ROOT and PROOF Tutorial

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Outline

- ➢ Introduction to ROOT
- ✓ ROOT hands-on exercises
- ➢ Introduction to PROOF
- ✓ PROOF hands-on exercises

What is ROOT?

- Object-oriented data handling and analysis framework
  - Framework: ROOT provides building blocks (root classes) to use in your program.
  - Data handling: ROOT has classes designed specifically for storing large amount of data (GB, TB, PB) to enable effective…
  - Analysis: ROOT has complete collection of statistical, graphical, networking and other classes that user can use in their analysis.
  - Object-oriented: ROOT is based on OO programming paradigm and is written in C++.

Who is developing ROOT?

- ROOT is an open source project started in 1995 by René Brun and Fons Rademakers.
- The project is developed as a collaboration between:
  - Full time developers:
    - 7 developers at CERN (PH/SFT)
    - 2 developers at Fermilab (US)
  - Large number of part-time contributors (160 in CREDITS file included in ROOT software package)
  - A vast army of users giving feedback, comments, bug fixes and many small contributions
    - ~5,500 users registered to RootTalk forum
    - ~10,000 posts per year

Who is using ROOT?

- All High Energy Physics experiments in the world
- Astronomy: AstroROOT (http://www.isdc.unige.ch/astroroot/index)
- Biology: xps package for Bioconductor project

  (http://prs.ism.ac.jp/bioc/2.7/bioc/html/xps.html)
- Telecom: Regional Internet Registry for Europe, RIPE (Réseaux IP Européens) NCC Network Coordination Centre

  (http://www.ripe.net/data-tools/stats/ttm/current-hosts/analyzing-test-box-data)
- Medical fraud detection, Finance, Insurance, etc.

ROOT is used in a many scientific fields as well as in industry.

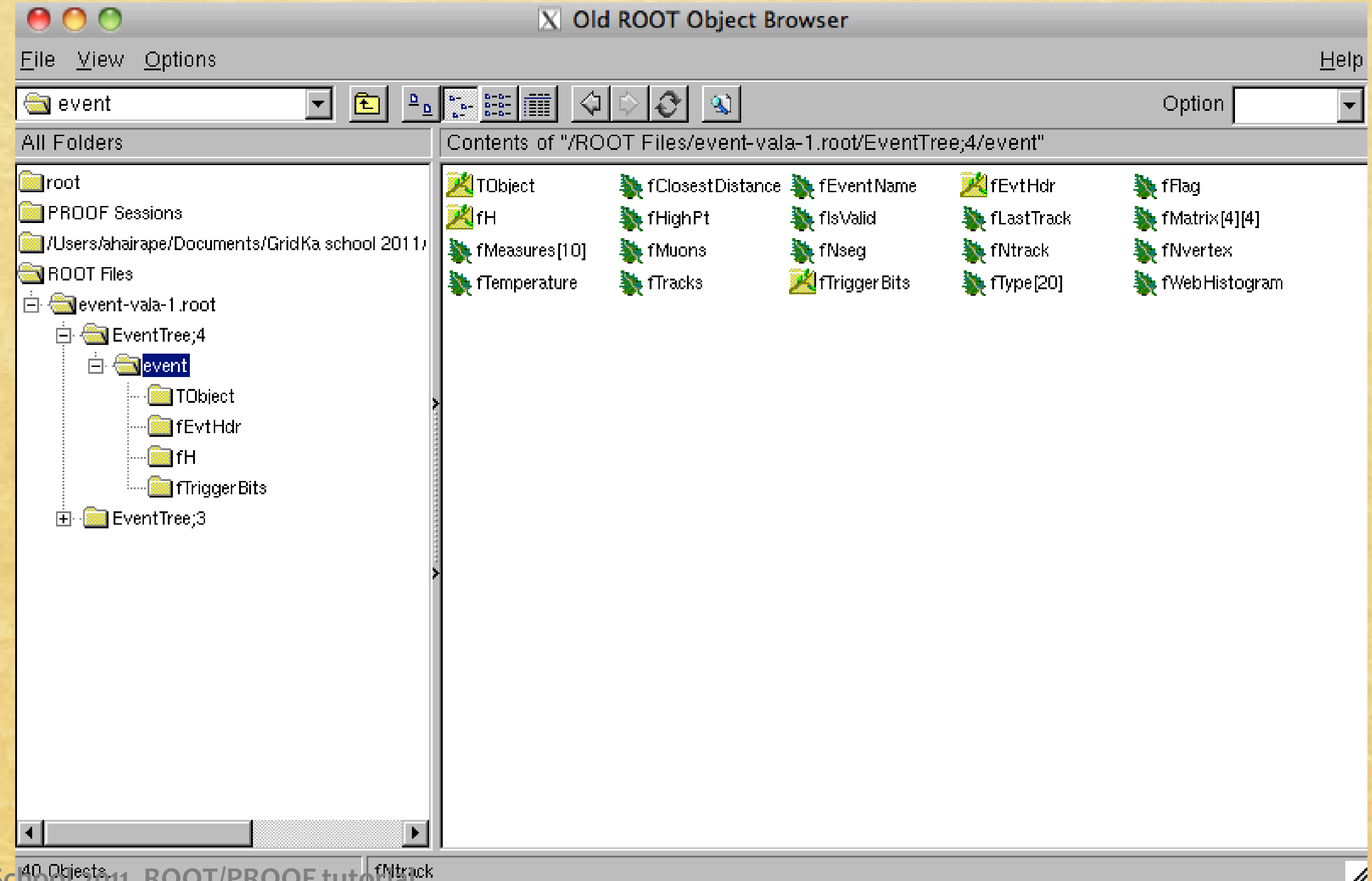
What can I do with ROOT?

You can:

- ✓ Store large amount of data (GB, TB, PB) in ROOT-provided containers: files, trees, tuples.
- ✓ Visualise the data in one of numerous ways provided by ROOT: histograms (1, 2 and 3-dimensional), graphs, plots, etc.
- ✓ Use physics analysis tools: physics vectors, fitting, etc.
- ✓ Write your own C++ code to process the data stored in ROOT containers.

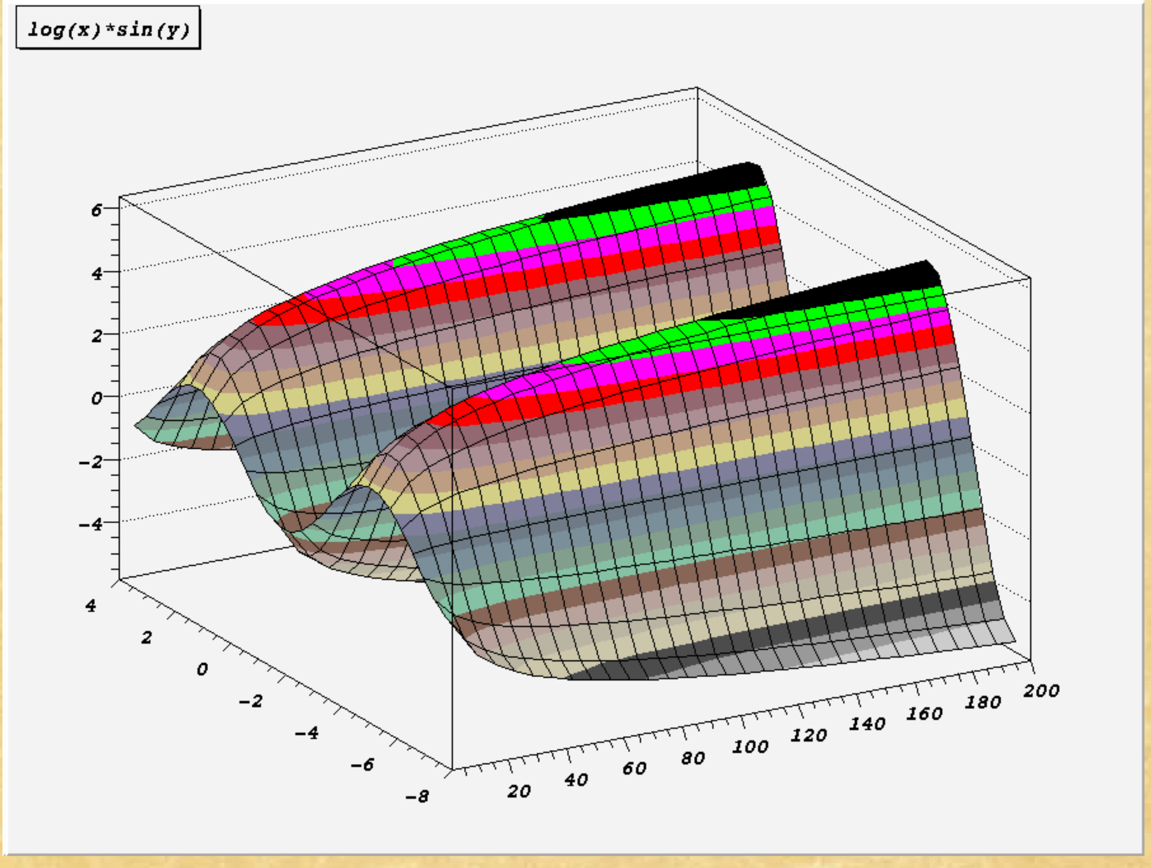
ROOT features: Data containers

- ROOT provides different types of data containers:
  - Files, folders
  - Trees, Chains, etc.



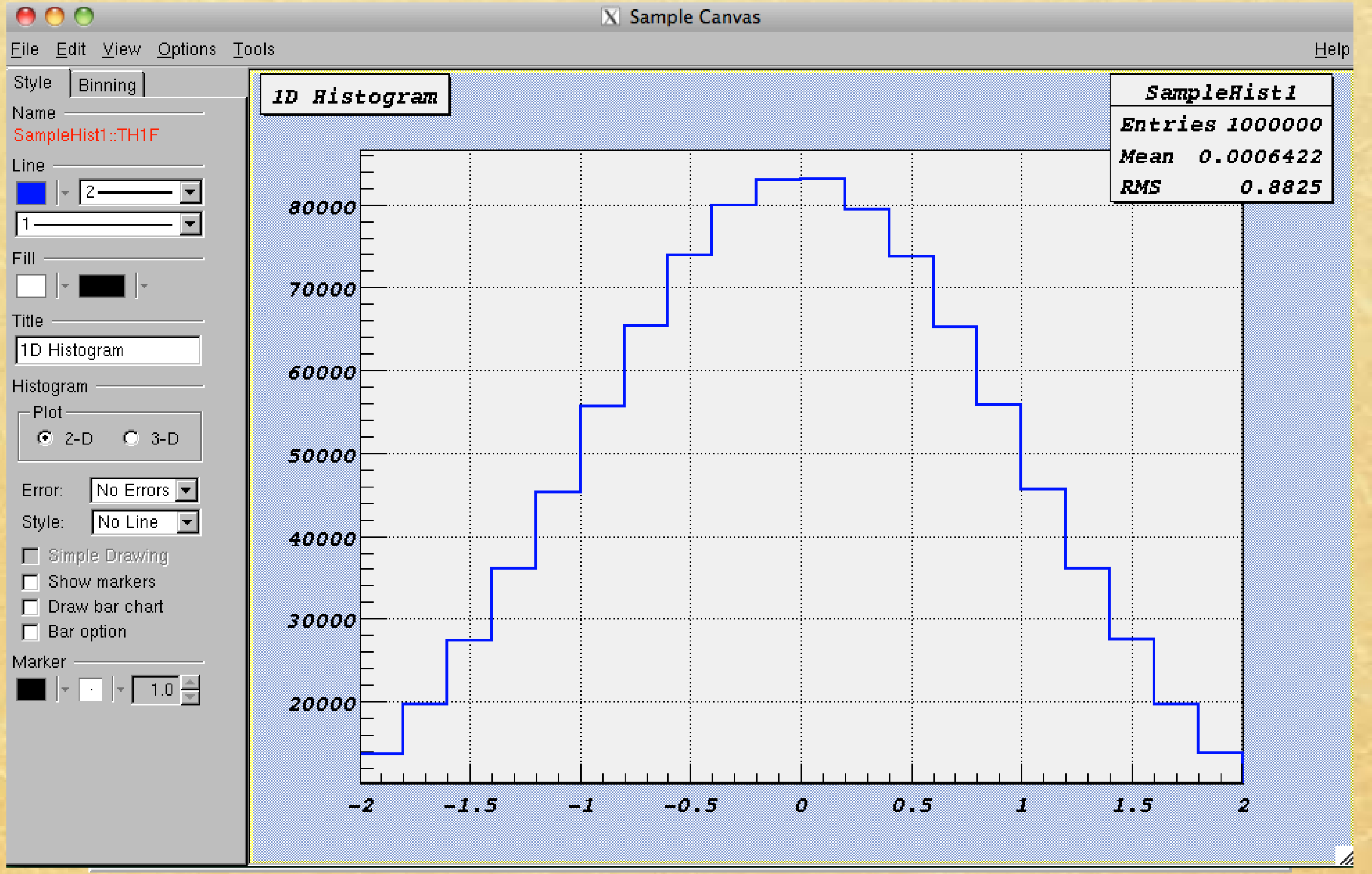
ROOT features: Data visualisation

- ROOT provides a range of data visualisation methods: histograms (one- and multi-dimensional), graphs, plots (scatter, surface, lego, …)



ROOT features: **GUI**

The Graphical User Interface (CLI) allows you to manipulate graphical objects (histograms, canvases, graphs, axes, plots, …) clicking on buttons and typing values in text boxes.



ROOT features: CLI

The Command Line Interface (CLI) allows you to type in the commands (C++, root-specific, OS shell) and processes them interactively via CINT – C++ interpreter.

Terminal — root.exe — 160×47

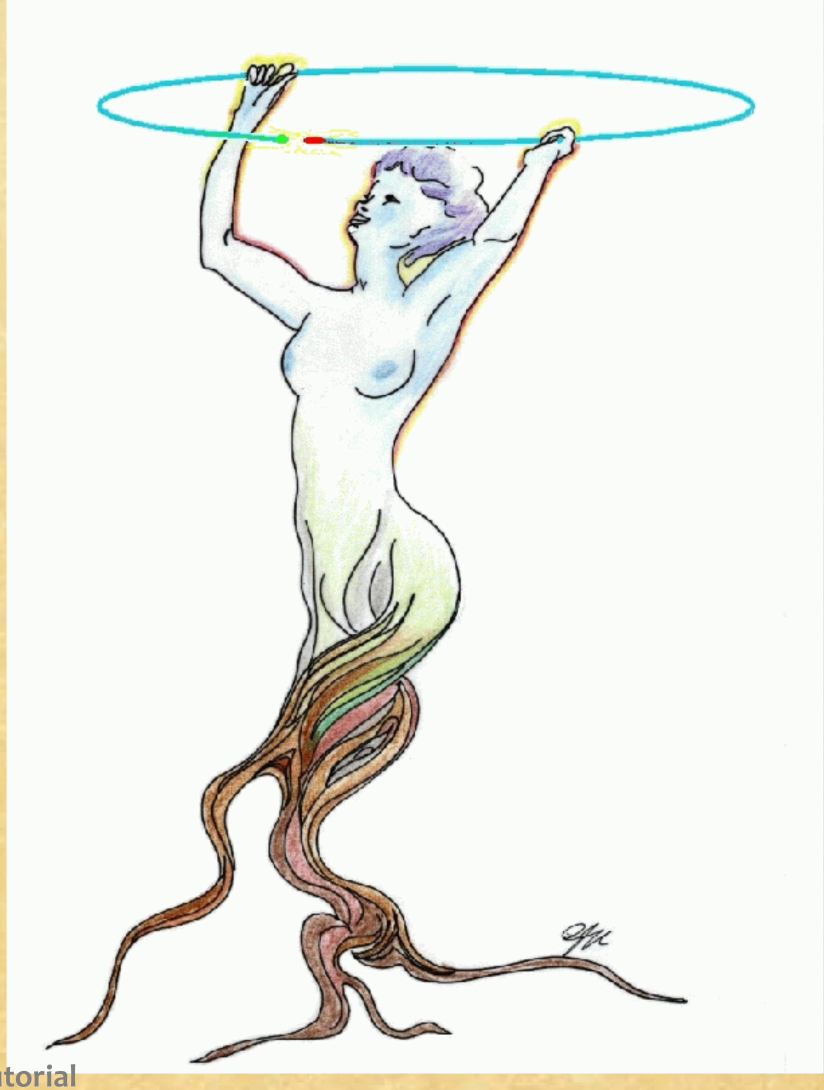
root.exe

```
pb-d-128-141-31-201:~ ahairape$ root
  *******************************************
  *                                         *
  *        W E L C O M E  to  R O O T       *
  *                                         *
  *   Version  5.28/00f     4 August 2011   *
  *                                         *
  *  You are welcome to visit our Web site  *
  *          http://root.cern.ch            *
  *                                         *
  *******************************************

ROOT 5.28/00f (tags/v5-28-00f@40489, Aug 18 2011, 19:33:26 on macosx64)

CINT/ROOT C/C++ Interpreter version 5.18.00, July 2, 2010
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0] TH1F* h = new TH1F("TestHist", "Test Histogram", 20, -2, 2);
root [1] h->FillRandom("gaus", 1000000);
root [2] h->Draw();
Info in <TCanvas::MakeDefCanvas>:  created default TCanvas with name c1
root [3] 
```

More information on ROOT

- http://root.cern.ch
  - Download
    - binaries, source
  - Documentation
    - User's guide
    - Tutorials
    - FAQ
  - Mailing list
  - Forum

ROOT Tutorial



In this tutorial you will learn how to…

- Use CLI and GUI
- Create functions and histograms
  - Visualise (draw) them
- Create and explore files
- Create and explore trees
- Create chains
- Analyse data contained in trees and chains on your machine

Preparations for the tutorial

- Connect to your UI login server
  - Attention! Use –Y option for SSH:
    - e.g. *ssh –Y –p 24 gs023@gks-2-151.fzk.de*
- Connect to one of machines gks-1-NNN.fzk.de
    - e.g. *ssh –Y gs023@gks-1-102.fzk.de*
    - *We will tell you the number of machine you should connect to*
    - *Verify that you have connected to proper machine running "hostname –f"*
- Run the following command:
    - source /opt/PEAC/sw/sl-x86_64-4.1.2/VO_PEAC/ROOT/v5-30-01/peac-env.sh
      - ✓ It will set system paths to include ROOT binary and the libraries
- Start root:
    - *root*
  - You should see ROOT start screen with logo and the ROOT version: 5-30-01

Macros for tutorial

- Create two directories on machines you logged in:
  - *mkdir macros*
  - *mkdir workspace*

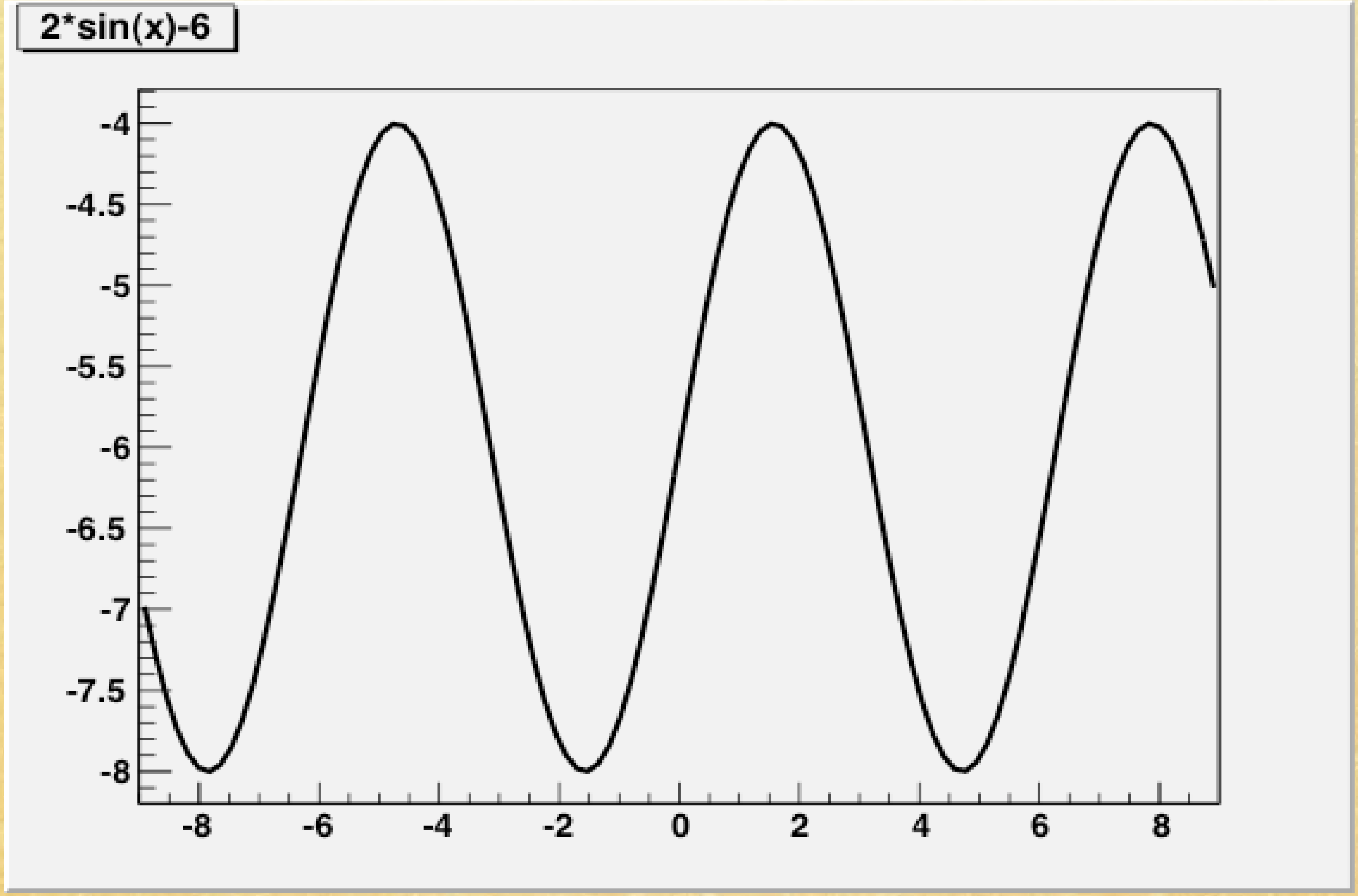
- Download tutorial macros:
  - cd macros
  - rsync -auvr --del rsync://mon1.saske.sk/gs .
    - ✓ You can root the macro codes during tutorial but we strongly recommend you to type root code you see on the slides!
  - Change to working directory
    - cd workspace

Ex. 1: Entering and quitting CLI

- To enter ROOT CLI, type the following command on the Linux shell:
  - *root*
  - ✓ You are provided with ROOT prompt, indicated by root [N] (N is the number of commands processed so far by root since starting it) where you can type in C++ statements, arithmetical expressions, and even Linux shell commands.
- To quit the CLI, type the following command:
  - *.q*
- To avoid opening the graphical screen with ROOT logo in the beginning supply '-l' option:
  - *root -l*

Ex. 2: Simple commands

- You can use ROOT CLI for mathematical calculations:
  - root [] *sin(0.5) * cos(0.5) + 3/4*
  - root [] *sin(0.5) * cos(0.5) +3/4;*
- C++ code snippet:
  - root [] *for (i=1; i<3; ++i) cout << "Hi there!\n";*
- Linux shell commands should be preceded .!:
  - root [] *.! date*


2*sin(x)-6
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8
-6
-4
-2
0
2
4
6
8

Macros

- ROOT macro is a file containing source code which can

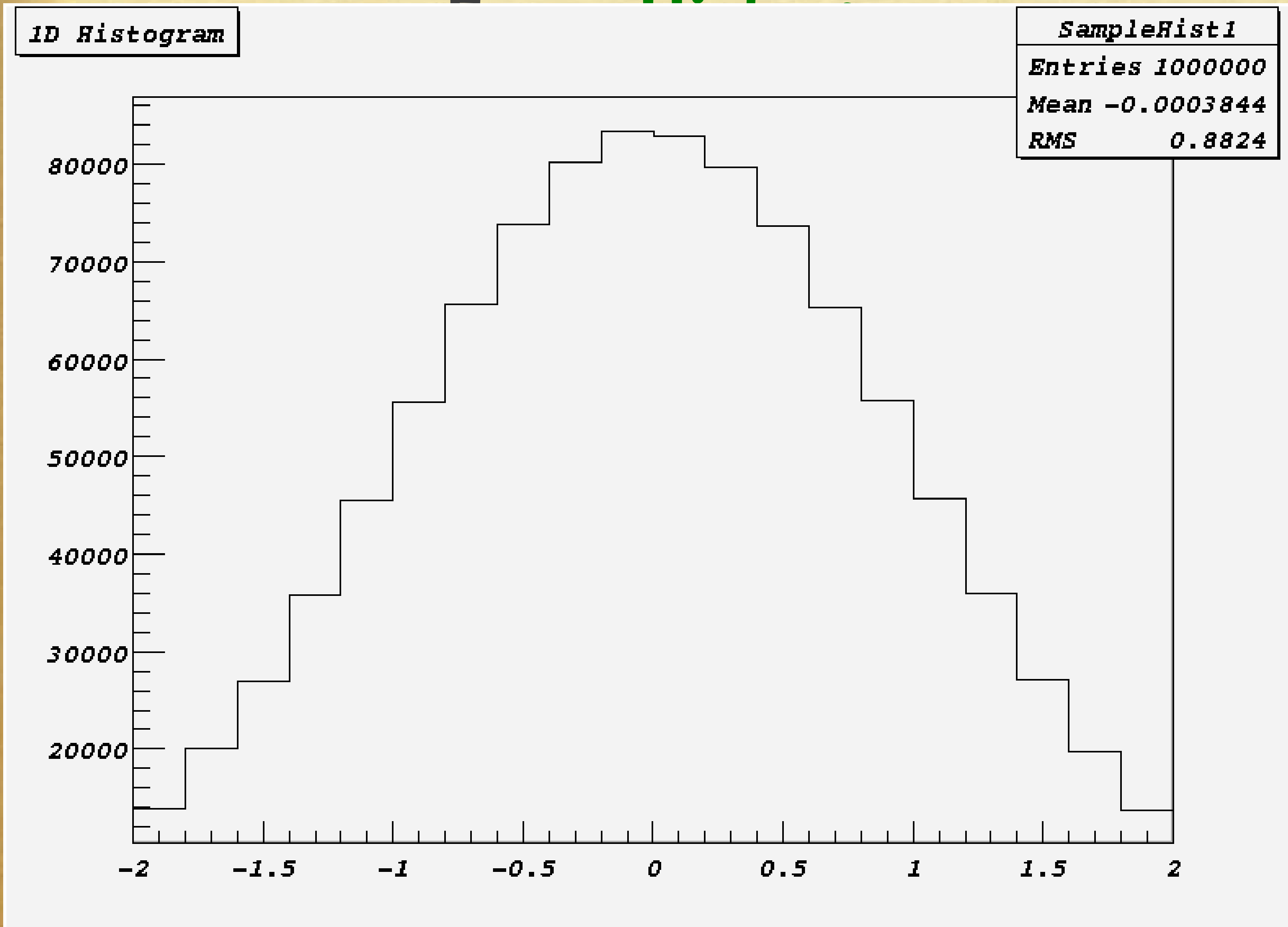
```
void mymacro() {
 TF1* f1 = new TF1("1DFunc", "2*sin(x)-6", -9,9);
 TCanvas* c1 = new TCanvas("c1", "c1", 0, 0, 800, 600);
 f1->Draw();
}
```

❖Macro: root/named_macro.C

- Named macro contains the code within a function having the same name as the macro file, without extension.

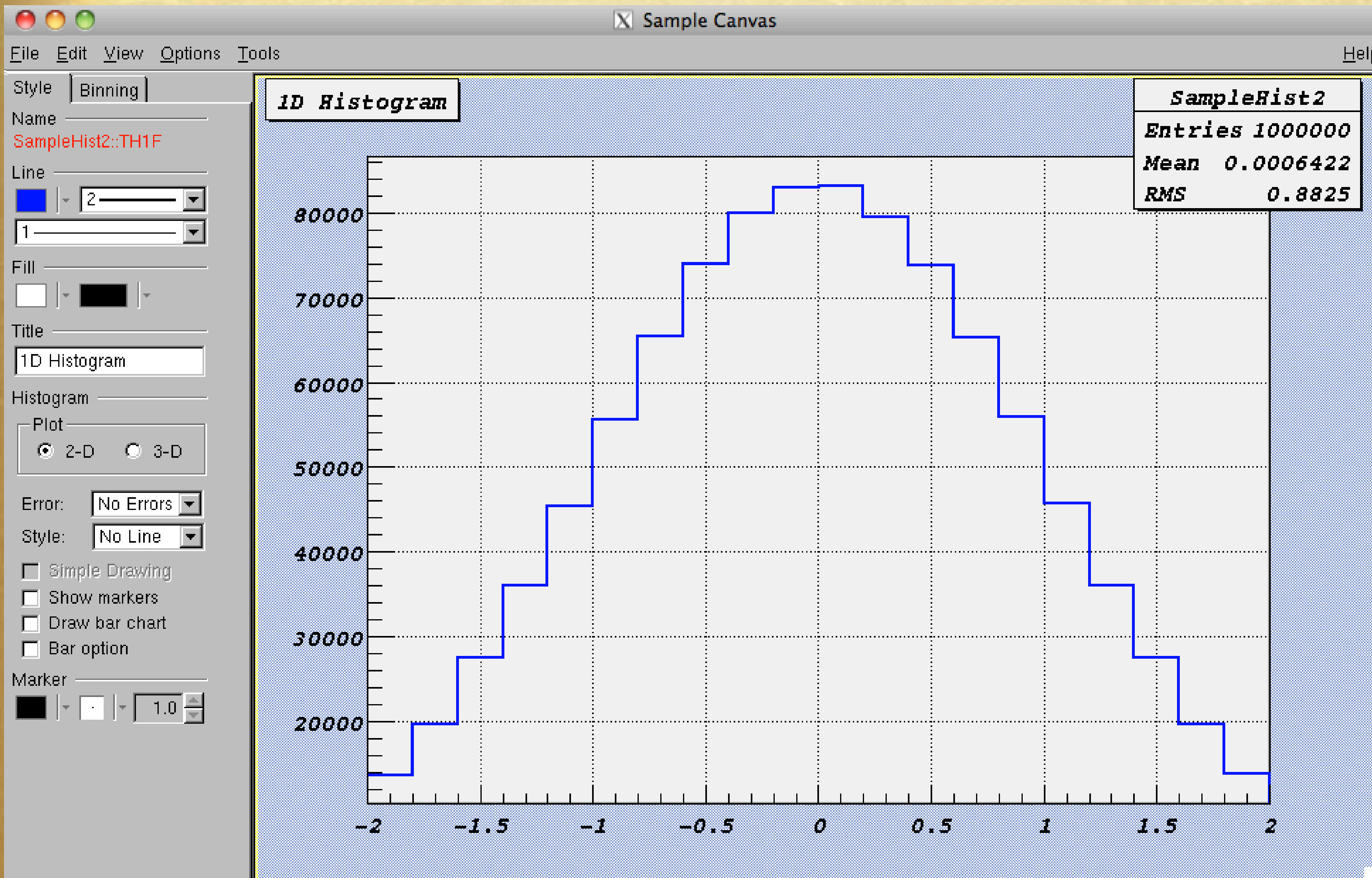
```
{
 TF1* f1 = new TF1("1DFunc", "2*sin(x)-6", -9,9);
 TCanvas* c1 = new TCanvas("c1", "c1", 0, 0, 800, 600);
 f1->Draw();
}
```

Macro: root/unnamed_macro.C



1D Histogram
SampleHist1
Entries 1000000
Mean -0.0003844
RMS 0.8824
80000
70000
60000
50000
40000
30000
20000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

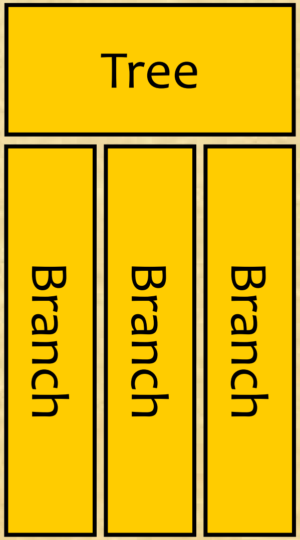
Ex. 5: GUI

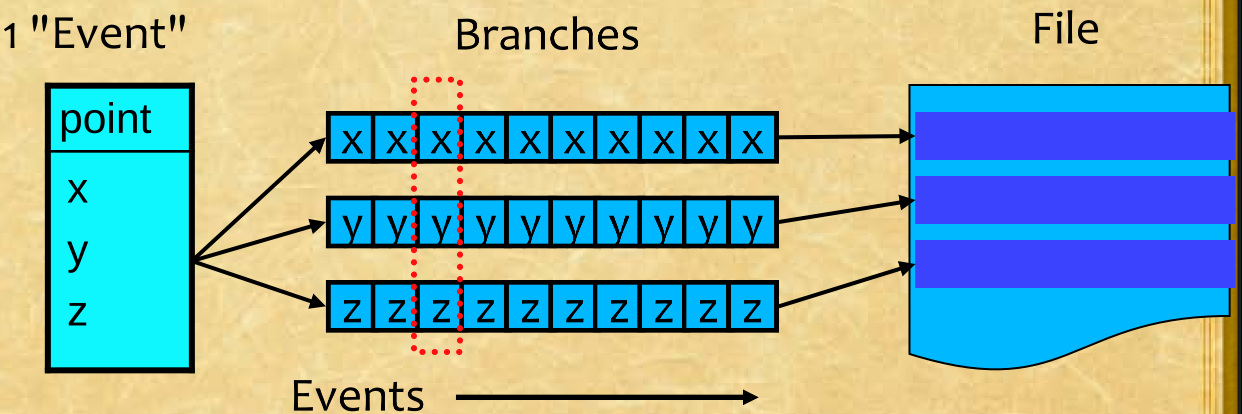


Sample Canvas
File
Edit
View
Options
Tools
Help
Style
Binning
Name
SampleHist2::TH1F
Line
Fill
Title
1D Histogram
Histogram
Plot
2-D
3-D
Error:
No Errors
Style:
No Line
Simple Drawing
Show markers
Draw bar chart
Bar option
Marker
1.0
1D Histogram
SampleHist2
Entries 1000000
Mean 0.0006422
RMS 0.8825
80000
70000
60000
50000
40000
30000
20000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Trees (class TTree)

- A tree is a container for data storage
- It consists of several *branches*
  - These can be in one or several files
  - Branches are stored contiguously (split mode)
- Set of helper functions to visualize the content (e.g. Draw, Scan)
- Compressed





Events

- Events are units of data which are stored in trees and can be processed independently from each other (PROOF's event-level parallelism is based on these properties).

✓ In the following exercises we will create a simple event class, then we will create a tree containing events, inspect and process/analyse it.

Ex. 6: Simple event class (1)

- Create a file *TGridKaEvent.C* with the following content.

```
#include <TObject.h>
class TGridKaEvent : public TObject {
 private:
 public:
  TGridKaEvent() : TObject() {};
  virtual ~TGridKaEvent() {};
  ClassDef(TGridKaEvent,1)
};
```

- Compile and print information about the class:
  - root [] .L TGridKaEvent.C+
  - root [] TGridKaEvent* event = new TGridKaEvent();
  - root [] event->Dump();

Ex. 6: Simple event class (2)

- We are now extending the TGridKaEvent class so that for every event it contains three variables fX, fY, fZ with double precision
  - Add 3 'Getter'-Functions GetX(),GetY(),GetZ()
  - Initialize fX, fY, fZ in the constructor with '0'
  - Add a method void FillGaus() which fills fX, fY, fZ with random variables from a Gaussian distribution
    - Use gRandom->Gaus(<mean>, <sigma>)

Ex. 6: Simple event class (3)

- Edit the file TGridKaEvent.C: add the lines marked with red:

```
#include <Tobject.h>
#include <TRandom.h>
#include <Rtypes.h>

class TGridKaEvent : public TObject {
private:
  Double_t fX, fY, fZ;
public:
  Double_t GetX() {return fX;}
  Double_t GetY() {return fY;}
  Double_t GetZ() {return fZ;}
  void FillGaus();
  TGridKaEvent() : TObject(), fX(0) , fY(0), fZ(0) {};
  virtual ~TGridKaEvent() {};
  ClassDef(TGridKaEvent,1)
};

void TGridKaEvent::FillGaus() {
  fX = gRandom->Gaus(4,2);
  fY = gRandom->Gaus(6,3);
  fZ = gRandom->Gaus(8,4);
}
```

Ex. 6: Simple event class (4)

- Recompile the class:
  - root [] .L TGridKaEvent.C+
- Create a new Event object:
  - root [] TGridKaEvent* e = new TGridKaEvent;
- Call the FillGaus() method and print the event object:
  - root [] e->FillGaus();
  - root [] e->Dump();
  - root [] e->FillGaus();
  - root [] e->Dump();

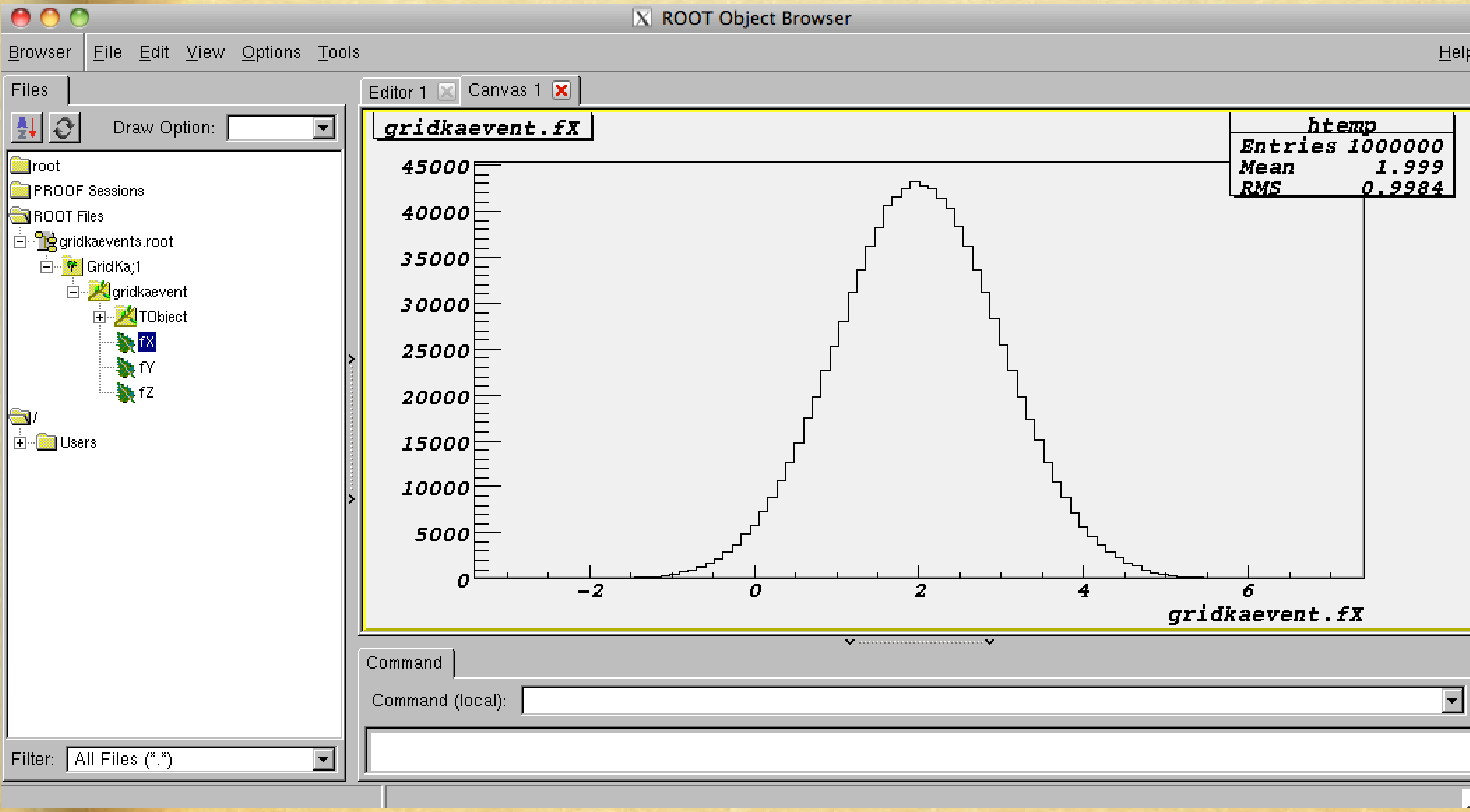
Ex. 7: Creating tree (1)

- In this exercise we will create a tree and fill it with events of class TGridKaEvent.
  - We will Create a macro *WriteGridKaTree.C* which will create a file gridkaevents.root to store a TTree wit*TGridKaEvent*h events containing one branch of type. We will use function FillGaus() to fill 1M times the event. Finally, we will fill the tree with events and save it to the file.

Ex. 7: Creating tree (2)

```
{
  gROOT->ProcessLine(".L TGridKaEvent.C+");

  TFile* f = TFile::Open("gridkaevents.root", "RECREATE");
  TTree* tree = new TTree("GridKa", "The GridKa Event Tree");
  TGridKaEvent* gridkaevent = new TGridKaEvent();
  TBranch* branch = tree->Branch("gridkaevent", "TGridKaEvent", &gridkaevent);

  for(Int_t i=0; i<1000000; ++i) {
   gridkaevent->FillGaus();
   tree->Fill();
  }

  tree->Write();
  f->Close();
}
```

Ex. 8: Inspecting the content of the tree



Data analysis: Selectors (1)

- To perform tree-based data analysis one can loop over all events in the tree and process them with Selector. The method TTree::Process() loops over the events in the tree and executes the code written in the Selector for every event.
  - ✓ We will create a selector to fill a histogram with the distribution of variable fX of the class GridKaEvent which we created in Exercise 7.

Data analysis: Selectors (2)

- The class TSelector provides the following methods:
  - *TSelector::Begin()* – This method is called once at the beginning of the tree processing. This is the place to create the histograms which you want to fill with the data of the tree.
  - TSelector::Process() – This method is invoked for every event in the tree. This is the place to put the analysis code and fill your histograms.
  - TSelector::Terminate() – This method is invoked at the end of the loop over tree events. This is the place to fit and draw your histograms.

Ex. 9: Creating Selector for data analysis (1)

- In this exercise we will create selector to traverse the tree events
- Create an empty selector macro GridKaAna.C to analyze your tree by calling MakeSelector on the tree object:
  - root [] .L TGridKaEvent.C+
  - root [] TFile* f = TFile::Open("gridkaevents.root");
  - root [] TTree* t = (TTree*) file->Get("GridKa");
  - root [] t->MakeSelector("GridKaAna");
    - ✓ Two files will be created in your current directory: GridKaAna.C and GridKaAna.h. They will contain the class GridKaAna inherited from TSelector. We need to add our code to methods Begin(), SlaveBegin(), Process(), SlaveTerminate() and Terminate() to do the analysis.

Ex. 9: Creating Selector for data analysis (2)

- Edit GridKaAna.h to add a pointer for the output histogram:
  - Add these two lines to GridKaAna.h in appropriate places:
    - `#include <TH1F.h>`
    - `TH1F* fHist;` (as a public data member)
- Add the following line to GridKaAna::SlaveBegin() in GridKaAna.C:
  - `fHist = new TH1F("fHist","x hist",100,-4,4);`
- Add the following line to GridKaAna::Process() in GridKaAna.C:
  - `GetEntry(entry);`
  - `fHist->Fill(fX);`
- Add the following line to GridKaAna::Terminate() in GridKaAna.C:
  - `fHist->DrawCopy();`

Ex. 9: Creating Selector for data analysis (3)

- (Re-)start your ROOT session
- Run the selector macro:

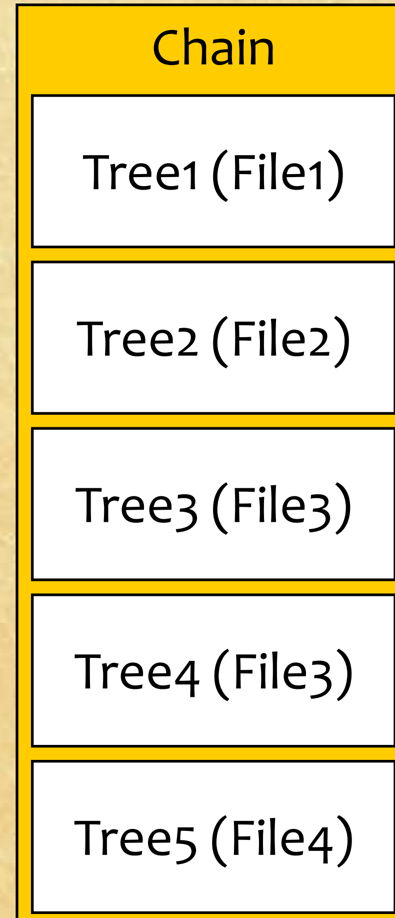
```
TFile* file = TFile::Open("gridkaevents.root");
TTree* GridKa = (TTree*) file->Get("GridKa");
GridKa->Process("GridKaAna.C+");
```

- The "+" after GridKaAna.C results in compilation of the code before execution
  - Always recommended
- Look at your results (in results.root)!

Chains (class TChain)

- A chain is a list of trees (in several files)
- TTree methods can be used
  - **Draw, Scan**

  → these iterate over all elements of the chain
- Selectors can be used with chains
  - **Process(const char* selectorFileName)**



Ex.10: Analysing the chain data

- Run the selector macro:

```
TChain* ch = new TChain(“GridKa”, “GridKa Chain”);
ch->AddFile(“gridkaevents.root”);
ch->Process("GridKaAna.C+");
```

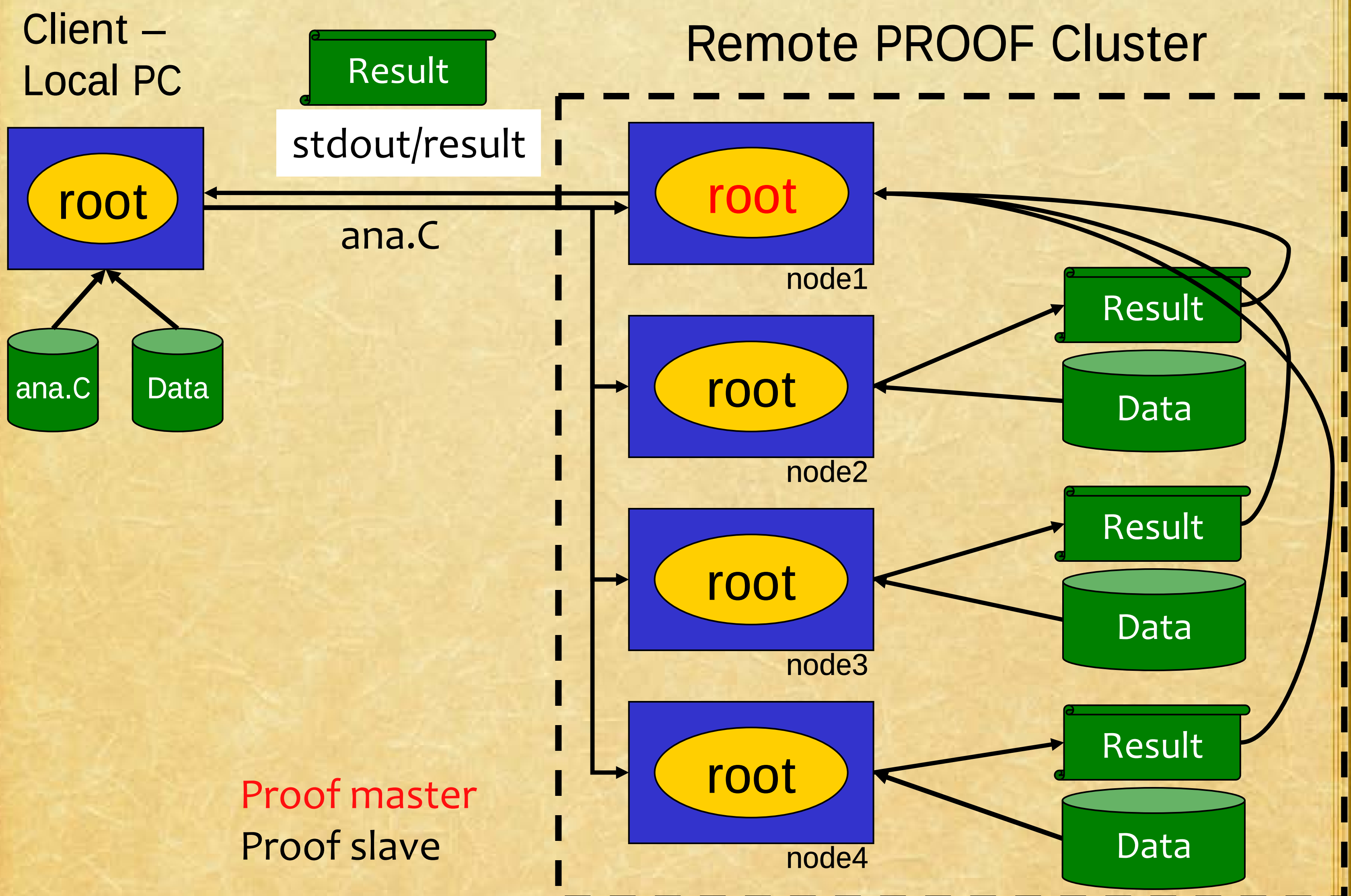
What is PROOF? Why PROOF?

- PROOF stands for Parallel ROOt Facility
- It allows parallel processing of large amount of data. The output results can be directly visualised (e.g. the output histogram can be drawn at the end of the proof session).
- PROOF is NOT a batch system.
- The data which you process with PROOF can reside on your computer, PROOF cluster disks or grid.
- The usage of PROOF is transparent: you should not rewrite your code you are running locally on your computer.
- No special installation of PROOF software is necessary to execute your code: PROOF is included in ROOT distribution.

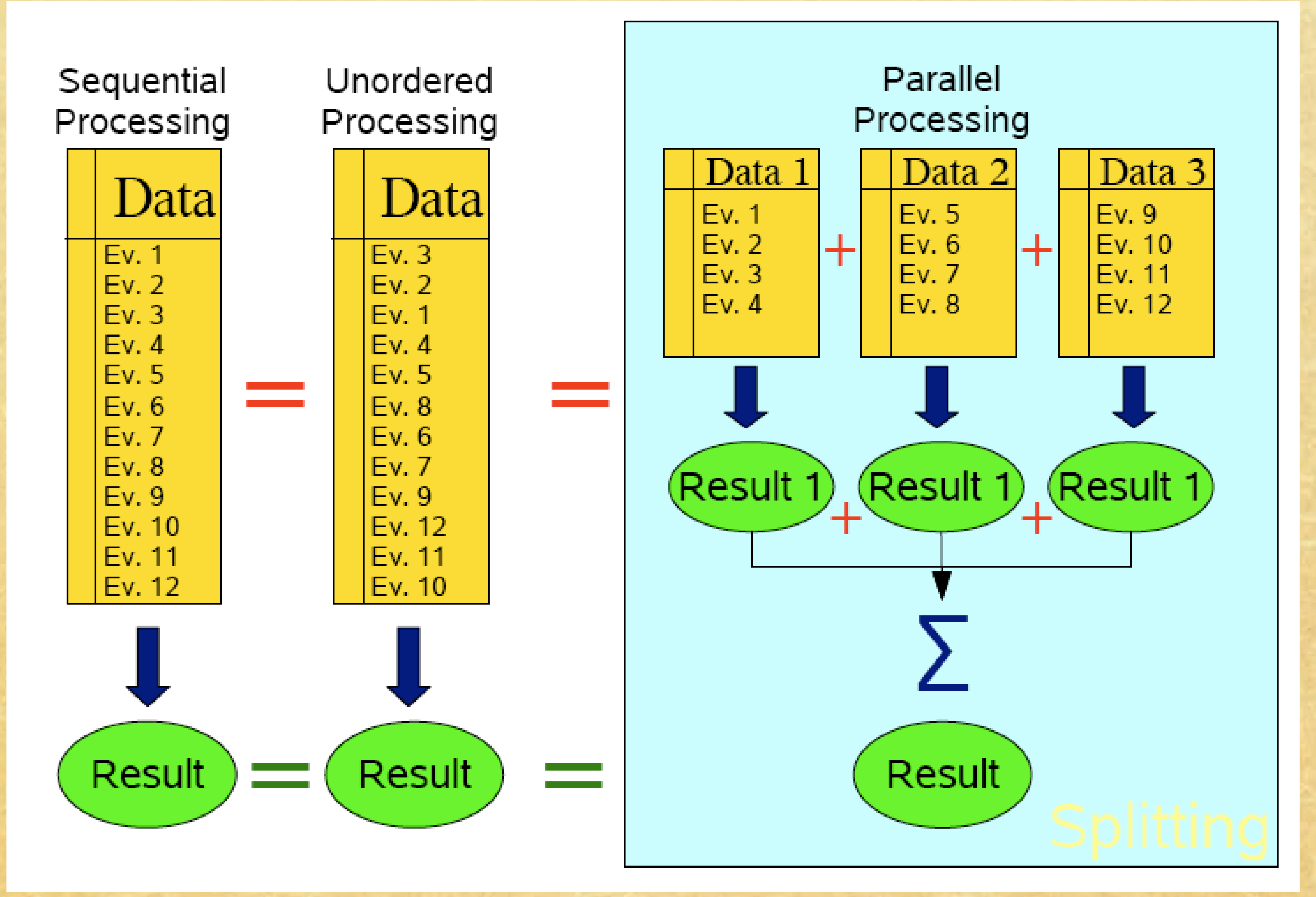
End of ROOT tutorial!

Questions?

How does PROOF analysis work?



Trivial parallelism



PROOF terminology

The following terms are used in PROOF:

- PROOF cluster
  - Set of machines communicating with PROOF protocol. One of those machines is normally designated as Master (multi-Master setup is possible as well). The rest of machines are Workers.
- Client
  - Your machine running a ROOT session that is connected to a PROOF master.
- Master
  - Dedicated node in PROOF cluster that is in charge of assigning workers the chunks of data to be processed, collecting and merging the output and sending it to the Client.
- Slave/Worker
  - A node in PROOF cluster that processes data.
- Query
  - A job submitted from the Client to the PROOF cluster.

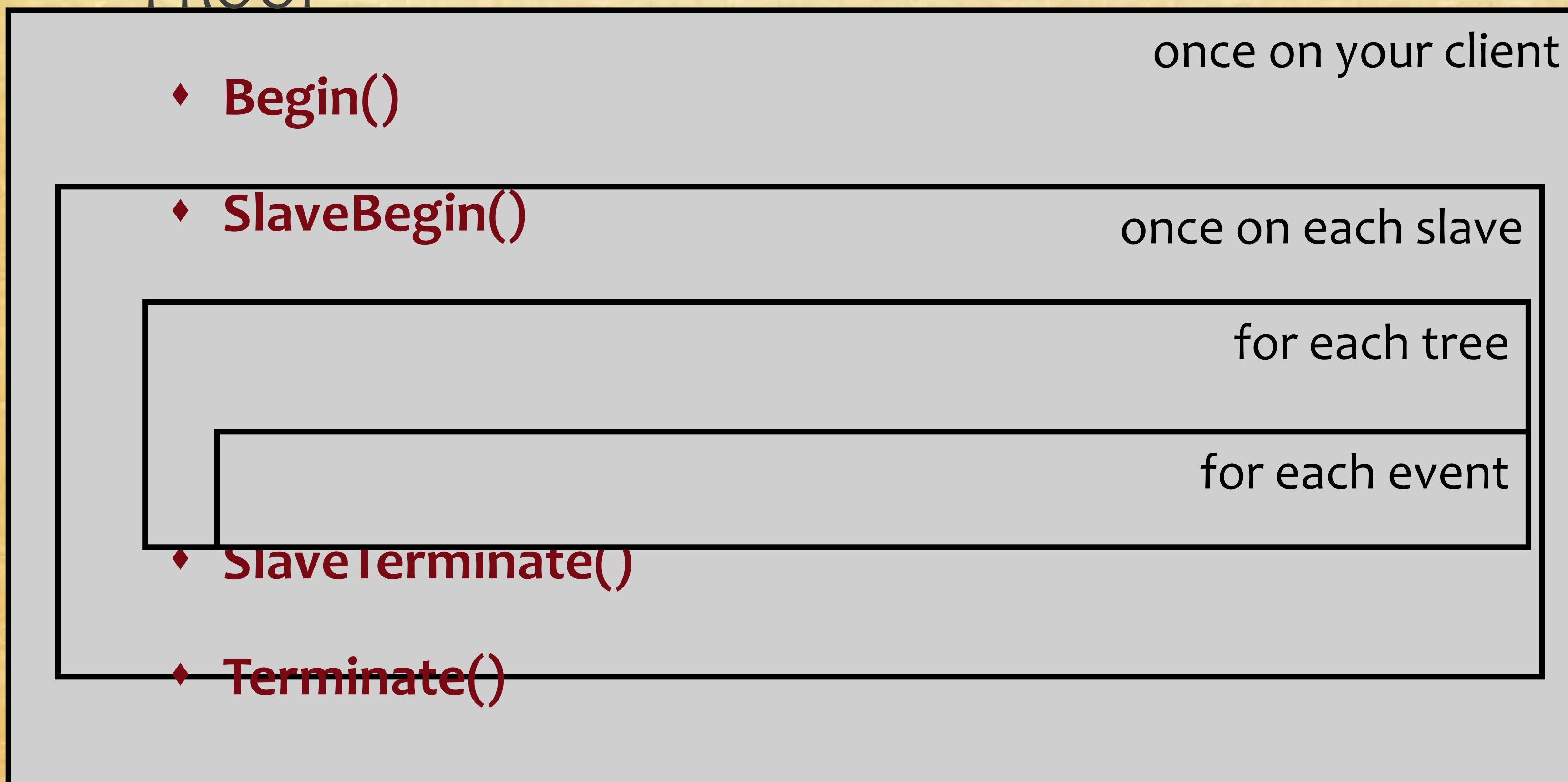
    A query consists of a selector and a chain.
- Selector
  - A class containing the analysis code (more details later)
- Chain
  - A list of files (trees) to process (more details later)
- PROOF Archive (PAR) file
  - Archive file containing files for building and setting up a package on the PROOF cluster. Normally is used to supply extra packages used by user job.

What should I do to run a job on PROOF cluster?

- Create a chain containing the files you want to analyse.
- Write your job code and put it in the selector (class deriving from TSelector).
- Define inputs and outputs via predefined (by class TSelector) lists (TList objects) *fInput* and *fOutput*.
- Create extra packages (if any) which you need by your analysis and put them in PAR file to be deployed on the PROOF cluster.

The structure of the Selector

- Classes derived from TSelector can run locally and in PROOF



Input / Output

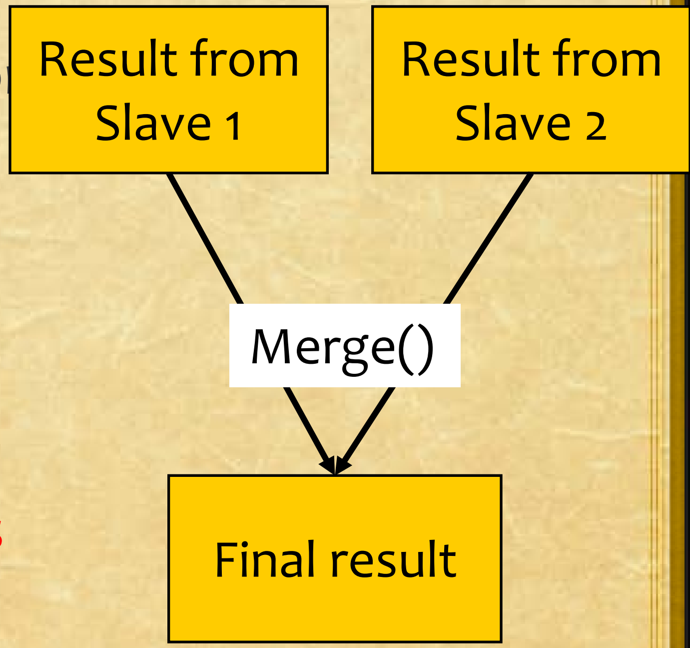
- The TSelector class has two members of type TList:
  - fInput, fOutput
  - These are used to get input data or put output data
- Input list
  - Before running a query the input list is populated **gProof->AddInput(myObj)**
  - In the selector (**Begin, SlaveBegin**) the object is retrieved: **fInput->FindObject("myObject")**

Input / Output (2)

- Output list
  - The output has to be added to the output list on each slave (in **SlaveBegin/SlaveTerminate**)
    fOutput->Add(fResult)
  - PROOF merges the results from each slave automatically (see next slide)
  - On the client (in **Terminate**) you retrieve the object and save it, display it, ...
    fOutput->FindObject("myResult")

Input / Output (3)

- Merging
  - Objects are identified by name
  - Standard merging implementation for histograms, trees, n-tuples available
  - Other classes need to implement **Merge(TCollection*)**
  - When no merging function is available all the individual objects are returned



The structure of the PAR files

- PAR files: **P**ROOF **AR**chive
  - Gzipped tar file
  - PROOF-INF directory
    - BUILD.sh, building the package, executed per Worker
    - SETUP.C, set environment, load libraries, executed per Worker

- API to manage and activate packages

gProof->UploadPackage("package")

gProof->EnablePackage("package")

ROOT Tutorial (4)

Use an automatic selector macro for tree analysis

- Load the next event; fill the histogram in Process

```
Bool_t GridKaAna::Process(Long64_t entry) {
  ...
  GetEntry(entry); // load the next event
  fHist->Fill(fX);
}
```

- Write the histogram to a file in Terminate

```
void GridKaAna::Terminate() {
  ...
  TFile resultfile("results.root", "RECREATE");
  fOutput->Write();
  resultfile.Close();

}
```

ROOT Tutorial (4)

How-to run your selector macro [chains]

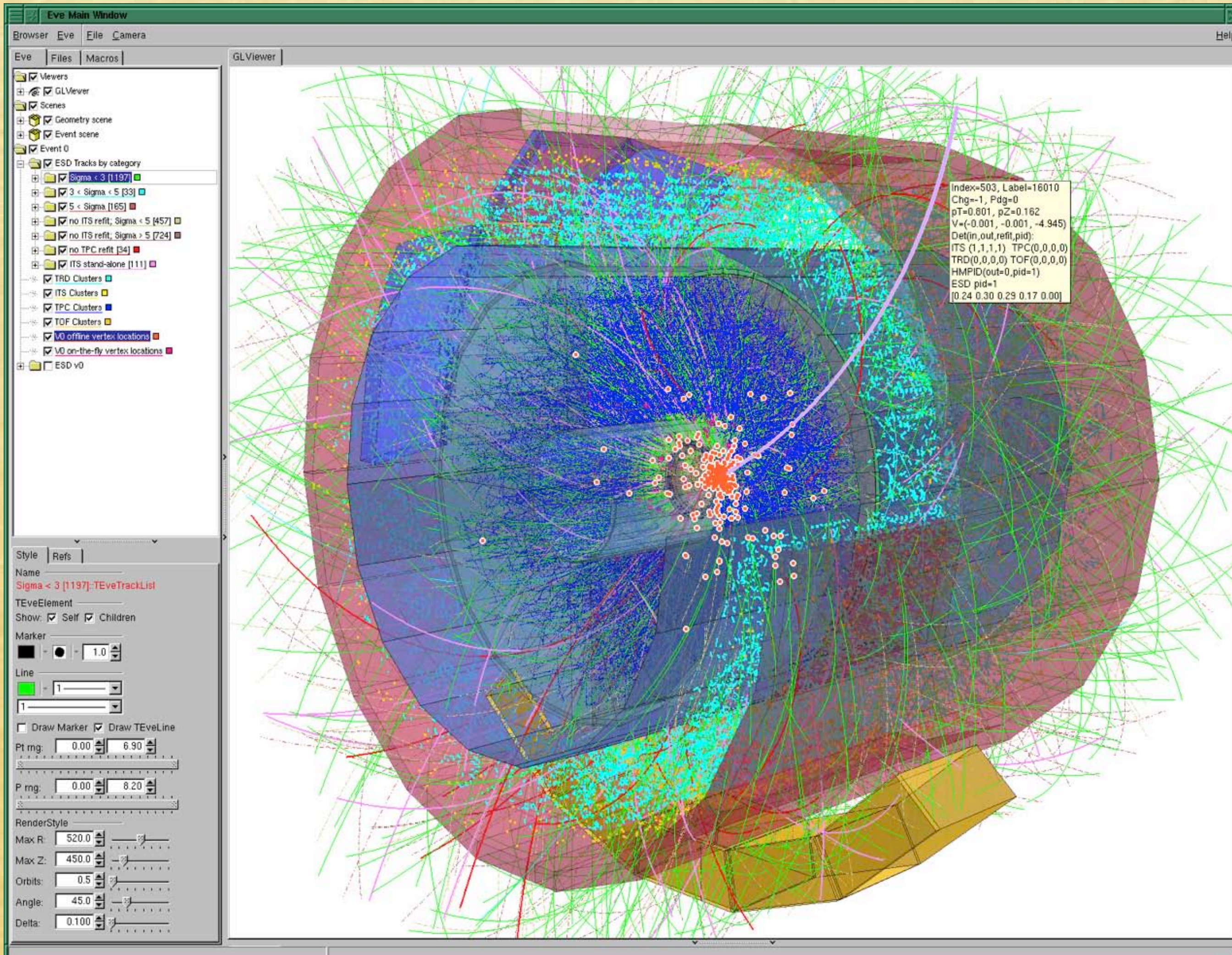
- Run the selector macro:

```
TChain* ch = new TChain(“GridKa”, “GridKa Chain”);
ch->AddFile(“gridkaevents.root”);
ch->Process("GridKaAna.C+");
```

Running on PROOF Lite

```
TPoof::Open(“”);
TChain* ch = new TChain(“GridKa”, “GridKa Chain”);
ch->AddFile(“gridkaevents.root”);
ch->SetProof();
ch->Process("GridKaAna.C+");
```

ROOT Features: Data Analysis



New Event structure

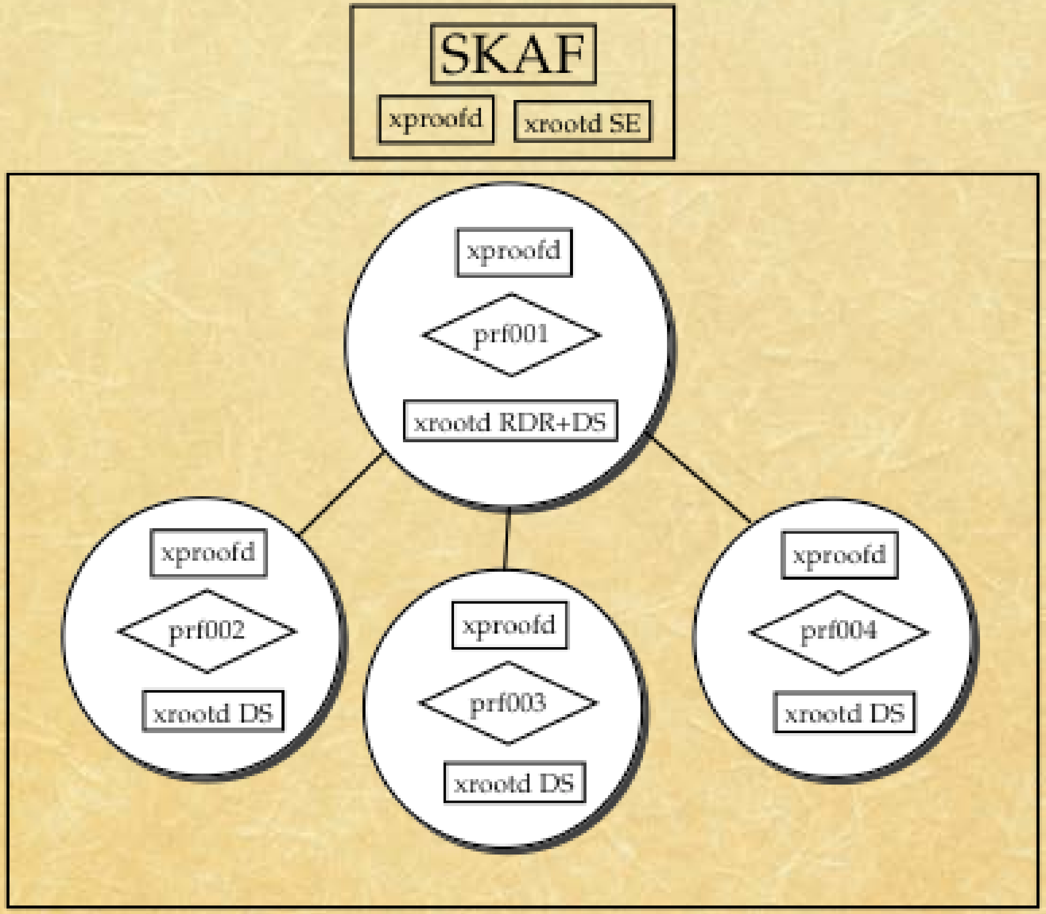
- We will look at more complex Event structure
  - Event
    - Tracks
    - EventHeader
  - Event.h, Event.cxx
- We will generate files
  - GenerateFiles.C
- We will create MySelector from scratch
  - MySelector.C, MySelector.h

Processing data on PROOF

- We will use
  - RunSelector.C
  - ProofBenchDataSel.par
  - CreateDataSet.C
- PROOF Lite
  - Local files
  - Local files using xrootd
  - Dataset
- PROOF cluster
  - Small dataset
  - Full dataset

Thank you for your attention!

How PROOF cluster works



Installation of PROOF cluster

- Install root on all workers
- Start xproofd daemon
  - By hand
  - Using PoD
    - http://pod.gsi.de
  - Using PEAC (using SSH plugin from PoD)
- Start xrootd and cmsd daemons
  - Using PEAC data management setup (available soon)

PoD schema

- picture