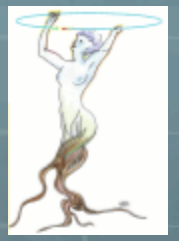
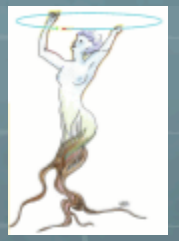


Large Data Bases in High Energy Physics

Frontiers in Diagnostic Technologies
Frascati November 26

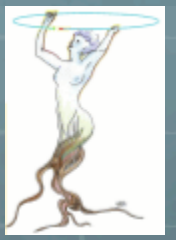
Rene Brun/CERN

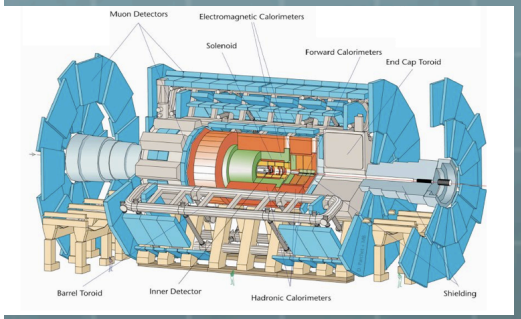


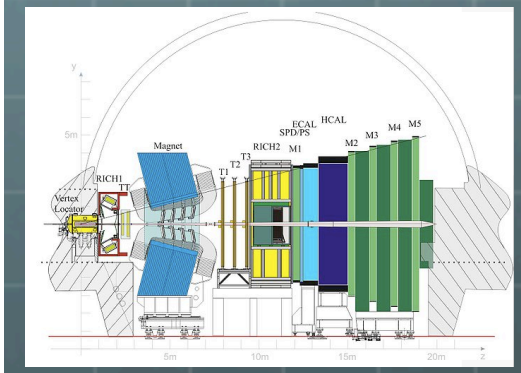
High Energy Physics

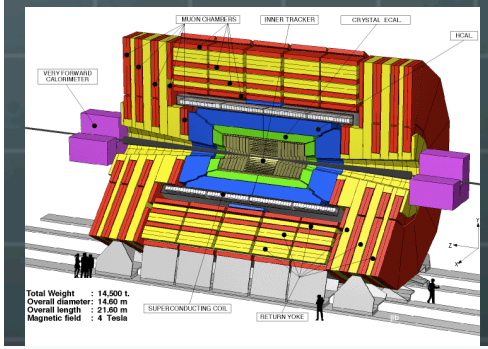
- About 10000 physicists in the HEP domain distributed in a few hundred universities/labs
- About 6000 involved in the CERN LHC program
  - ATLAS : 2200
  - CMS : 2100
  - ALICE: 1100
  - LHCb : 600

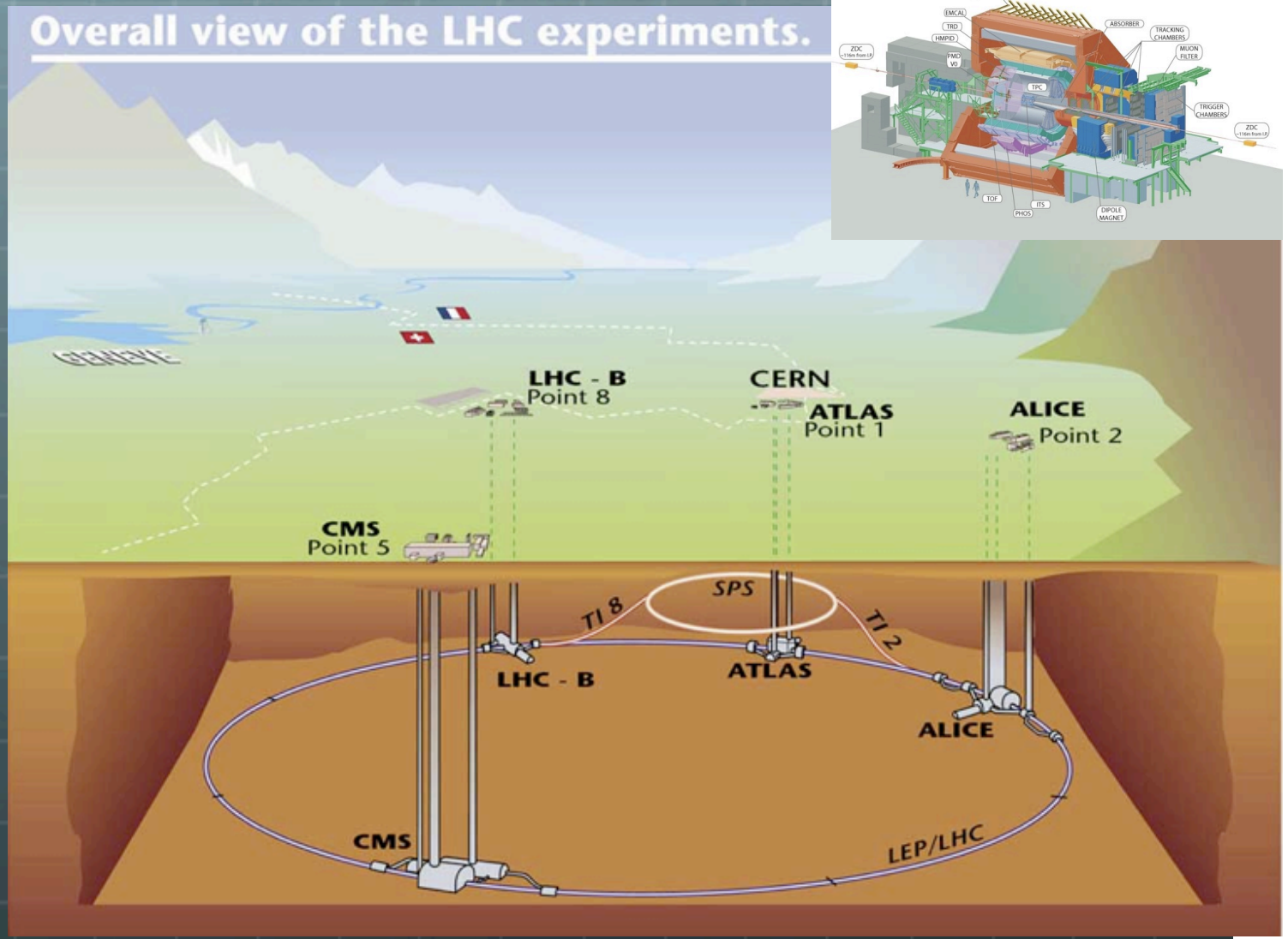
LHC




Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

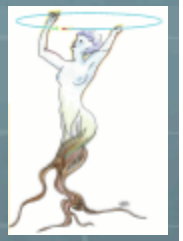

Magnet
RICH1
RICH2
TT
T1
T2
T3
M1
M2
M3
M4
M5
ECAL
HCAL
SPD/PS
5m
10m
15m
20m


MUON CHAMBERS
INNER TRACKER
CRYSTAL ECAL
HCAL
VERY FORWARD CALORIMETER
SUPERCONDUCTING COIL
RETURN YOKE
Total Weight : 14,500 t.
Overall diameter : 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla


Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

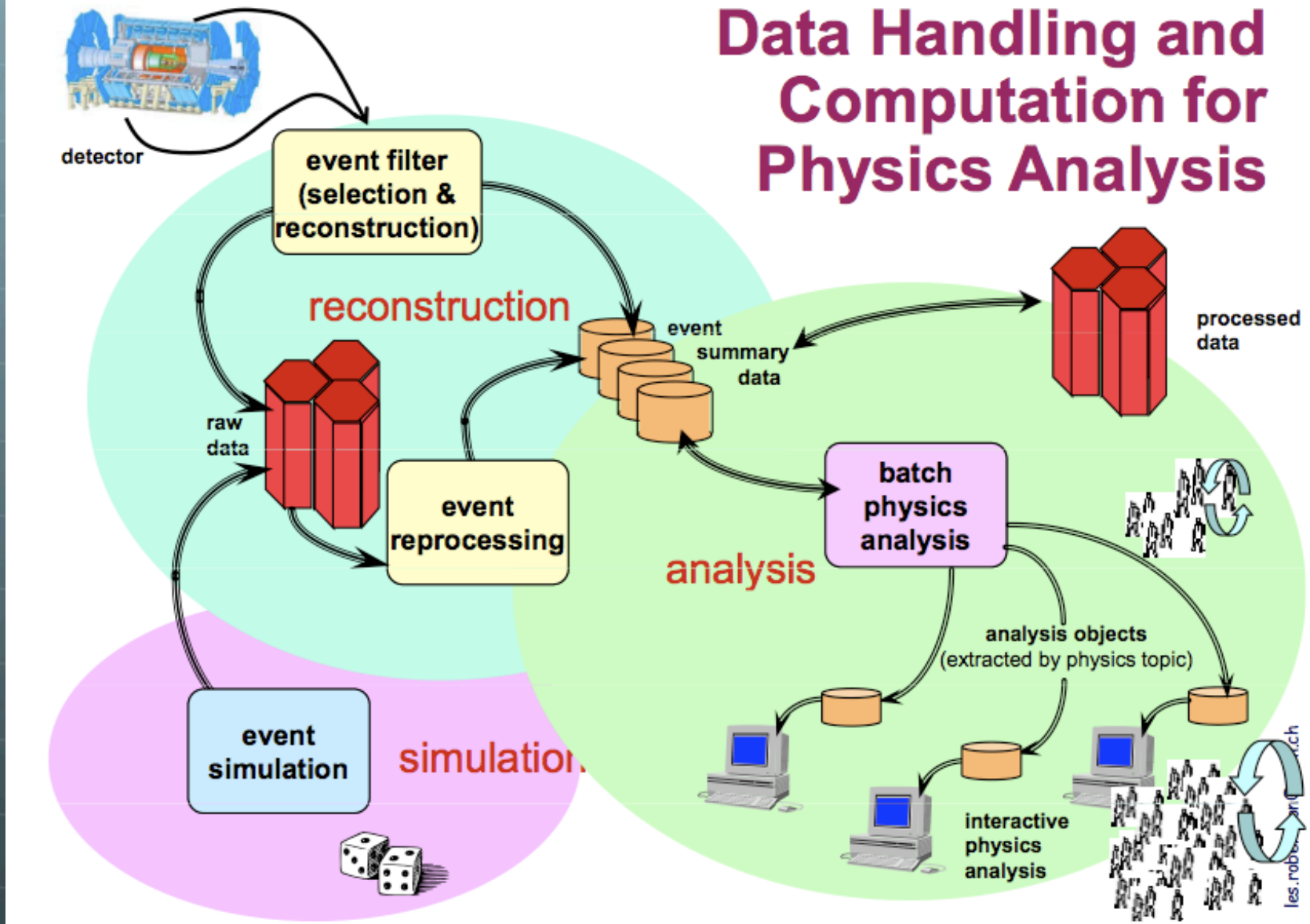
ACORDE
EMCAL
TRD
HMPID
PMD
V0
ABSORBER
TRACKING CHAMBERS
MUON FILTER
ZDC
TPC
TRIGGER CHAMBERS
ZDC
TOF
ITS
PHOS
DIPOLE MAGNET

HEP environment

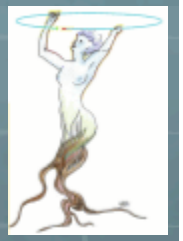


- In the following slides I will discuss mainly the LHC data bases, but the situation is quasi identical in all other labs in HEP and Nuclear Physics labs too.
- A growing number of AstroPhysics experiments is following a similar model.
- HEP tools also used in Biology, Finance, Oil industry, car makers, etc

LHC expts data flow



Data Sets types



Simulated data
10 Mbytes/event

Raw data
1 Mbyte/event

1000 events/data set

Event Summary Data
1 Mbyte/event

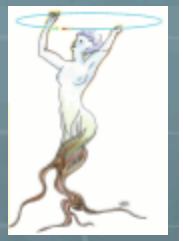
A few reconstruction passes

About 10 data sets for 1 raw data set

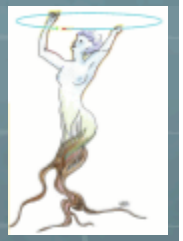
Analysis Objects Data
100 Kbytes/event

Several analysis groups
Physics oriented

Data Sets Total Volume



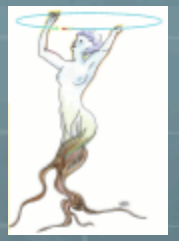
- Each experiment will take about 1 billion events/year
- 1 billion events → 1 million raw data sets of 1 Gbyte
- ===→10 million data sets with ESDs and AODs
- ==→ 100 million data sets with the replica on the GRID
- All event data are C++ objects streamed to ROOT files



Relational Data Bases

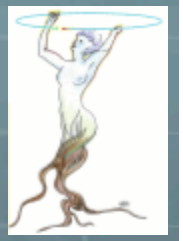
- RDBMS (mainly Oracle) are used in many places and mainly at T0
  - for detector calibration and alignment
  - for File Catalogs
- The total volume is small compared to event data (a few tens of Gigabytes, may be 1 Terabyte)
- Often RDBMS exported as ROOT read-only files for processing on the GRID
- Because most physicists do not see the RDBMS, I will not describe /mention it any more in this talk.

How did we reach this point



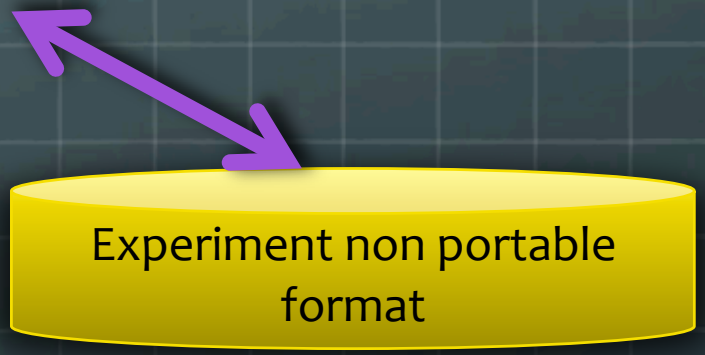
- Today's situation with ROOT + RDBMS was reached circa 2002 when it was realized that an alternative solution based on an object-oriented data base (Objectivity) could not work.
- It took us a long time to understand that a file format alone was not sufficient and that an automatic object streaming for any C++ class was fundamental.
- One more important step was reached when we understood the importance of self-describing files and automatic class schema evolution.

The situation in the 70s

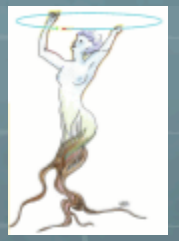


- Fortran programming. Data in common blocks written and read by user controlled subroutines.
- Each experiment has his own format. The experiments are small (10 to 50 physicists) with short life time (1 to 5 years).

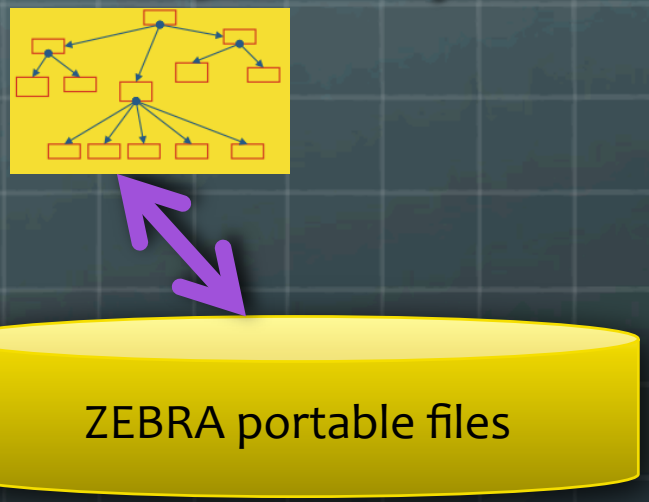
```
common /data1/np, px(100),py(100),pz(100)...
common/data2/nhits, adc(50000), tdc(10000)
```



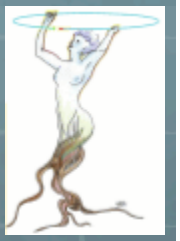
The situation in the 80s



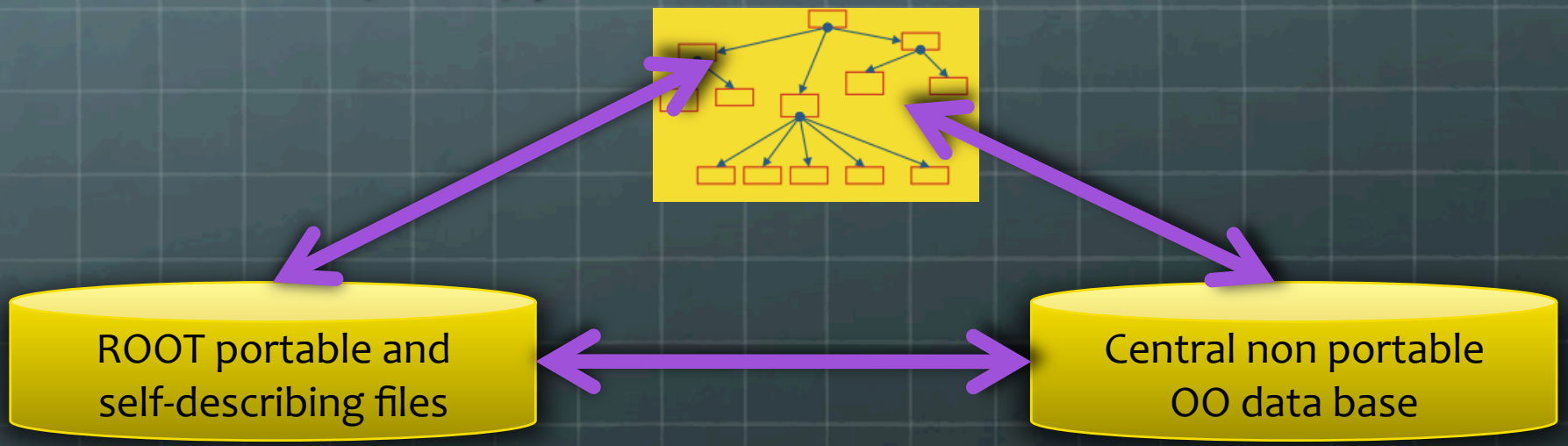
- Fortran programming. Data in banks managed by data structure management systems like ZEBRA, BOS writing portable files with some data types description.
- The experiments are bigger (100 to 500 physicists) with life time between 5 and 10 years.



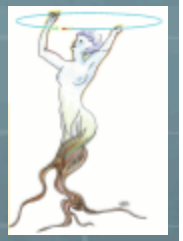
The situation in the 90s



- Painful move from Fortran to C++.
- Drastic choice between HEP format (ROOT) or a commercial system (Objectivity).
- It took more than 5 years to show that a central OO data base with transient object = persistent object and no schema evolution could not work
- The experiments are huge (1000 to 2000 physicists) with life time between 15 and 25 years.

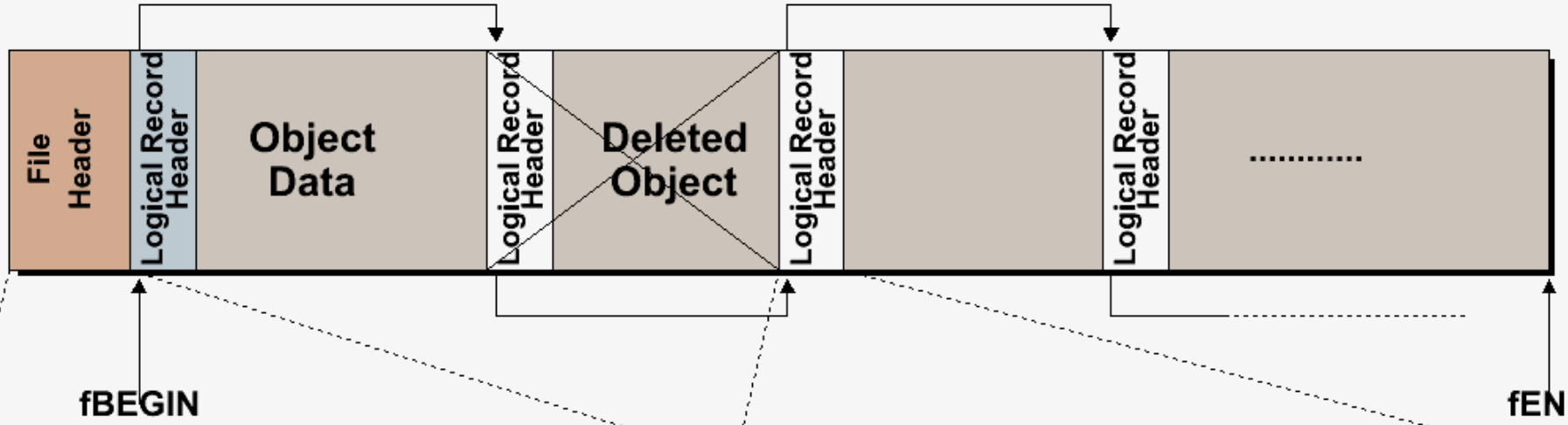


ROOT in a nutshell



- Automatic C++ objects Input/Output
- C++ interpreter, class parser, JIT with LLVM
- Histogram, Math Libs (Linear algebra, random numbers, minimization, multivariate analysis, etc)
- Detector geometry with navigation in millions of objects
- 2 and 3D visualization
- GUI with designer, recorder, re-player

ROOT File description



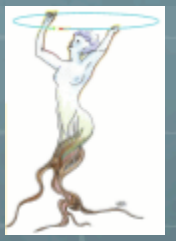
File Header

"root": Root File Identifier
fVersion: File version identifier
fBEGIN: Pointer to first data record
fEND: Pointer to first free word at EOF
fSeekFree: Pointer to FREE data record
fNbytesFree: Number of bytes in FREE
fNfree: Number of free data records
fNbytesName: Number of bytes in name/title
fUnits: Number of bytes for pointers
fCompress: Compression level

Logical Record Header (TKEY)

fNbytes: Length of compressed object
fVersion: Key version identifier
fObjLen: Length of uncompressed object
fDatime: Date/Time when written to store
fKeylen: Number of bytes for the key
fCycle : Cycle number
fSeekKey: Pointer to object on file
fSeekPdir: Pointer to directory on file
fClassName: class name of the object
fName: name of the object
fTitle: title of the object

TFile::Map

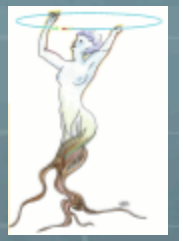


```
root [0] TFile *falice = TFile::Open("http://root.cern.ch/files/alice_ESDs.root")
root [1] falice->Map()
20070713/195136  At:100     N=120       TFile
20070713/195531  At:220     N=274       TH1D            CX =  7.38
20070713/195531  At:494     N=331       TH1D            CX =  2.46
20070713/195531  At:825     N=290       TH1D            CX =  2.80
….
20070713/195531  At:391047  N=1010      TH1D            CX =  3.75
Address = 392057        Nbytes = -889   =====G A P==========
20070713/195519  At:392946  N=2515      TBasket         CX = 195.48
20070713/195519  At:395461  N=23141     TBasket         CX =  1.31
20070713/195519  At:418602  N=2566      TBasket         CX = 10.40
20070713/195520  At:421168  N=2518      TBasket         CX = 195.24
20070713/195532  At:423686  N=2515      TBasket         CX = 195.48
20070713/195532  At:426201  N=2023      TBasket         CX = 15.36
20070713/195532  At:428224  N=2518      TBasket         CX = 195.24
20070713/195532  At:430742  N=375281    TTree           CX =  4.28
20070713/195532  At:806023  N=43823     TTree           CX = 10.84
20070713/195532  At:849846  N=6340      TH2F            CX =
20070713/195532  At:856186  N=951       TH1F            CX =  9.02
20070713/195532  At:857137  N=16537     StreamerInfo    CX =  3.74
20070713/195532  At:873674  N=1367      KeysList
20070713/195532  At:875041  N=1         END
root [2]
```

Classes dictionary

List of keys

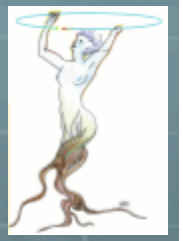
TFile::ls



```
root [3] falice->ls()
  KEY: TH1D     logTRD_backfit;1
  KEY: TH1D     logTRD_refit;1
  KEY: TH1D     logTRD_clSearch;1
  KEY: TH1D     logTRD_X;1
  KEY: TH1D     logTRD_ncl;1
  KEY: TH1D     logTRD_nclTrack;1
  KEY: TH1D     logTRD_minYPos;1
  KEY: TH1D     logTRD_minYNeg;1
  KEY: TH2D     logTRD_minD;1
  KEY: TH1D     logTRD_minZ;1
  KEY: TH1D     logTRD_deltaX;1
  KEY: TH1D     logTRD_xCl;1
  KEY: TH1D     logTRD_clY;1
  KEY: TH1D     logTRD_clZ;1
  KEY: TH1D     logTRD_clB;1
  KEY: TH1D     logTRD_clG;1
  KEY: TTree    esdTree;1       Tree with ESD objects
  KEY: TTree    HLTesdTree;1    Tree with HLT ESD objects
  KEY: TH2F     TOFDig_ClusMap;1
  KEY: TH1F     TOFDig_NClus;1
  KEY: TH1F     TOFDig_ClusTime;1
  KEY: TH1F     TOFDig_ClusToT;1
  KEY: TH1F     TOFRec_NClusW;1
  KEY: TH1F     TOFRec_Dist;1
  KEY: TH2F     TOFDig_SigYVsP;1
  KEY: TH2F     TOFDig_SigZVsP;1
  KEY: TH2F     TOFDig_SigYVsPWin;1
  KEY: TH2F     TOFDig_SigZVsPWin;1
```

Shows the list of objects
In the current directory
(like in a file system)

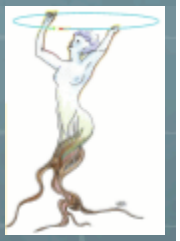
Self-describing files



- Dictionary for persistent classes written to the file.
- ROOT files can be read by foreign readers
- Support for Backward and Forward compatibility
- Files created in 2001 must be readable in 2015
- Classes (data objects) for all objects in a file can be regenerated via TFile::MakeProject

```
Root >TFile f("demo.root");

Root > f.MakeProject("dir","*","new++");
```

TFile::MakeProject



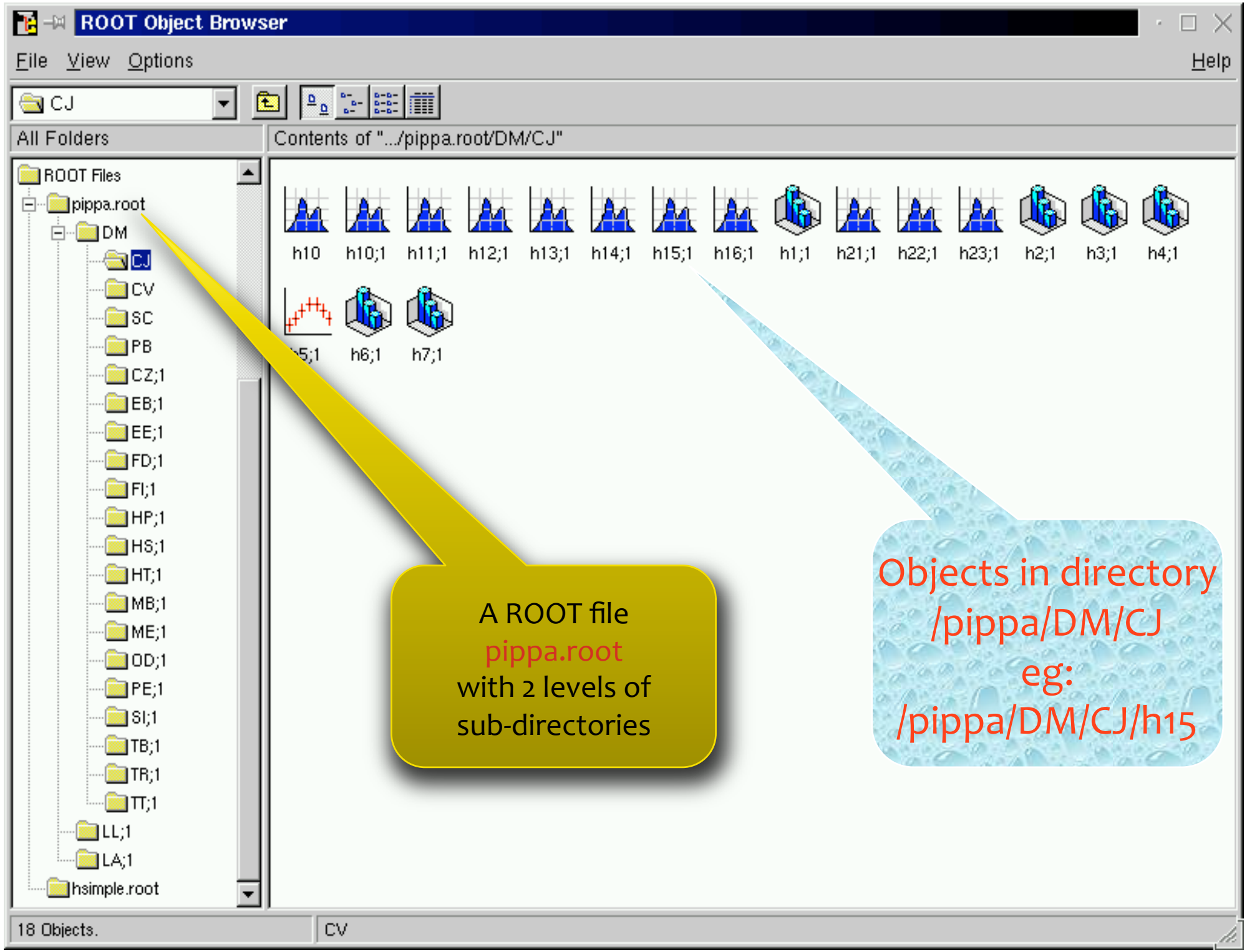
Generate C++ header files
and shared lib for the cla

```
(macbrun2) [253] root
root [0] TFile *falice = TFile::Open("http://ro
root [1] falice->MakeProject("alice","*","++");
MakeProject has generated 26 classes in alice
alice/MAKEP file has been generated
Shared lib alice/alice.so has been generated
Shared lib alice/alice.so has been dynamically
root [2] .!ls alice
AliESDCaloCluster.h      AliESDZDC.h
AliESDCaloTrigger.h      AliESDcascade.h
AliESDEvent.h            AliESDfriend.h
AliESDFMD.h              AliESDfriendTrack.h
AliESDHeader.h           AliESDkink.h
AliESDMuonTrack.h        AliESDtrack.h
AliESDPmdTrack.h         AliESDv0.h
AliESDRun.h              AliExternalTrackParam.h
AliESDTZERO.h            AliFMDFloatMap.h
AliESDTrdTrack.h         AliFMDMap.h
AliESDVZERO.h            AliMultiplicity.h
AliESDVertex.h           AliRawDataErrorLog.h
root [3]
```

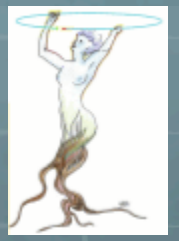
AliESDCaloCluster.h

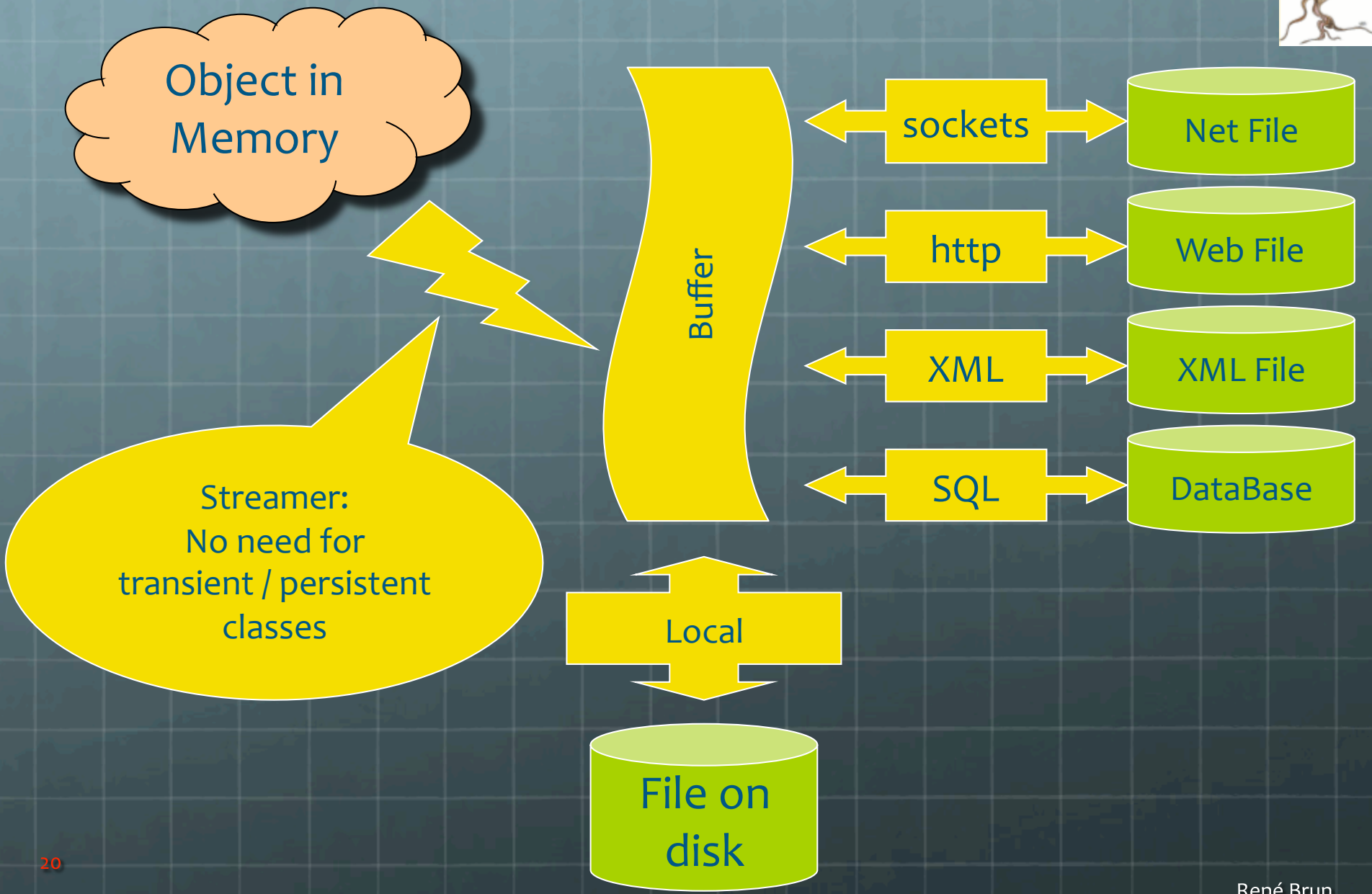
AliESDCaloCluster.h:2 <No selected symbol>

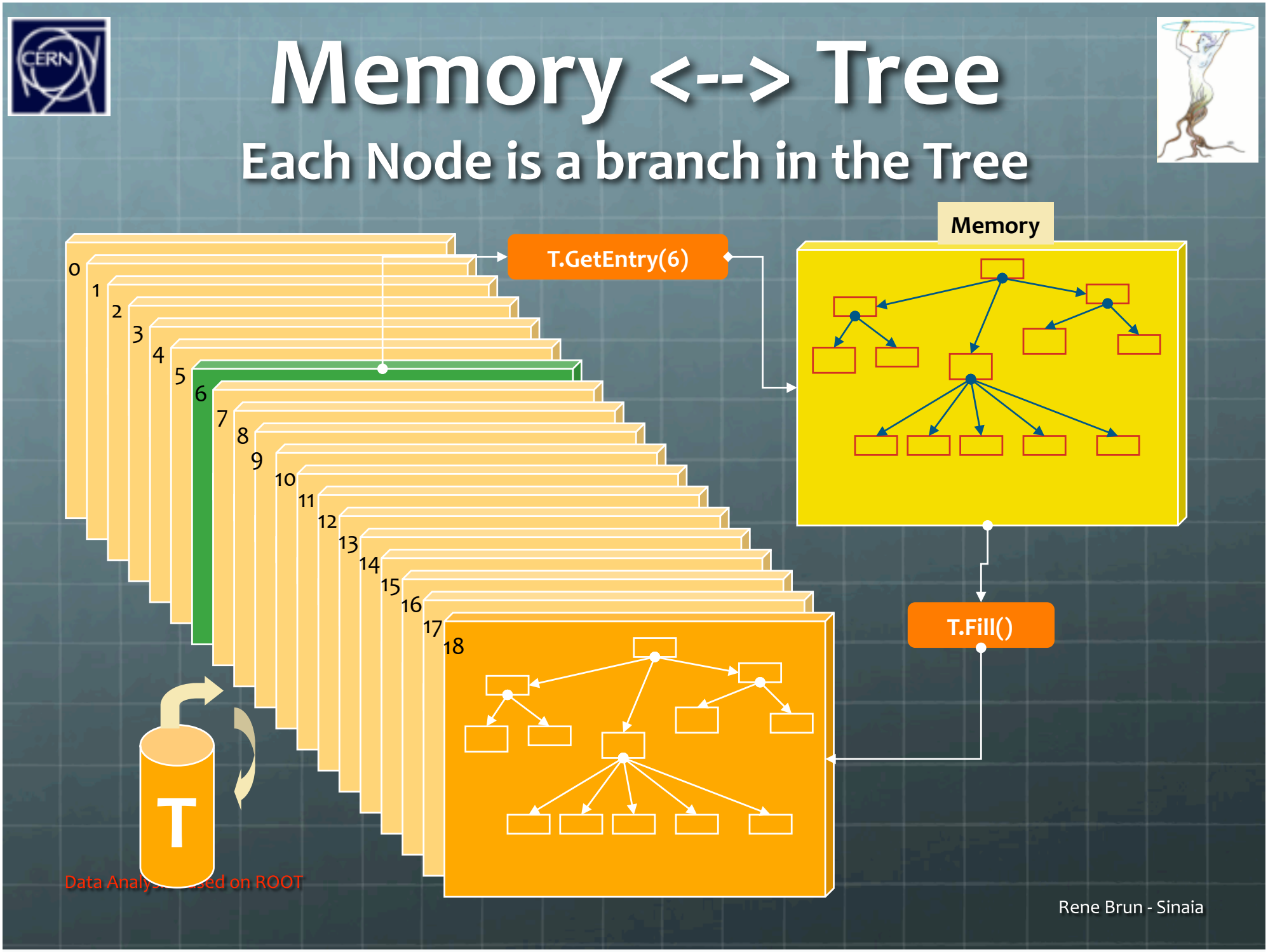
```
//////////////////////////////////////////////////////////
//   This class has been generated by TFile::MakeProject
//     (Sat Jan 24 15:24:51 2009 by ROOT version 5.23/01)
//      from the StreamerInfo in file http://root.cern.ch/files/alice_ESDs.root
//////////////////////////////////////////////////////////


#ifndef AliESDCaloCluster_h
#define AliESDCaloCluster_h
class AliESDCaloCluster;

#include "TObject.h"
#include "TArrayS.h"

class AliESDCaloCluster : public TObject {

public:
   Int_t     fID;                //Unique Id of the cluster
   Int_t     fClusterType;       //Flag for different clustering versions
   Bool_t    fEMCALCluster;      //Is this is an EMCAL cluster?
   Bool_t    fPHOSCluster;       //Is this is a PHOS cluster?
   Float_t   fGlobalPos[3];      //position in global coordinate system
   Float_t   fEnergy;            //energy measured by calorimeter
   Float_t   fDispersion;        //cluster dispersion, for shape analysis
   Float_t   fChi2;              //chi2 of cluster fit
   Float_t   fPID[10];           //"detector response probabilities" (for the PID)
   Float_t   fM20;               //2-nd moment along the main eigen axis
   Float_t   fM02;               //2-nd moment along the second eigen axis
   Float_t   fM11;               //2-nd mixed moment Mxy
   UShort_t  fNExMax;            //number of (Ex-)maxima before unfolding
   Float_t   fEmcCpvDistance;    //the distance from PHOS EMC rec.point to the closes
   Float_t   fDistToBadChannel;  //Distance to nearest bad channel
   TArrayS*  fTracksMatched;     //Index of tracks close to cluster. First entry is t
   TArrayS*  fLabels;            //list of primaries that generated the cluster, orde
   TArrayS*  fDigitAmplitude;    //digit energy (integer units)
   TArrayS*  fDigitTime;         //time of this digit (integer units)
   TArrayS*  fDigitIndex;        //calorimeter digit index

   AliESDCaloCluster();
   virtual ~AliESDCaloCluster();

   ClassDef(AliESDCaloCluster,5); // Generated by MakeProject.
};
#endif
```


ROOT Object Browser
File View Options Help
CJ
All Folders
Contents of ".../pippa.root/DM/CJ"
ROOT Files
pippa.root
DM
CJ
CV
SC
PB
CZ;1
EB;1
EE;1
FD;1
FI;1
HP;1
HS;1
HT;1
MB;1
ME;1
OD;1
PE;1
SI;1
TB;1
TR;1
TT;1
LL;1
LA;1
hsimple.root
h10 h10;1 h11;1 h12;1 h13;1 h14;1 h15;1 h16;1 h1;1 h21;1 h22;1 h23;1 h2;1 h3;1 h4;1
h6;1 h7;1
A ROOT file
pippa.root
with 2 levels of
sub-directories
Objects in directory
/pippa/DM/CJ
eg:
/pippa/DM/CJ/h15
18 Objects.
CV

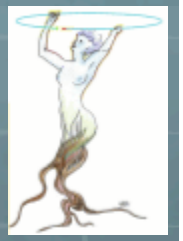
I/O



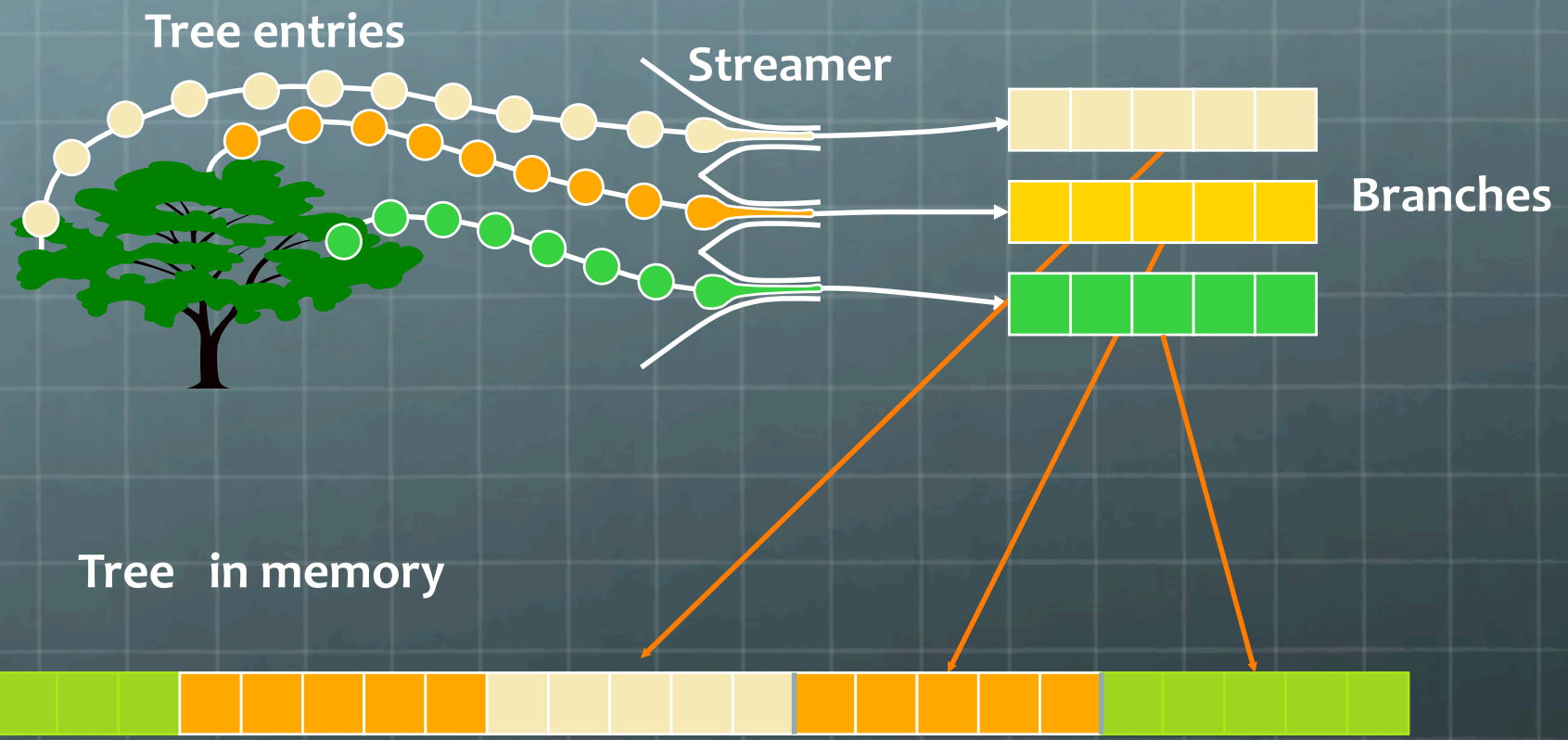

Object in Memory
Buffer
sockets
Net File
http
Web File
XML
XML File
SQL
DataBase
Streamer:
No need for
transient / persistent
classes
Local
File on disk


Memory <--> Tree
Each Node is a branch in the Tree
Memory
T.GetEntry(6)
T.Fill()
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
T
Data Analysis Based on ROOT
Rene Brun - Sinaia

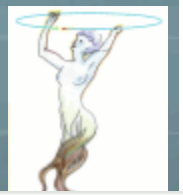
ROOT I/O -- *Split/Cluster*



Tree version



Browsing a TTree with TBrowser



ROOT Object Browser

File View Options Help

Electrons

All Folders

Contents of ".../atlfast.root/T/Electrons"

- Classes
- Global Variables
- Canvases
- Geometries
- Colors
- Styles
- Functions
- Network Connections
- Memory Mapped Files
- /home/brun/atlfast
- ROOT Files
- atlfast.root
  - T
    - Particles
    - Muons
    - Electrons
    - Photons
    - Jets
    - Misc
    - Trigger
    - Tracks
  - T;5
  - atlfast;1
- ATLFast

Electrons.fBits | Electrons.fUniqueID | Electrons.m_Eta | Electrons.m_KFcode

Electrons.m_KFmother | Electrons.m_MCParticle | Electrons.m_PT | Electrons.m_Phi

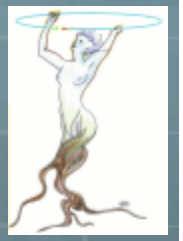
8 leaves of branch Electrons

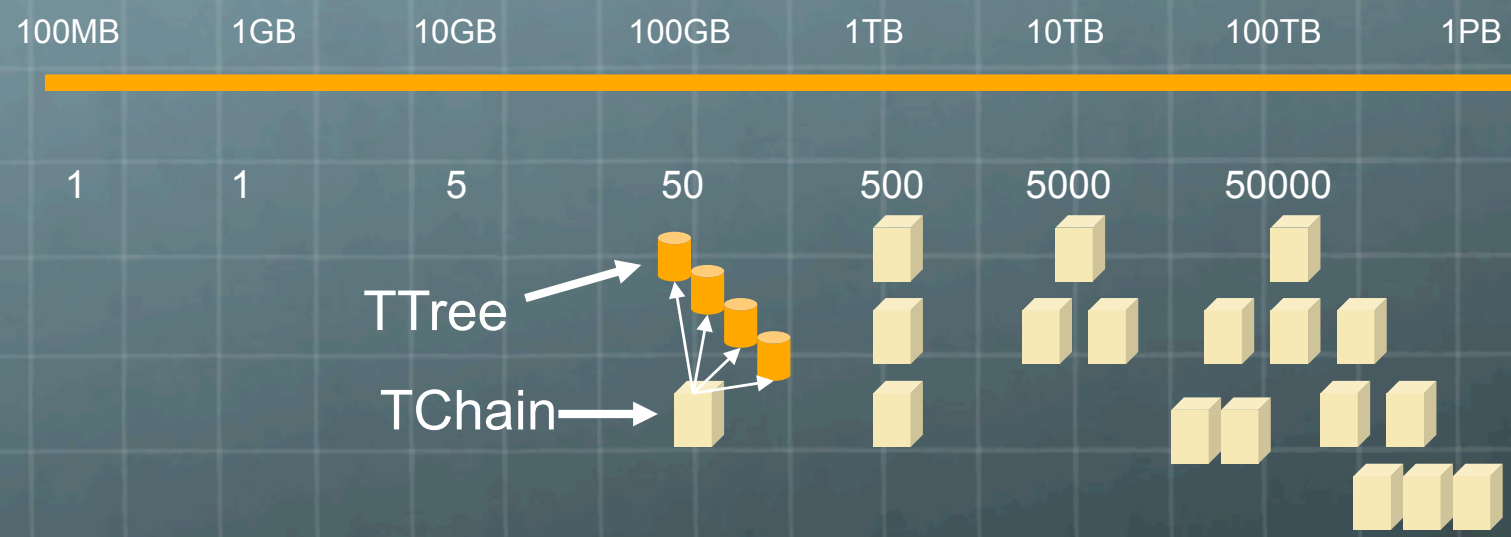
A double click To histogram The leaf

8 branches of T

8 Objects.

Data Volume & Organization



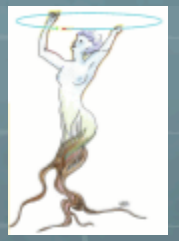


A TFile typically contains 1 TTree

A TChain is a collection of TTrees or/and TChains

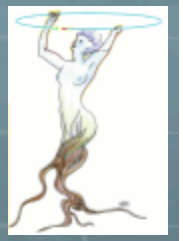
A TChain is typically the result of a query to the file catalogue

The situation in 2000-a



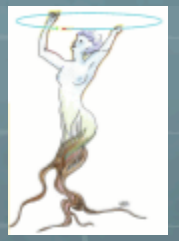
- Following the failure of the OODBMS system, an attempt to store event data in a relational data base fails also quite rapidly when we realized that RDBMS systems are not designed to store petabytes of data.
- The ROOT system is adopted by the large US experiments at FermiLab and BNL. This version is based on object streamers specific to each class and generated automatically by a preprocessor.

The situation in 2000-b



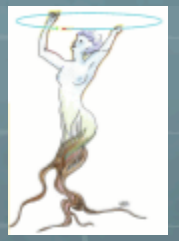
- Although automatically generated object streamers were quite powerful, they required the class library containing the streamer code at read time.
- We realized that this will not fly in the long term as it is quite obvious that the streamer library used to write the data will not likely be available when reading the data several years later.

The situation in 2000-c



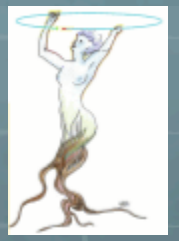
- A system based on class dictionaries saved together with the data was implemented in ROOT. This system was able to write and read objects using the information in the dictionaries only and did not required anymore the class library used to write the data.
- In addition the new reader is able to process in the same job data generated by successive class versions.
- This process, called automatic class-schema-evolution proved to be a fundamental component of the system.
- It was a huge difference with the OODBMS and RDBMS systems that forced a conversion of the data sets to the latest class version.

The situation in 2000-d



- Circa 2000 it was also realized that streaming objects or objects collections in one single buffer was totally inappropriate when the reader was interested to process only a small subset of the event data.
- The ROOT Tree structure was not only a Hierarchical Data Format, but was designed to be optimal when
  - The reader was interested by a subset of the events, by a subset of each event or both.
  - The reader has to process data on a remote machine across a LAN or WAN.
- The TreeCache minimizes the number of transactions and also the amount of data to be transferred.

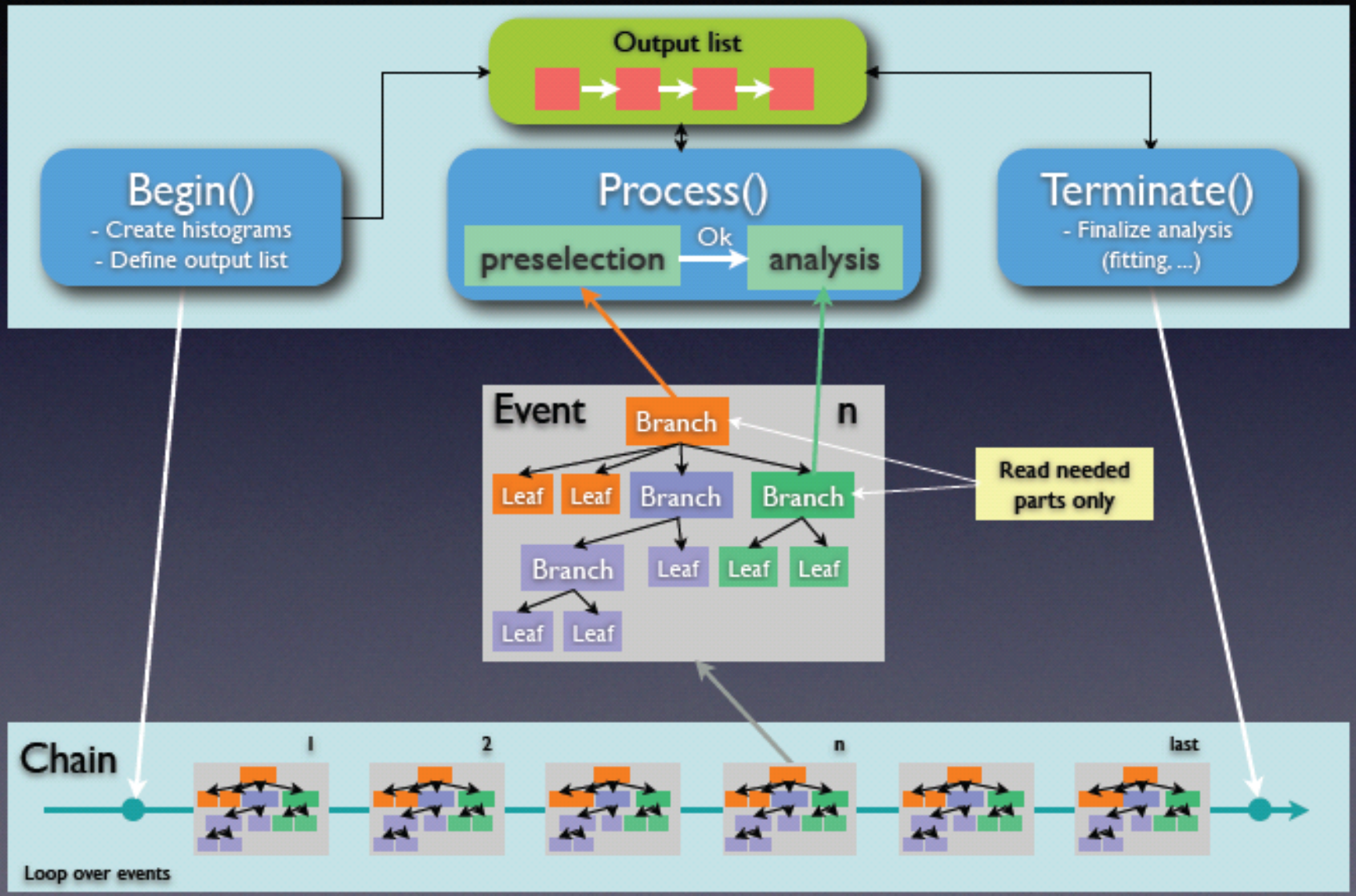
The situation in 2005



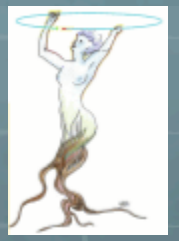
- Distributed processing on the GRID, but still moving the data to the job.
- Very complex object models. Requirement to support all possible C++ features and nesting of STL collections.
- Experiments have thousands of classes that evolve with time.
- Data sets written across the years with evolving class versions must be readable with the latest version of the classes.
- Requirement to be backward compatible (difficult) but also forward compatible (extremely difficult)

The ROOT Data Model

Trees & Selectors



Parallelism everywhere



- What about this picture in the very near future?

file catalogue

32 cores

Local cluster

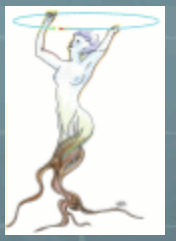
1000x32 cores

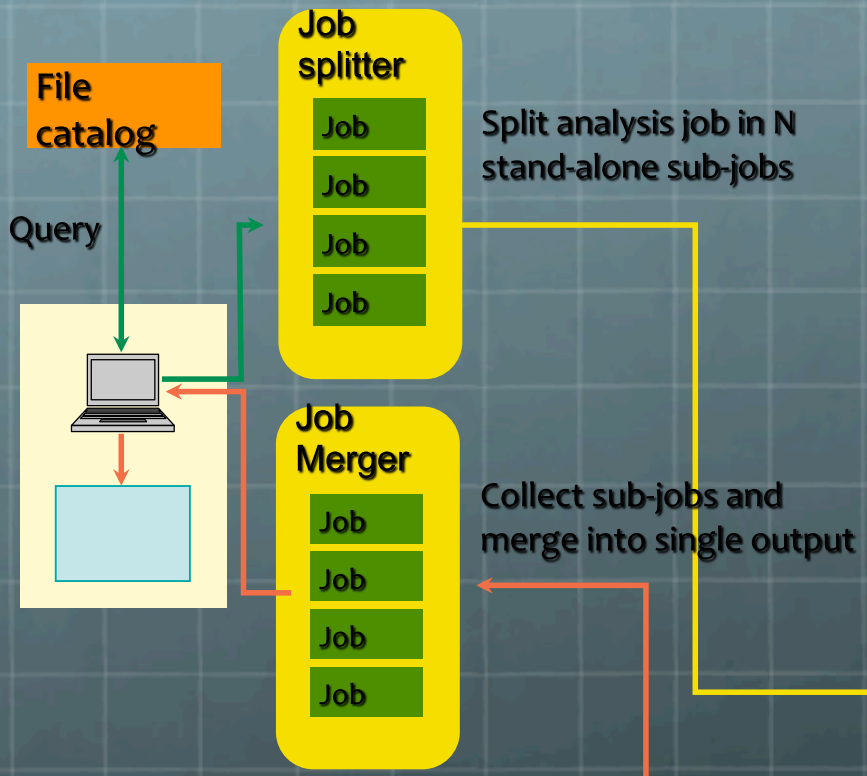
Remote clusters

Cache 1 PByte

Cache 1TByte

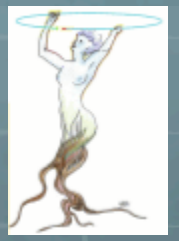
Traditional Batch Approach

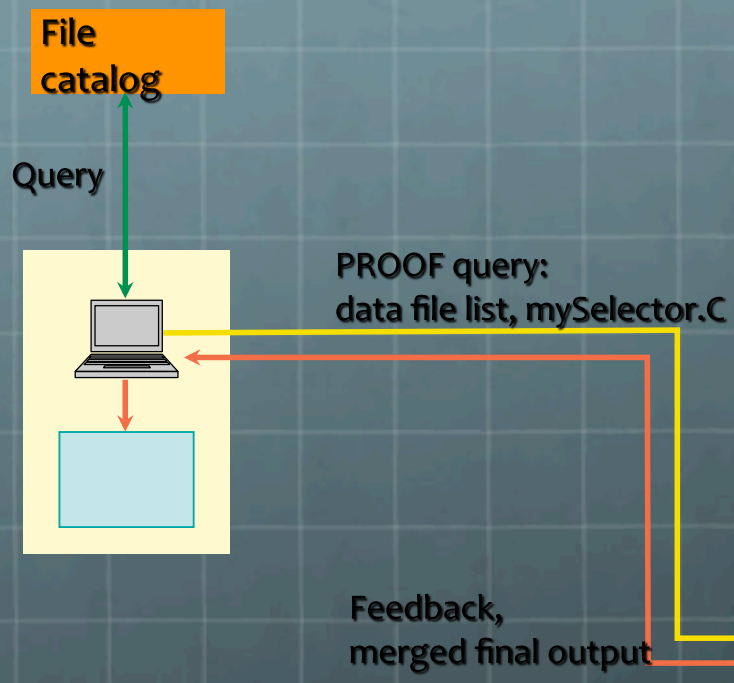


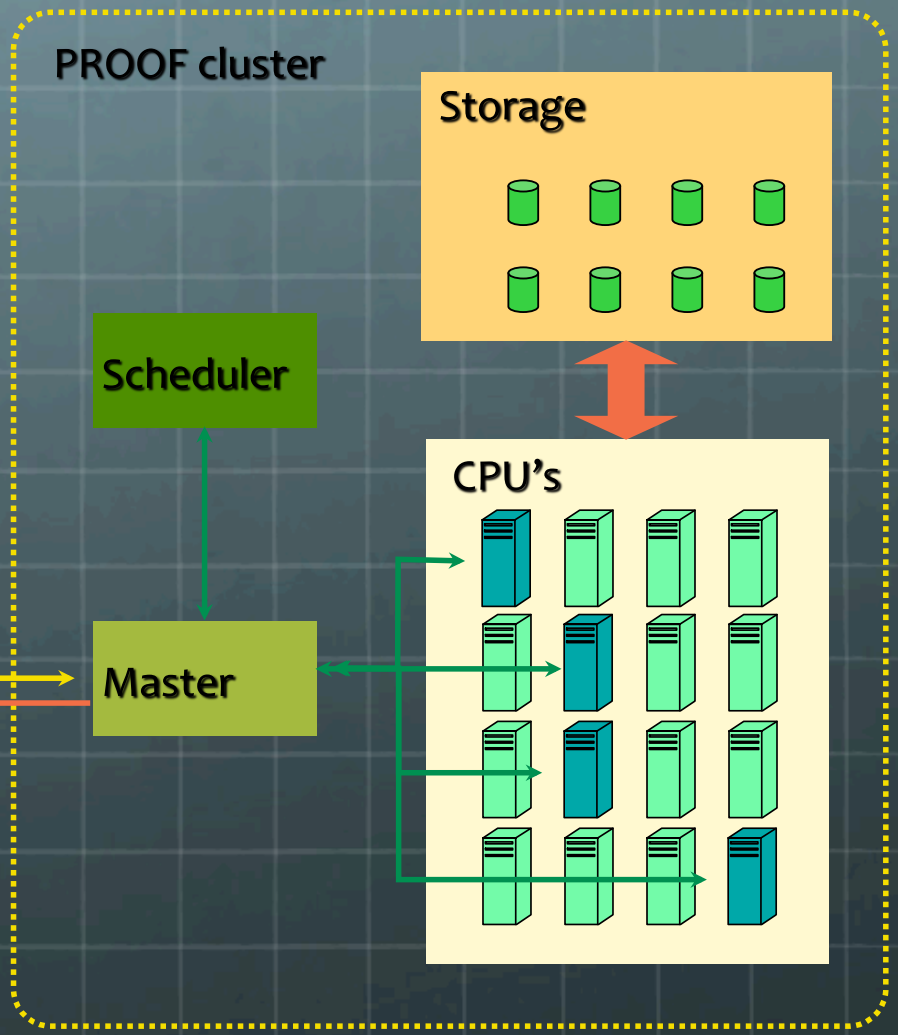


- Split analysis task in N batch jobs
- Job submission sequential
- Very hard to get feedback during processing
- Analysis finished when last sub-job finished

The PROOF Approach

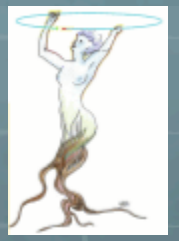






- Cluster perceived as extension of local PC
- *Same macro and syntax* as in local session
- More *dynamic* use of resources
- Real-time feedback
- Automatic *splitting* and *merging*

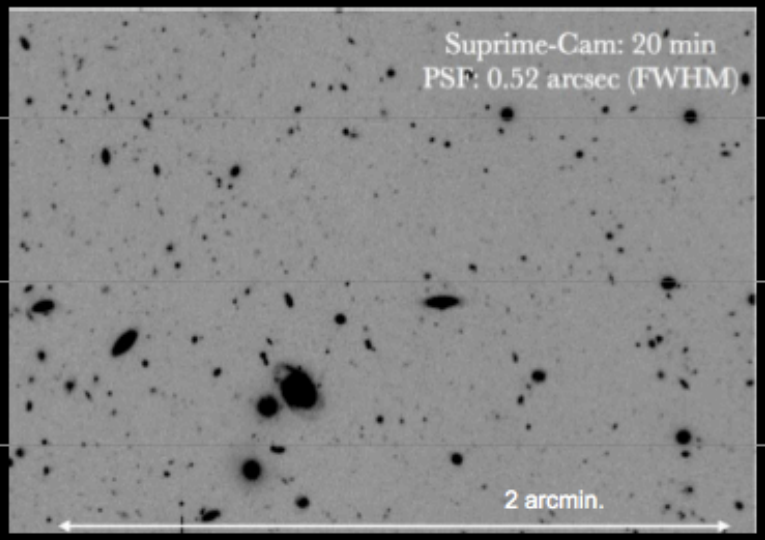
Summary



- The ROOT system is the result of 15 years of cooperation between the development team and thousands of heterogeneous users.
- ROOT is not only a file format, but mainly a general object I/O storage and management designed for rapid data analysis of very large shared data sets.
- It allows concurrent access and supports parallelism in a set of analysis clusters (LAN and WAN).

Functionality Test in SC (Suprime-Cam)

- The framework is combined with HSC modules and the functionalities are tested



WEB

Analysis/visualization using ROOT

Suprime Cam DAQ

FITS files for one CCD

Output FITS

N-tuple

Framework

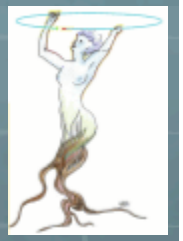
FITS reader | Overscan Subtractor | GetPar | Flat Fielding | AGP Mask | Sextractor | Stat

Histogram Manager

ROOT Object (on memory)

R. Itoh (KEK), N. Katayama (KEK)
S. Lee (Korea University), S. Mineo (University of Tokyo)

TSelector: Our recommended analysis skeleton



- Classes derived from TSelector can run locally and in PROOF

  - Begin() — once on your client
  - SlaveBegin() — once on each slave
  - Init(TTree* tree) — for each tree
  - Process(Long64_t entry) — for each event
  - SlaveTerminate()
  - Terminate()