Challenges in Long Term Computing Models ROOT Solutions

First Workshop on Data Preservation

And Long Term Analysis in HEP

DESY

27 January 2009

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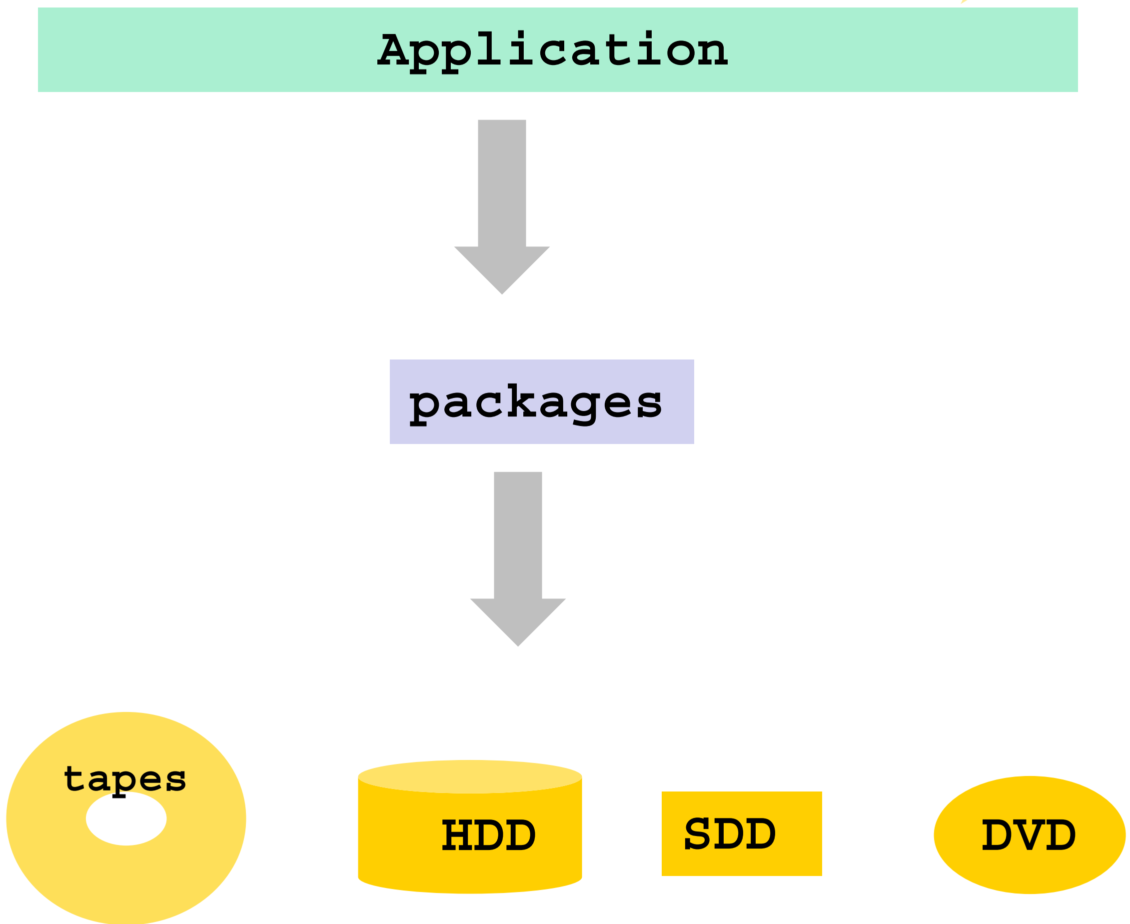
CERN

Everything changes

Atlas with more than 25000 classes



A long time ago

- With the advent of time sharing systems like VAX/VMS, then personal work stations, the request for interactive analysis systems is growing.
- Two systems emerge in 1982
- HTV at CERN (interactive histogram presenter)
- GEP at DESY (support for vectors/tuples)
- Attempt to combine these two systems in 1984 fails (GEP was written in PL1)

BOS, ZEBRA: The banks era

- Designed for Fortran aplications.
- Mainly 2 data types: ints and floats
- Could describe complex structures
- Self-described bank format (3 ints, then floats)
- Up to the application to interpret contents
- No schema evolution
- Not appropriate for languages supporting derived data types

The PAW era (1984 →)

- First version end 1984:
- No ntuples
- A command line interface KUIP
- An “abstract” interface to graphics (HIGZ) with implementations for the CORE system (US), GKS, Apollo graphics, PHIGS
- New data set format (Zebra/RZ) with support for row-wise ntuples

The PAW era (2)

- New version end 1986
- A ntuple query system (ntuple/plot)
- Column-wise ntuples
- Fortran interpreter: COMIS
- Successful system for the final steps of data analysis. Still in use today in many places.
- However, the PAW file format was not designed to support collections of large data sets.

LHC software: first steps: 1994

- First attempts to organize the software for LHC
- RD44 (Geant4) and RD45 (objy) projects
- Some gurus predict that Object-Oriented data bases will dominate the market in 2000
- Painful move to C++
- Commercial software approach (LHC++)
- Transient model = persistent model
- Central data base, single point of failure
- No schema evolution

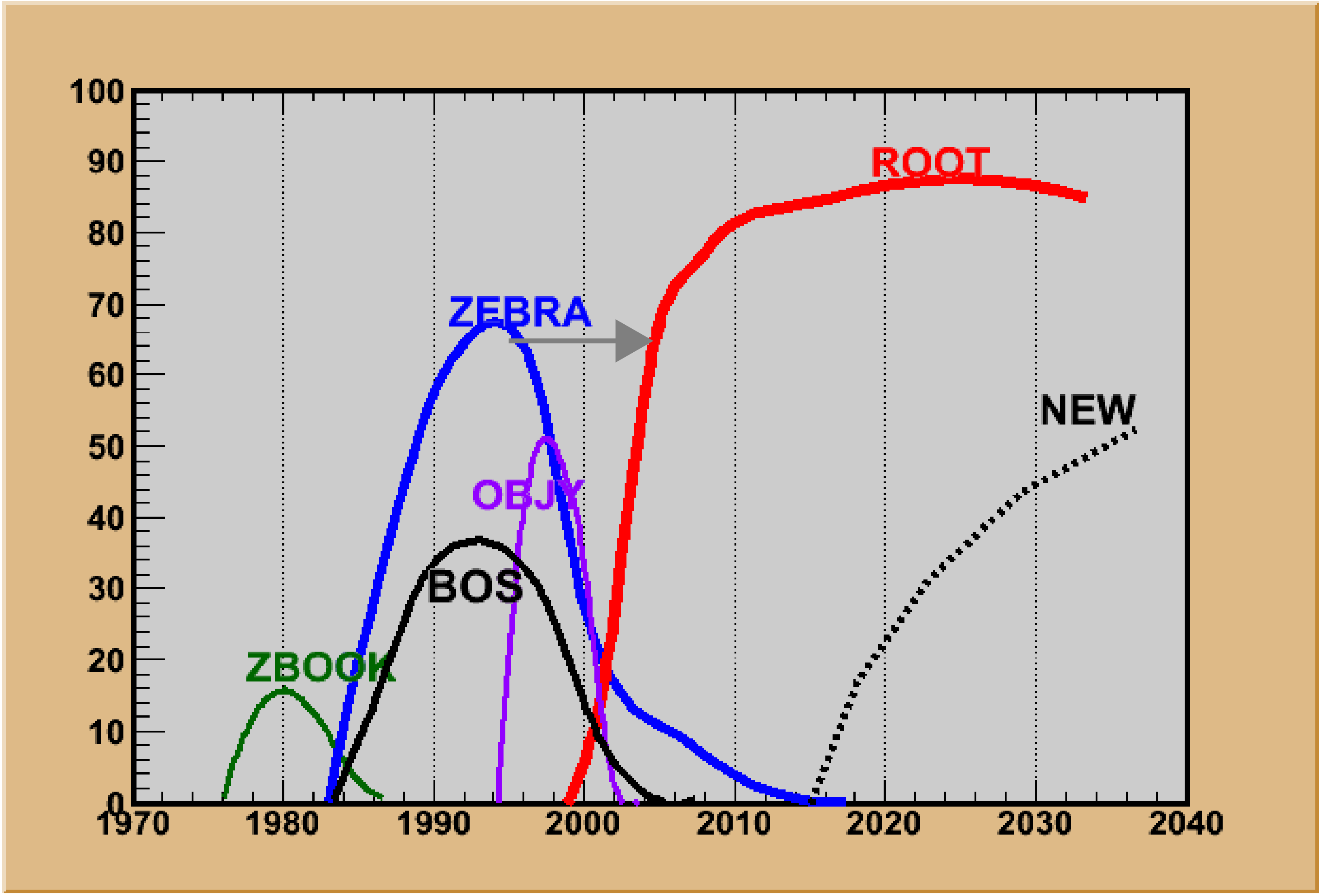
ROOT project starts: 1995

- Based on previous experience with PAW/GEANT
- Use C++ for interpreter
- Use lessons learned with PAW and ZEBRA I/O
- Design for very large data sets (mainly read-only)
- Object-Orientation; GUI, Graphics, I/O
- Quickly realize importance of object dictionaries
- From custom streamers to automatic schema evolution.
- Member-wise streaming vs object-wise streaming
- Query system very important
- Design for Parallelism and Network Access

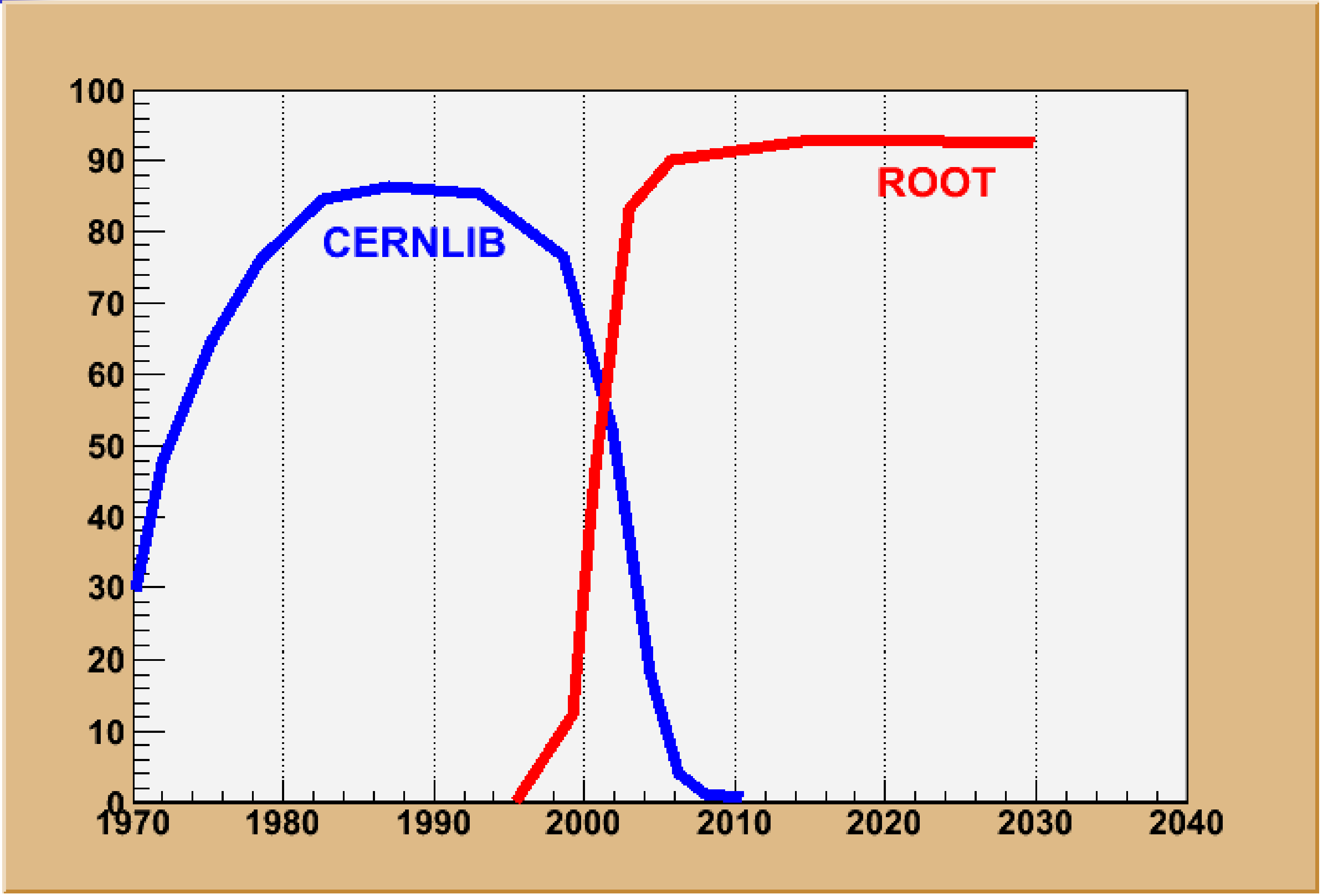
HDF, HDF5

- The Hierarchical Data Format is the standard in the astronomy, astrophysics world.
- Very good attempt to structure data sets in files
- BUT, missing the essential components to automatically build in memory complex data structures (application task!)
- No support for automatic schema evolution
- Efficient network access left to the application

I/O packages evolution in HEP



CERNLIB to ROOT



ROOT shared libs

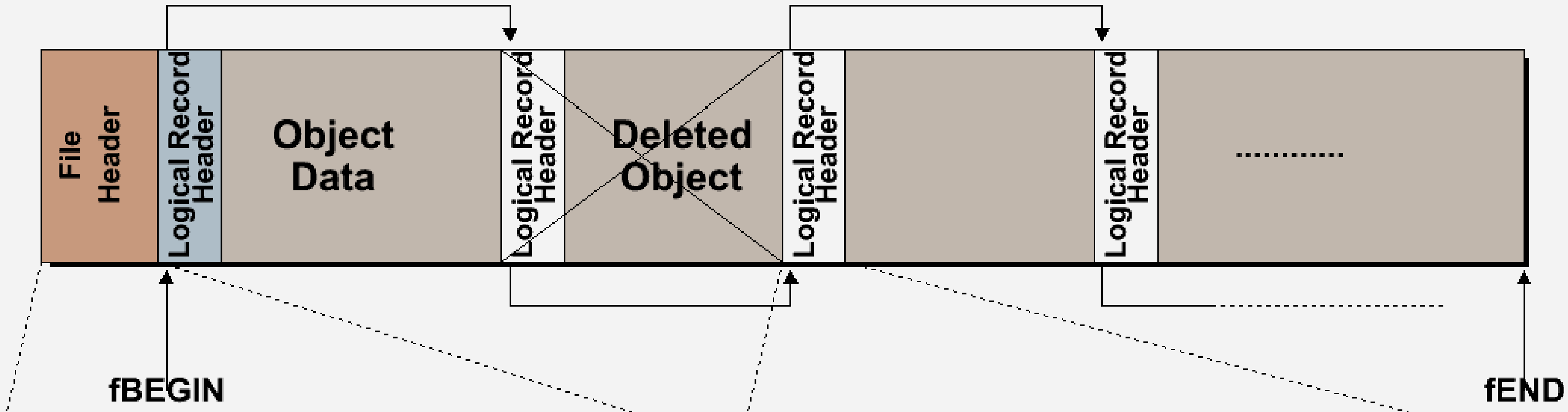
You dynamically load what you use

```
libASImage.so
libASImageGui.so
libCint.so
libCintex.so
libCore.so
libEG.so
libEGPythia6.so
libEGPythia8.so
libEve.so
libFFTW.so
libFTGL.so
libFitPanel.so
libFoam.so
libFumili.so
libGX11.so
libGX11TTF.so
libGdml.so
libGed.so
libGenVector.so
libGeom.so
libGeomBuilder.so
libGeomPainter.so
libGpad.so
libGraf.so
libGraf3d.so
libGui.so
libGuiBld.so
libGuiHtml.so
libHbook.so
libHist.so
libHistPainter.so
libHtml.so
libKrb5Auth.so
libMLP.so
libMathCore.so
libMathMore.so
libMatrix.so
libMinuit.so
libMinuit2.so
libNet.so
libNetx.so
libNew.so
libPhysics.so
libPostscript.so
libProof.so
libProofDraw.so
libProofPlayer.so
libProofx.so
libQuadp.so
libRGL.so
libRIO.so
libRLDAP.so
libRODBC.so
libRecorder.so
libReflex.so
libReflexDict.so
libRint.so
libRooFit.so
libRooFitCore.so
libRooStats.so
libRootAuth.so
libRuby.so
libSPlot.so
libSQL.so
libSessionViewer.so
libSmatrix.so
libSpectrum.so
libSpectrumPainter.so
libSrvAuth.so
libTMVA.so
libTable.so
libThread.so
libTree.so
libTreePlayer.so
libTreeViewer.so
libUnuran.so
libVMC.so
libX3d.so
libXMLIO.so
libXMLParser.so
libXrdBwm.so
libXrdClient.so
libXrdCrypto.so
libXrdCryptossl.so
libXrdOfs.so
libXrdProofd.so
libXrdRootd.so
libXrdSec.so
libXrdSecgsi.so
libXrdSecgsiGMAPLDAP.so
libXrdSeckrb5.so
libXrdSecpwd.so
libXrdSecsss.so
libXrdSecunix.so
libXrdSut.so
libdequeDict.so
liblistDict.so
libmap2Dict.so
libmapDict.so
libminicern.so
libmultimap2Dict.so
libmultimapDict.so
libmultisetDict.so
libsetDict.so
libvalarrayDict.so
libvectorDict.so
```

ROOT Files and Trees

Analysis model

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.[illegible]
20070713/195532  At:806023  N=43823    TTree         CX = 1[illegible].84
20070713/195532  At:849846  N=6340     TH2F          CX = 100.63
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
```

TFile::MakeProject

```
(macbrun2) [253] root -l
root [0] TFile *falice = TFile::
root [1] falice->MakeProject("al
MakeProject has generated 26 cl
alice/MAKEP file has been gene
Shared lib alice/alice.so has bee
Shared lib alice/alice.so has bee
root [2] .!ls alice
AliESDCaloCluster.h      AliESDZD
AliESDCaloTrigger.h      AliESDca
AliESDEvent.h            AliESDfr
AliESDFMD.h              AliESDfr
AliESDHeader.h           AliESDki
AliESDMuonTrack.h        AliESDtr
AliESDPmdTrack.h         AliESDv0
AliESDRun.h              AliExter
AliESDTZERO.h            AliFMDFl
AliESDTrdTrack.h         AliFMDMa
AliESDVZERO.h            AliMulti
AliESDVertex.h           AliRawDa
root [3]
```

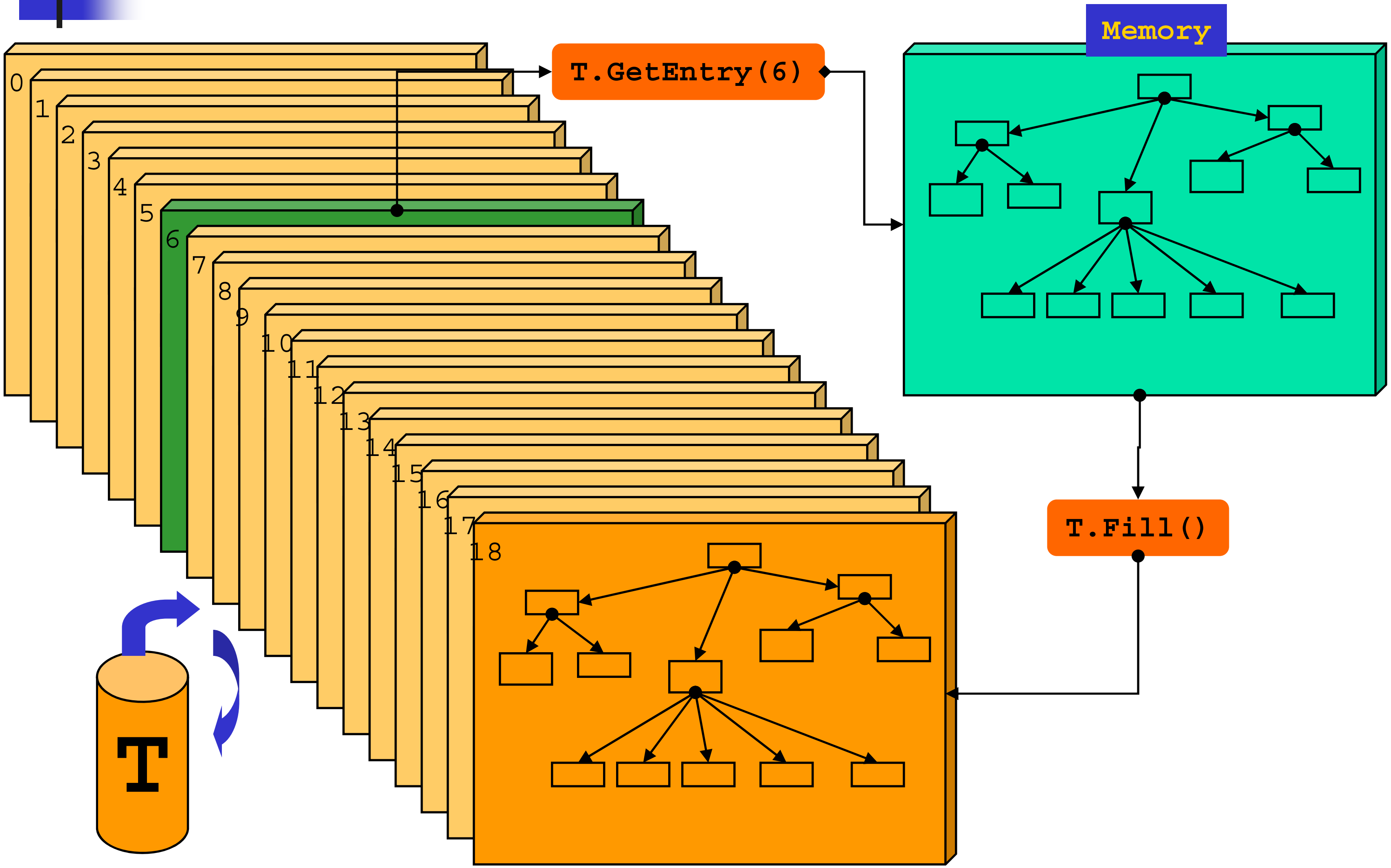
AliESDCaloCluster.h

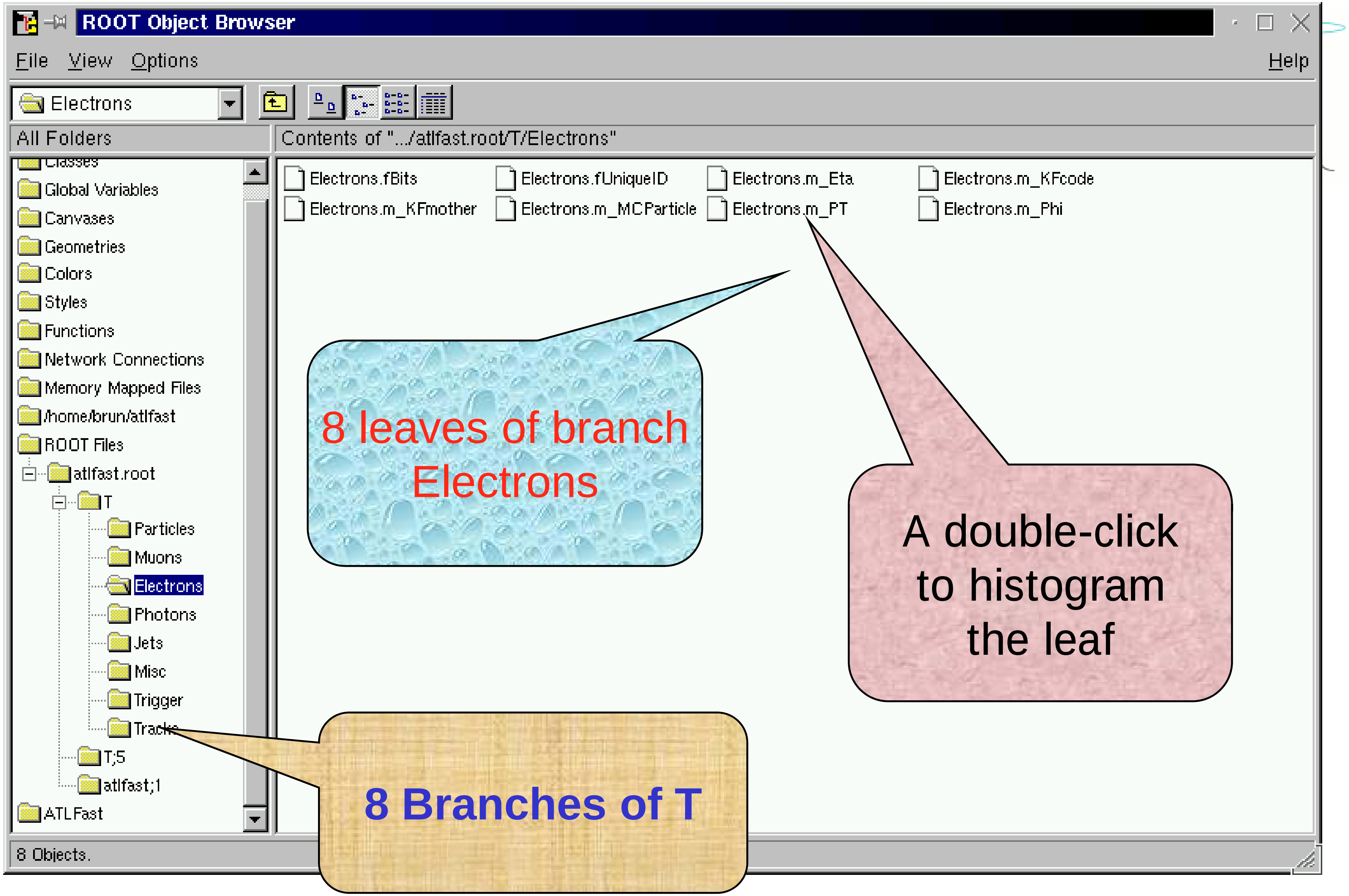
AliESDCaloCluster.h:2 <No selected symbol>

```
//////////////////////////////////////////////////////////
//   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 closest CPV rec.point
   Float_t    fDistToBadChannel;   //Distance to nearest bad channel
   TArrayS*   fTracksMatched;      //Index of tracks close to cluster. First entry is the most likely
   TArrayS*   fLabels;             //list of primaries that generated the cluster, ordered in deposit
   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
```

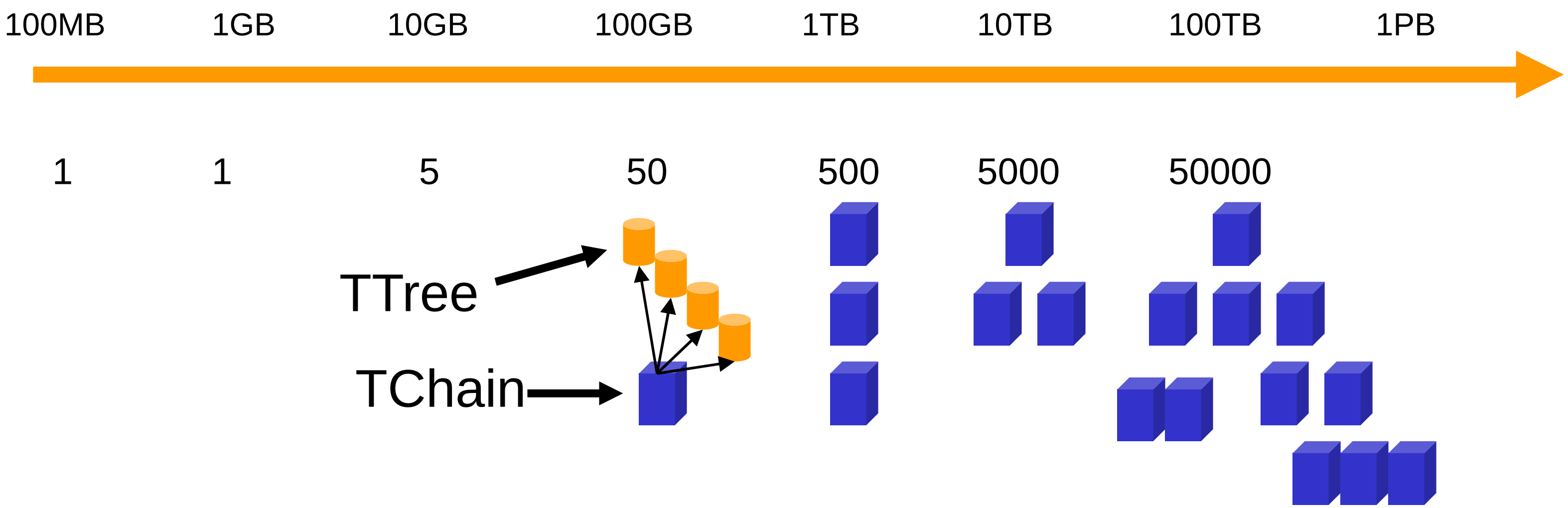
Memory <--> Tree

Each Node is a branch in the Tree




ROOT Object Browser
File View Options
Help
Electrons
All Folders
Contents of ".../atlfast.root/T/Electrons"
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
T;5
atlfast;1
ATLFast
8 Objects.
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

Data Volume & Organisation



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

Access Transparency

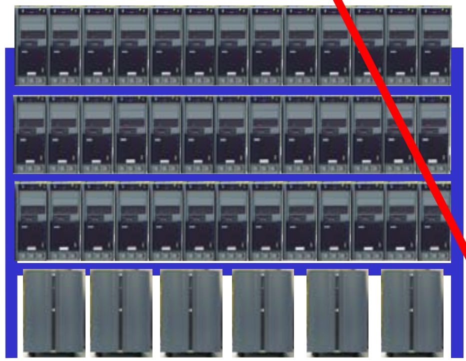
```
TFile *f1 = TFile::Open("local.root")

TFile *f2 = TFile::Open("root://cdfsga.fnal.gov/bigfile.root")

TFile *f3 = TFile::Open("rfio:/castor.cern.ch/alice/aap.root")

TFile *f4 = TFile::Open("dcache://main.desy.de/h1/run2001.root")

TFile *f5 = TFile::Open("chirp://hep.wisc.edu/data1.root")

TFile *f5 = TFile::Open("http://root.cern.ch/geom/atlas.root")
```

From the desktop to the GRID
Parallelism at all levels

Desktop

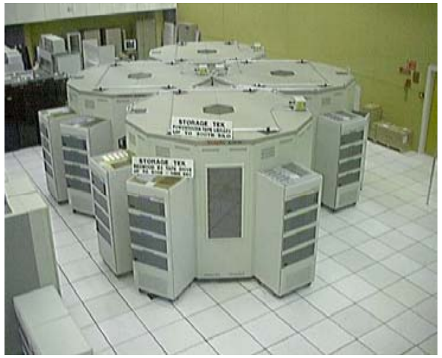
Online/Offline

Farms

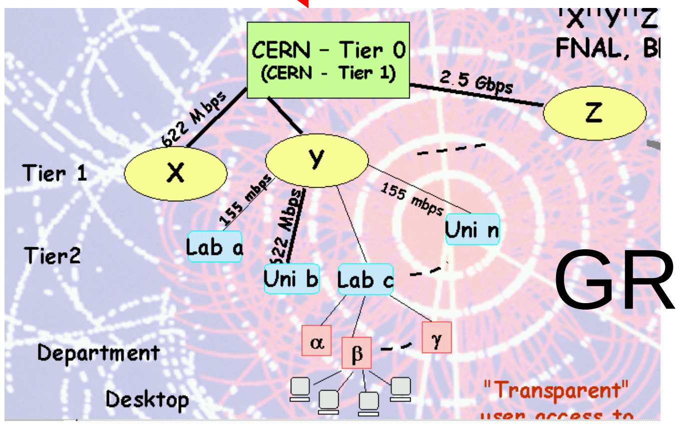


Local/remote

Storage



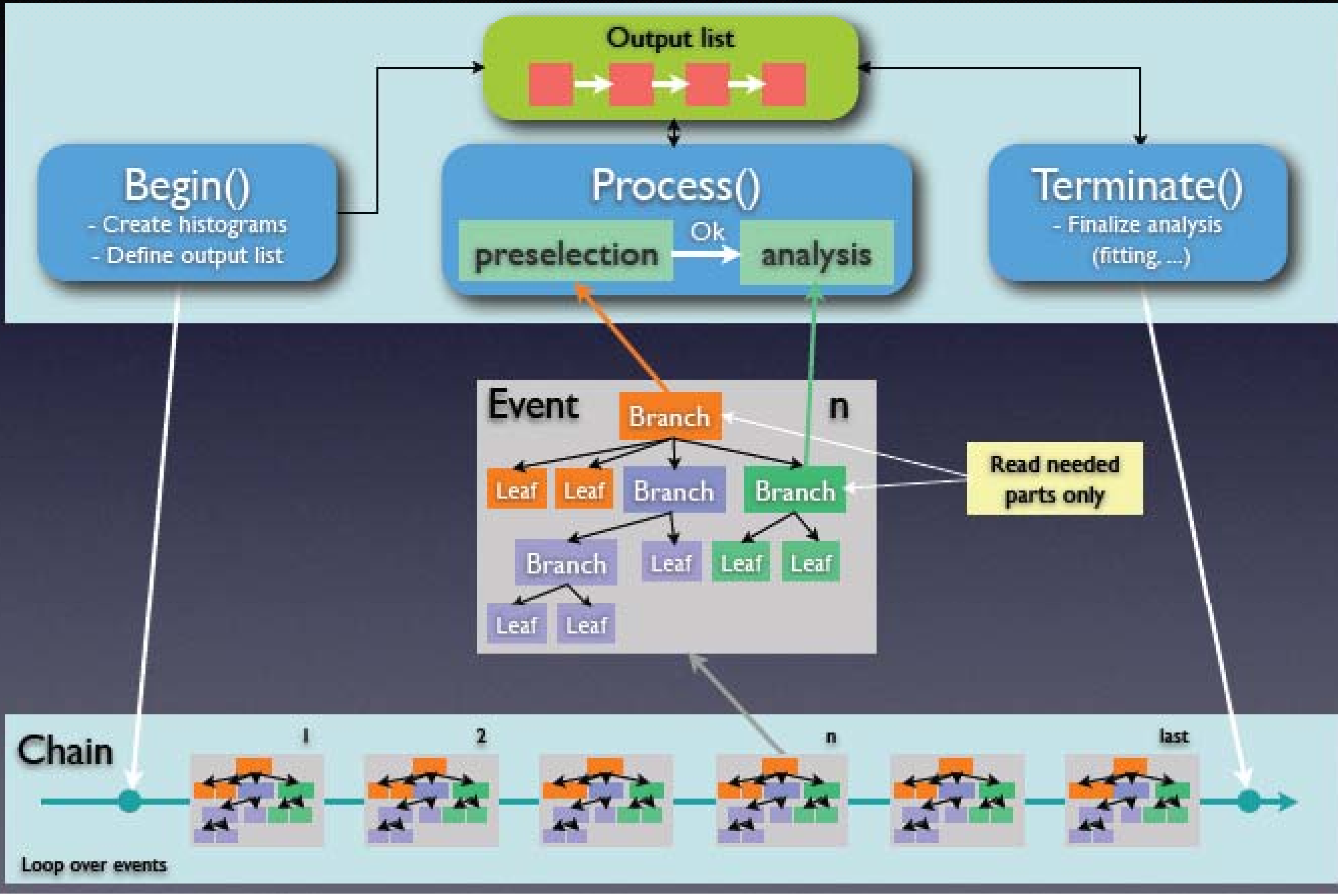
Data analysis tools must be able to exploit parallelism on the laptop, use remote CPUS in parallel, and storage elements and networks in a transparent way



GRID

The ROOT Data Model

Trees & Selectors

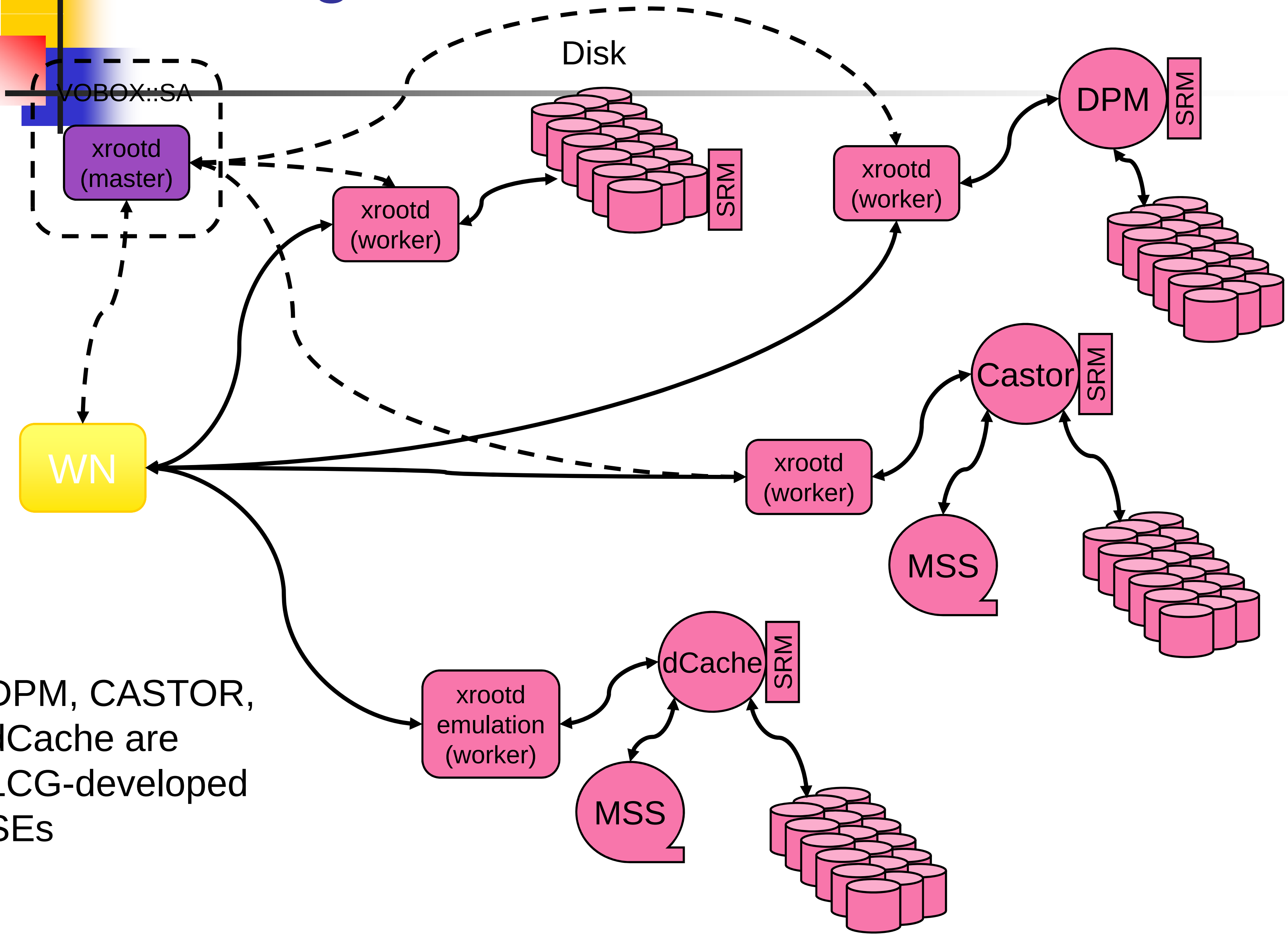


TSelector: Our recommended analysis skeleton

- 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()**

Storage element

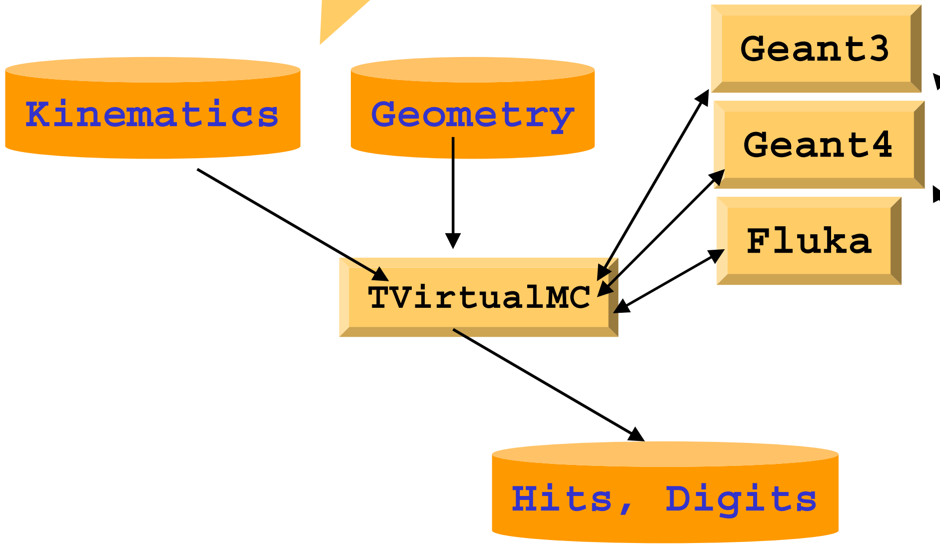


DPM, CASTOR, dCache are LCG-developed SEs

Virtual Monte Carlo

This strategy facilitates migration or comparisons with a common input and a common output

ROOT can provide a solid base for: geometry, visualisation, interactivity, interpreter and persistency



Dectector Simulation

Geant3.tar.gz includes an upgraded Geant3 with a C++ interface

Geant4_mc.tar.gz includes the TVirtualMC <-->Geant4 interface classes

Current developments

CINT Interpreter

- replace important components by LLVM, a Just In Time compiler (JIT)
- LLVM is gcc compliant compiler(Open source project, sponsor Apple)
- the interpreter is the compiler
- this will introduce a more robust C++ parser (C++0x compliant)
- JIT will provide an excellent replacement for the internals of TFormula,
- TTreeFormula (code generated and compiled in a few milliseconds)

PROOF, xrootd

- PROOF
  - -in production in Alice
  - -under evaluation by groups in Atlas, CMS
  - -close cooperation with the xrootd developers
  - -prototyping multi-core, SDD, HDD, zfs/Lustre, xrootd
- PROOF-LITE
  - -mini version of PROOF designed for multi-core laptops
  - -will become default-ROOT (automatic parallelism)
- XROOTD
  - -important developments, robustness
  - -caching and proxies wor LAN and WAN files

Fitting, Stats

- ROOFIT
- -many developments by Wouter Verkerke (now Atlas)

- ROOSTATS
- -common project Atlas, CMS, etc for a statistics library
- -in very active development
- -based on ROOFIT

We recommend

- Make your event model as simple as possible
- do not over-use the system (eg Atlas, CMS produce Trees with >6000 branches!)
- do not make derivations of the main ROOT objects like TH1, TTree. You must be able to browse your files with standard ROOT and without your classes.
- use TSelector as analysis model and not your own event loop
- think parallelism

```
for(int event=0;event<nevents;event++) {
   T->GetEvent(event);
   //do some analysis
}
```

```
T.Process(mySelector)
```

ROOT :Stability, Robustness

- Substantial manpower effort
  - 10 FTE at CERN + 1.5 at FNAL
- Support in place for the LHC era
- Still many developments
  - I/O robustness for LHC is vital
  - I/O performance improvements
- Micro and macro parallelism : a must

Doc + web site

- New ROOT web site will be introduced end of February
- (see snapshot at http://root.cern.ch/drupal)
- Better introduction for beginners
- Better tutorials
- Better look & feel