TRestGenericEventViewer
restViewG4Event	REST_Viewer_G4Event()	TString fName	Shows a TRestBrowser which visualizes TRestG4Event by calling TRestG4EventViewer
restViewGeometry	REST_Viewer_Geometry()	TString fName	Shows Geometry info saved in the given file by calling TGeoManager
restViewHitsEvent	REST_Viewer_HitsEvent()	TString fName	Shows a TRestBrowser which visualizes TRestHitsEvent by calling TRestHitsEventViewer
restViewReadout	REST_Viewer_Readout()	TString rootFile TString name Int_t plane = 0	Draw a figure of readout definition according to the save TRestReadout object in the file
restViewReadoutEvent	REST_Viewer_ReadoutEvent()	TString fName TString cfgFilename = "template/config.rml"	Shows a TRestBrowser which visualizes TRestReadoutEvent by calling TRestReadoutEventViewer

printer macros

Command	Function name	Input arguments	Description
restPrintEvents	REST_Printer_GenericEvents()	TString fName TString EventType="" Int_t firstEvent = 0	Print the event in file with given type. It calls the method TRestEvent::Print()
restPrintFileContents	REST_Printer_FileContents()	TString fName	Print name and title of Metadata/Application/Trees saved in the file.(Anything inherted from TNamed)
restPrintMetadata	REST_Printer_Metadata()	TString fName	Print the metadata content of metadata objects in the file.
restPrintTrees	REST_Printer_Trees()	TString fName	Print EventTree, AnalysisTree and observables in the file.

geant4 macros

Command	Function name	Input arguments	Description
restFindGammasEmitted	REST_Geant4_FindGammasEmitted()	TString fName	
restFindIsotopes	REST_Geant4_FindIsotopes()	TString fName TString fIsotope	
restGetBiasingError	REST_Geant4_GetBiasingError()	TString fName Int_t finalEvents = 0	
restGetROIEvents	REST_Geant4_GetROIEvents()	TString fName Double_t mean=2457.83 Double_t fwhm=0.03	
restGetROIEvents_Fiducial	REST_Geant4_GetROIEvents_Fiducial()	TString fName Double_t zMin Double_t zMax Double_t radius Double_t mean=2457.83 Double_t fwhm=25	
restListIsotopes	REST_Geant4_ListIsotopes()	TString fName TString fOutName	
restMeanTrackLeng	REST_Geant4_MeanTrackLength()	TString fName	
restQuickLookAnalysis	REST_Geant4_QuickLookAnalysis()	TString fName	
restReadNEvents	REST_Geant4_ReadNEvents()	TString fName int n1 int n2	

tool macros

Command	Function name	Input arguments	Description
restCheckReadout	REST_Tools_CheckReadout()	TRestReadoutPlane *p Int_t mask[4] Double_t region[4] Int_t N	
restCheckRunFileList	REST_Tools_CheckRunFileList()	TString namePattern Int_t N = 100000	
restDrawCombinedGasCurves	REST_Tools_DrawCombinedGasCurves()	TString fName	
restDrawResponseSignal	REST_Tools_DrawResponseSignal()		
restGenerateGasFiles	REST_Tools_GenerateGasFile()	TString cfgFile	
restMergeFiles	REST_Tools_MergeFiles()	TString pathAndPattern TString outputFilename	Merge ROOT files with given pattern
restProduceResponseSignal	REST_Tools_ProduceResponseSignal()	TString inputFileName TString outputFileName Int_t nPoints = 512 Double_t threshold = 1	
restValidateGeometry	REST_Tools_ValidateGeometry()	TString gdmlName	

REST pre-definition data

needs to be filled

> Author: Ni Kaixiang 1160274182@qq.com