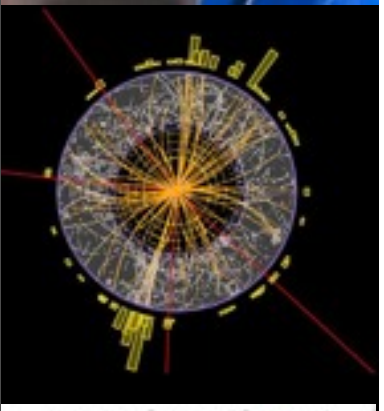

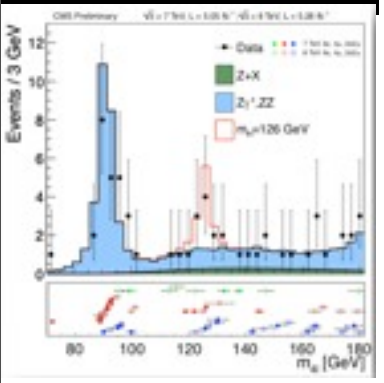

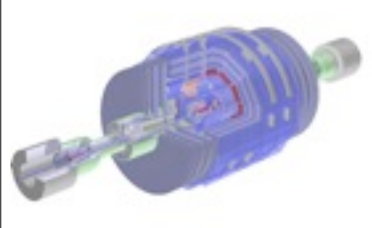

ROOT for Big Data Analysis

Fons Rademakers

Workshop on the future of Big Data management
Imperial College, London, 27-28 June 2013

HEP's Core Competency

- Handling, processing and analyzing "Big Data"
- For the previous (popular) trends, Grid and Clouds, we were buyers
- For this Big Data trend we have something to offer
- Industry is now reinventing the wheel we started to develop almost 20 years ago as HEP data sizes are becoming more common

Industry Catching Up

- Map-Reduce (Hadoop)
  - Parallel batch solution for analyzing unstructured data
- Dremel (Drill)
  - Interactive analysis of structured nested data stored in columnar format
- SciDB
  - Parallel analysis of matrix data stored in a DB
- Several commercial offerings

Google’s Dremel

- Dremel: Interactive Analysis of Web-Scale Datasets

“Dremel is a scalable, interactive ad-hoc query system for analysis of read-only nested data. By combining multi-level execution trees and [a novel] columnar data layout, it is capable of running aggregation queries over trillion-row tables in seconds. The system scales to thousands of CPU’s and petabytes of data.”

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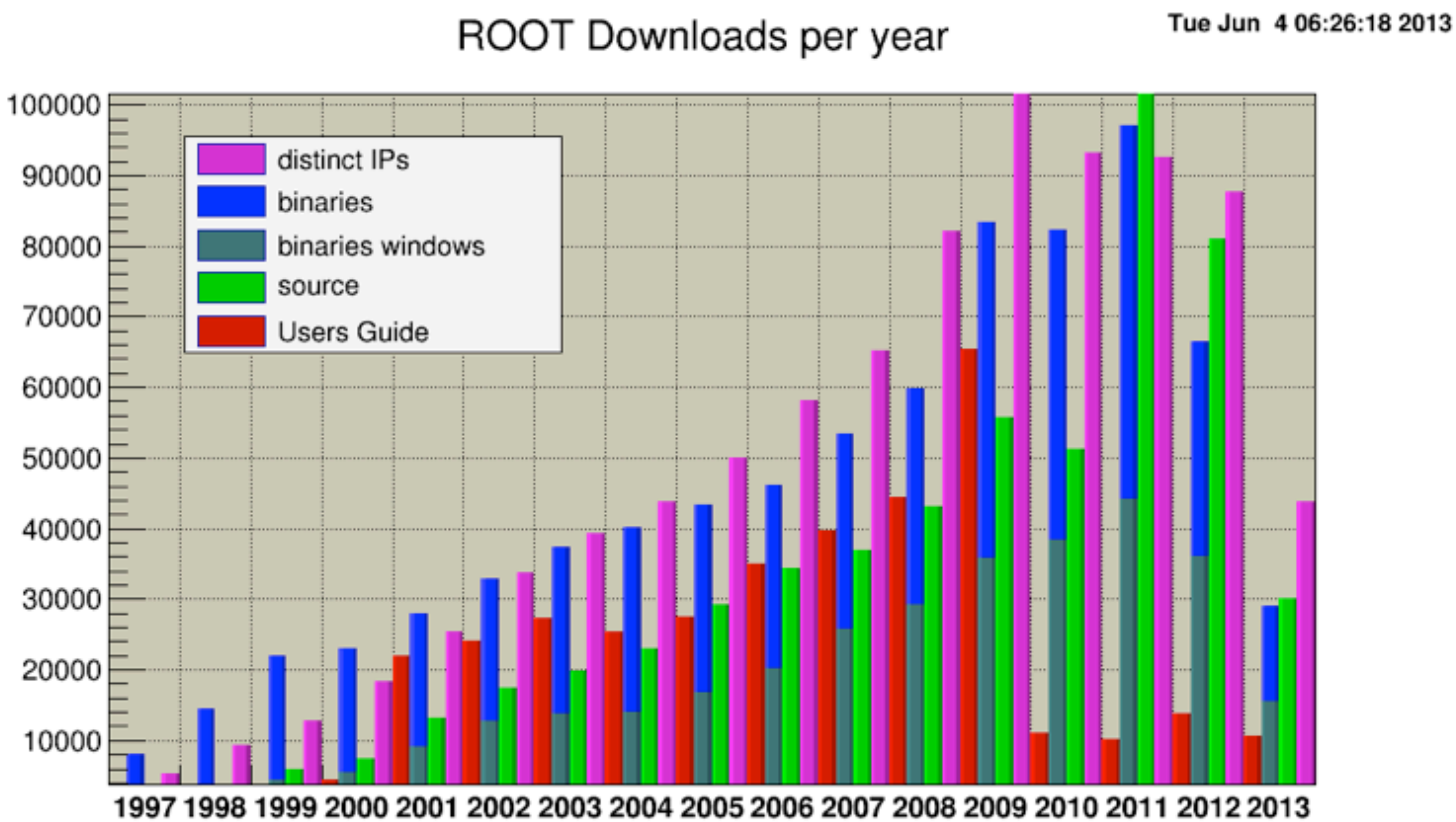
Sounds pretty much like ROOT

The ROOT System

- ROOT is a extensive data handling and analysis framework
  - Efficient object data store scaling from KB's to PB's
  - C++ interpreter
  - Extensive 2D+3D scientific data visualization capabilities
  - Extensive set of data fitting, modeling and analysis methods
  - Complete set of GUI widgets
  - Classes for threading, shared memory, networking, etc.
  - Parallel version of analysis engine runs on clusters and multi-core
  - Fully cross platform, Unix/Linux, Mac OS X and Windows
  - 2.7 million lines of C++, building into more than 100 shared libs
- Development started in 1995
- Licensed under the LGPL

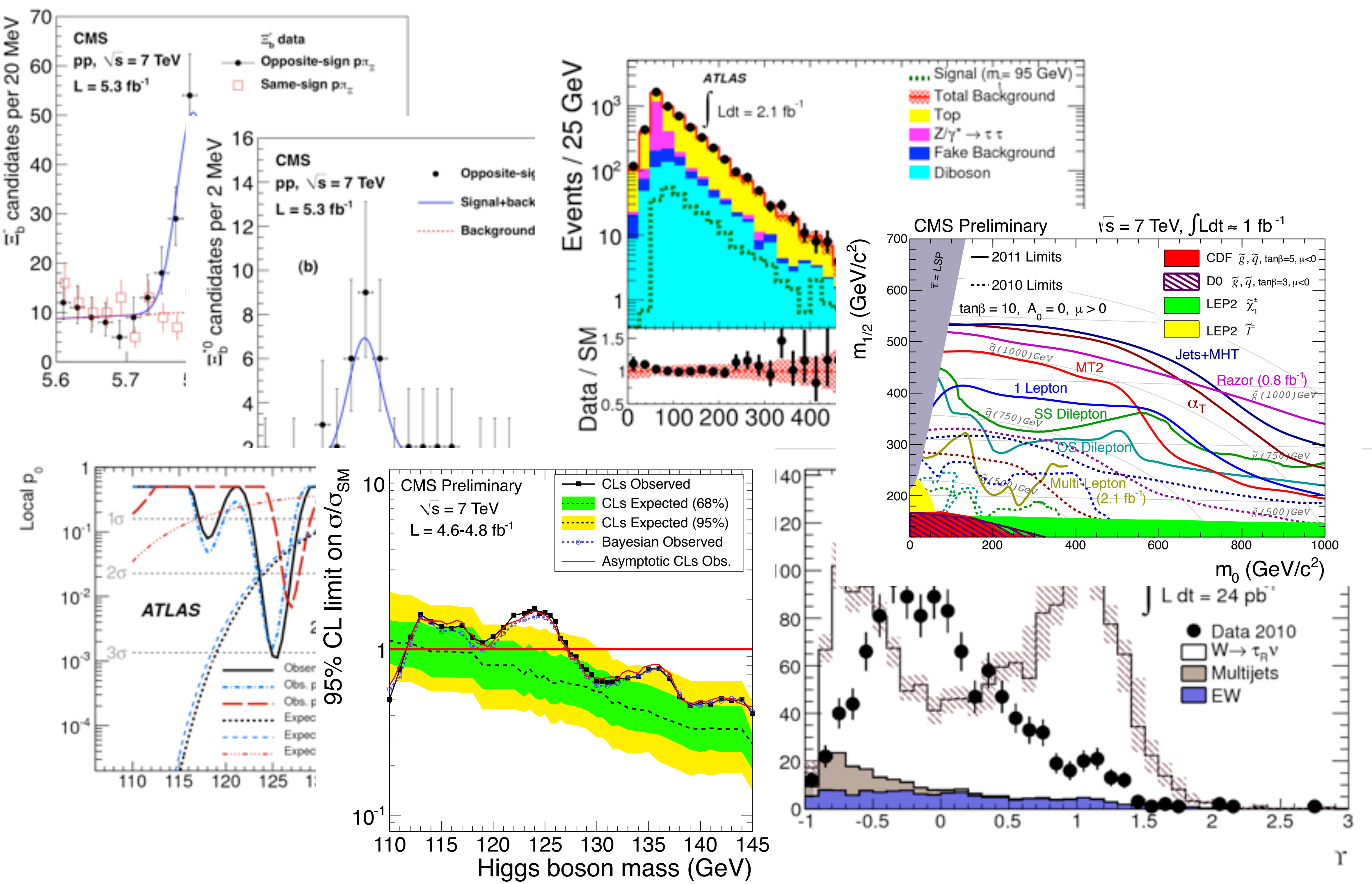
ROOT - In Numbers of Users

- Ever increasing number of users
  - 6800 forum members, 68750 posts, 1300 on mailing list
  - Used by basically all HEP experiments and beyond

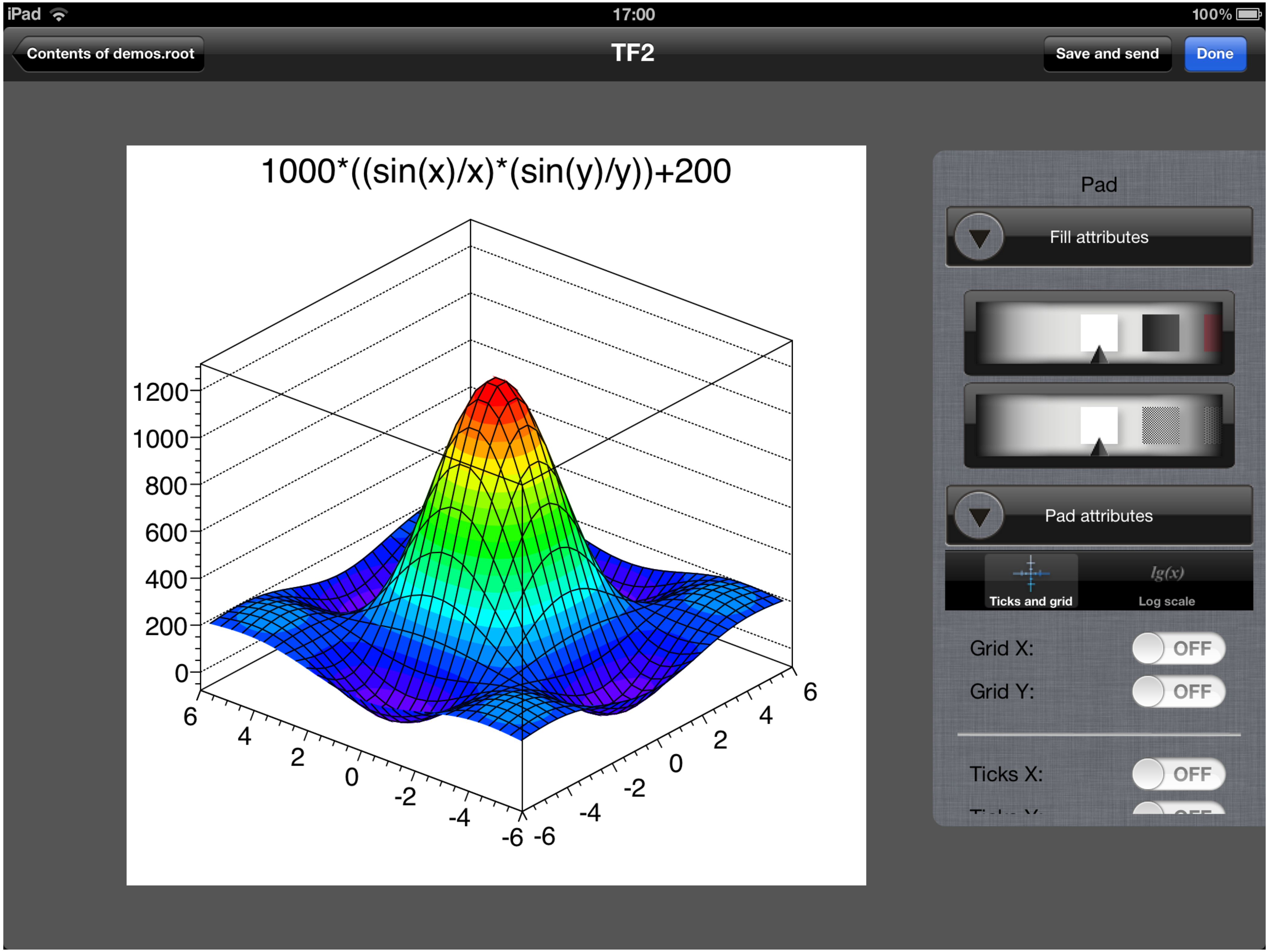


ROOT - In Plots

ROOT - In Plots



ROOT - On iPad


iPad
17:00
100%
Contents of demos.root
TF2
Save and send
Done
1000*((sin(x)/x)*(sin(y)/y))+200
1200
1000
800
600
400
200
0
6
4
2
0
-2
-4
-6
-6
-4
-2
0
2
4
6
Pad
Fill attributes
Pad attributes
lg(x)
Ticks and grid
Log scale
Grid X:
OFF
Grid Y:
OFF
Ticks X:
OFF

ROOT - In Numbers of Bytes Stored

As of today

177 PB

of LHC data

stored in ROOT format

ALICE: 30PB, ATLAS: 55PB, CMS: 85PB, LHCb: 7PB

The Importance of the C++ Interpreter

- The CINT C++ interpreter is the core of ROOT for:
  - Parsing and interpreting code in macros and on command line
  - Providing class reflection information
  - Generating I/O streamers and columnar layout
- We are moving to a new Clang/LLVM based interpreter called Cling

```
bash$ root
root [0] TH1F *hpx = new TH1F("hpx","This is the px distribution",100,-1,1);
root [1] for (Int_t i = 0; i < 25000; i++) hpx->Fill(gRandom->Rndm());
root [2] hpx->Draw();
```

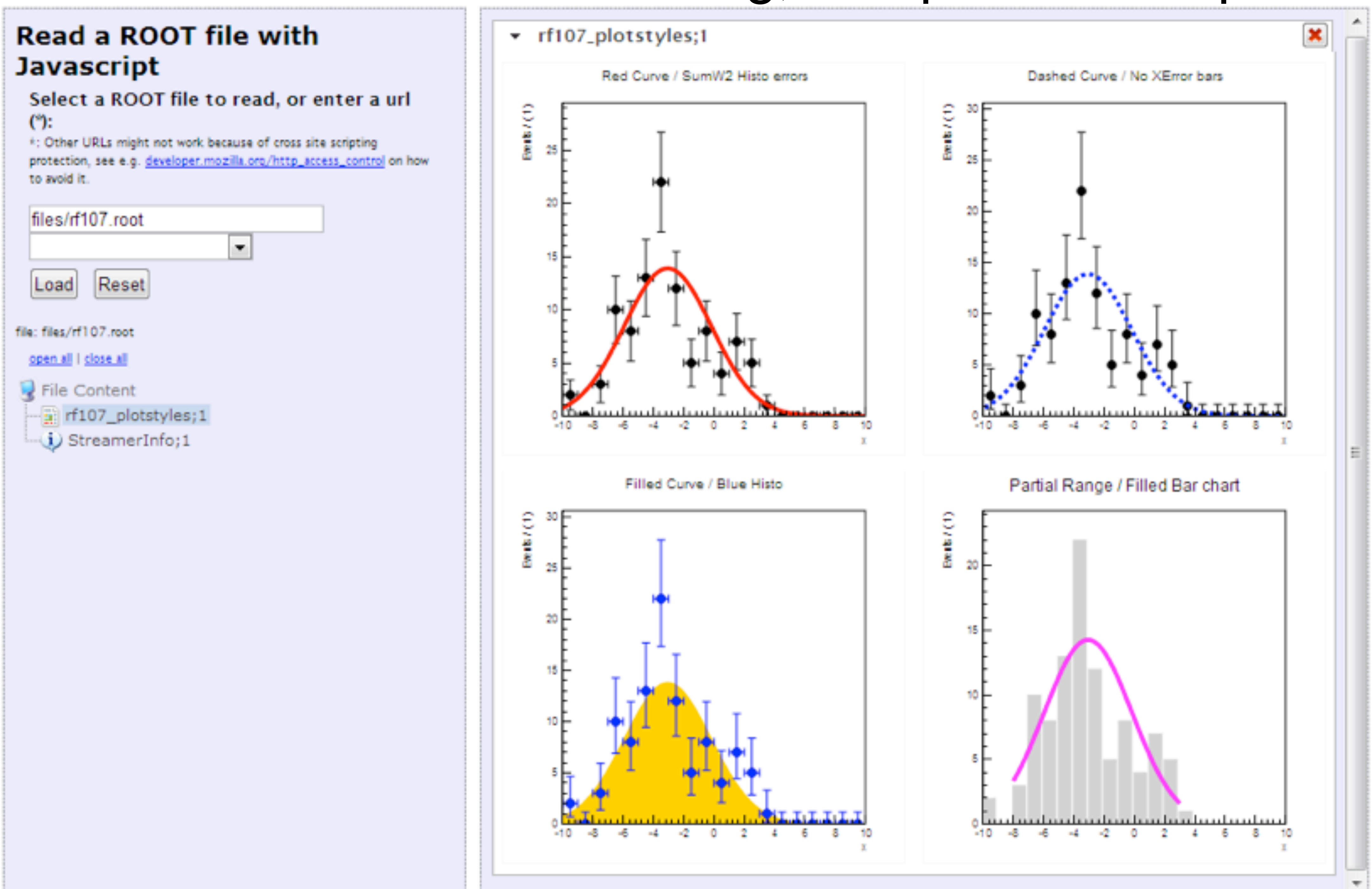
```
bash$ cat script.C
{
   TH1F *hpx = new TH1F("hpx","This is the px distribution",100,-1,1);
   for (Int_t i = 0; i < 25000; i++) hpx->Fill(gRandom->Rndm());
   hpx->Draw();
}
bash$ root
root [0] .x script.C
```

ROOT Object Persistency

- Scalable, efficient, machine independent format
- Orthogonal to object model
  - Persistency does not dictate object model
- Based on object serialization to a buffer
- Automatic schema evolution (backward and forward compatibility)
- Object versioning
- Compression
- Easily tunable granularity and clustering
- Remote access
  - HTTP, HDFS, Amazon S3, CloudFront and Google Storage
- Self describing file format (stores reflection information)
- ROOT I/O is used to store all LHC data (actually all HEP data)

ROOT I/O in JavaScript

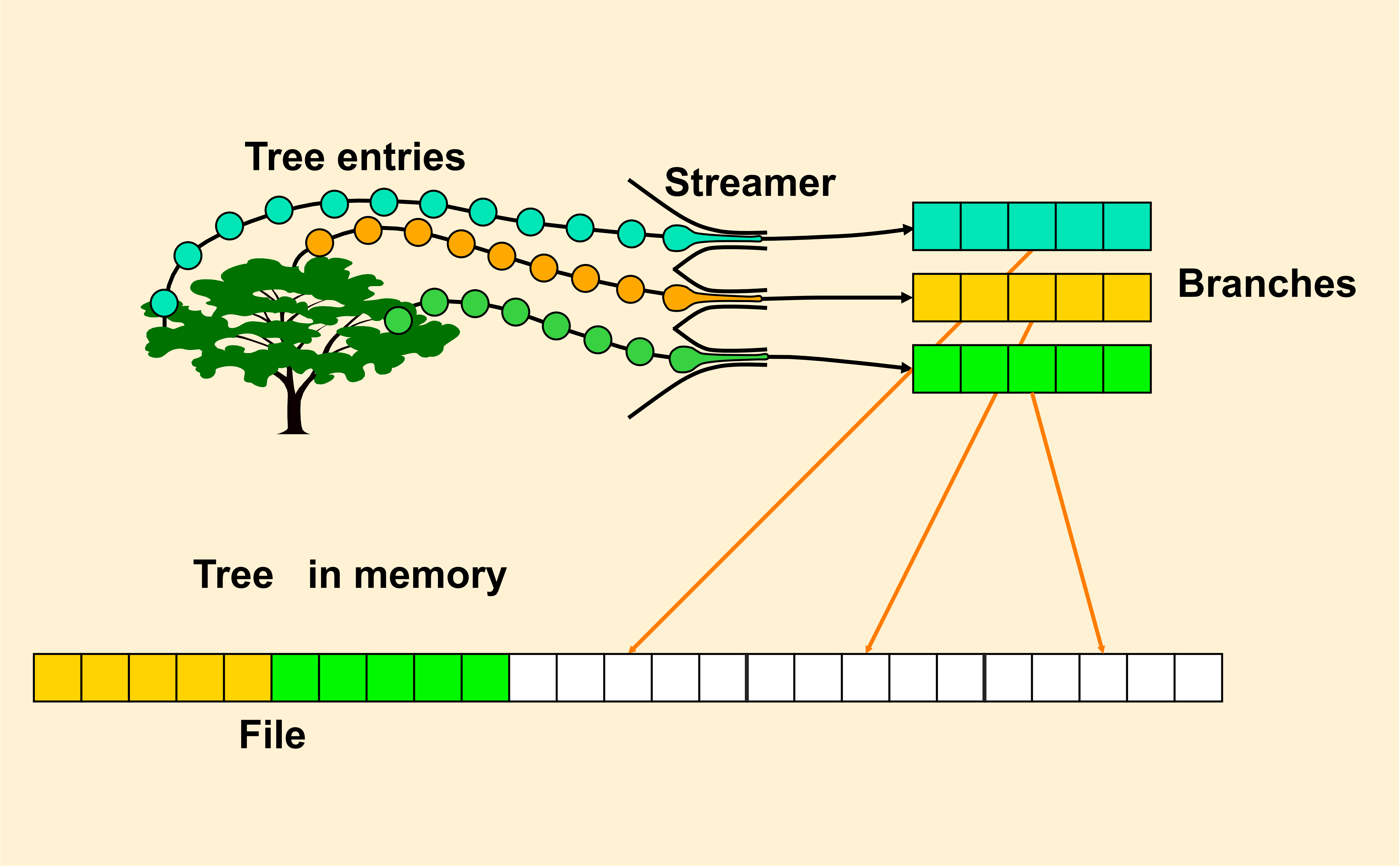
- Provide ROOT file access entirely locally in a browser
  - ROOT files are self describing, the “proof of the pudding...”



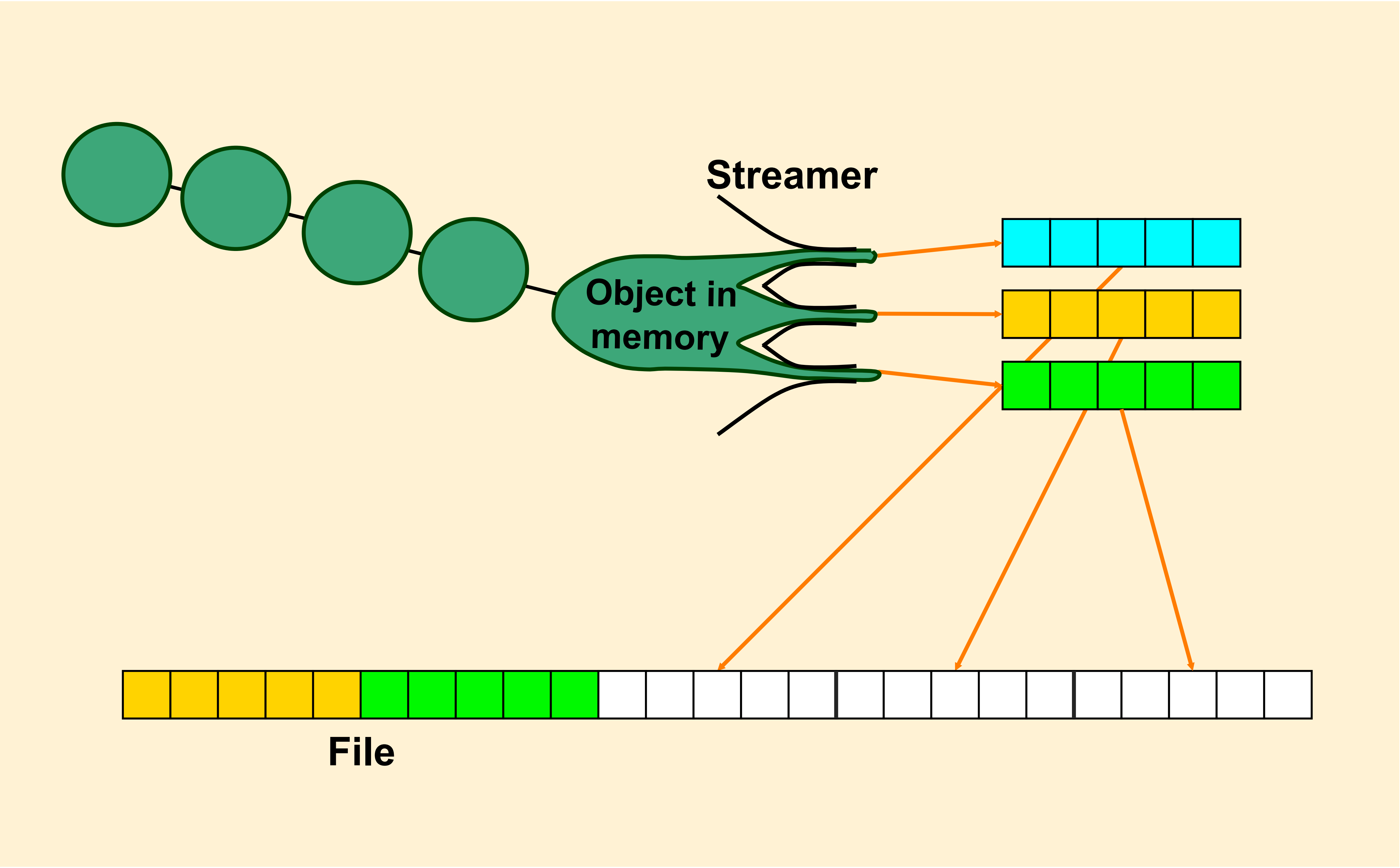
Object Containers - TTree's

- Special container for very large number of objects of the same type (events)
- Minimum amount of overhead per entry
- Objects can be clustered per sub object or even per single attribute (clusters are called branches)
- Each branch can be read individually
  - A branch is a column

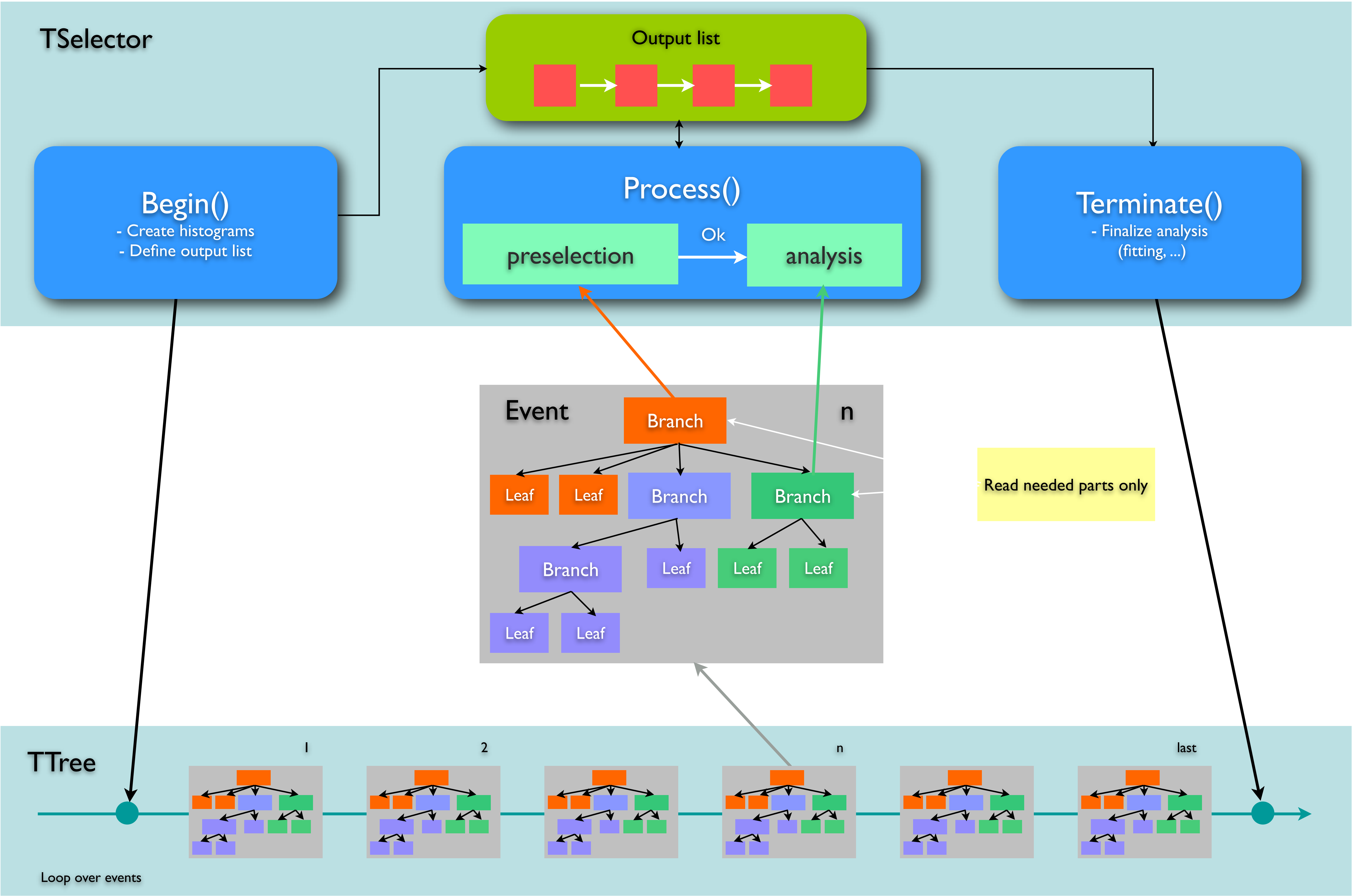
TTree - Clustering per Object



TTree - Clustering per Attribute



Processing a TTree



TSelector - User Code

```
// Abbreviated version
class TSelector : public TObject {
protected:
    TList *fInput;
    TList *fOutput;
public
    void   Notify(TTree*);
    void   Begin(TTree*);
    void   SlaveBegin(TTree *);
    Bool_t Process(int entry);
    void   SlaveTerminate();
    void   Terminate();
};
```

TSelector::Process()

```
...
...
// select event
b_nlhk->GetEntry(entry);          if (nlhk[ik] <= 0.1)    return kFALSE;
b_nlhpi->GetEntry(entry);         if (nlhpi[ipi] <= 0.1)  return kFALSE;
b_ipis->GetEntry(entry); ipis--; if (nlhpi[ipis] <= 0.1) return kFALSE;
b_njets->GetEntry(entry);         if (njets < 1)          return kFALSE;

// selection made, now analyze event
b_dm_d->GetEntry(entry);          //read branch holding dm_d
b_rpd0_t->GetEntry(entry);        //read branch holding rpd0_t
b_ptd0_d->GetEntry(entry);        //read branch holding ptd0_d

//fill some histograms
hdmd->Fill(dm_d);
h2->Fill(dm_d,rpd0_t/0.029979*1.8646/ptd0_d);
...
...
```

RAW - Using SQL to Query TTree's

- Developed at DIAS lab @ EPFL
- SQL makes querying easy

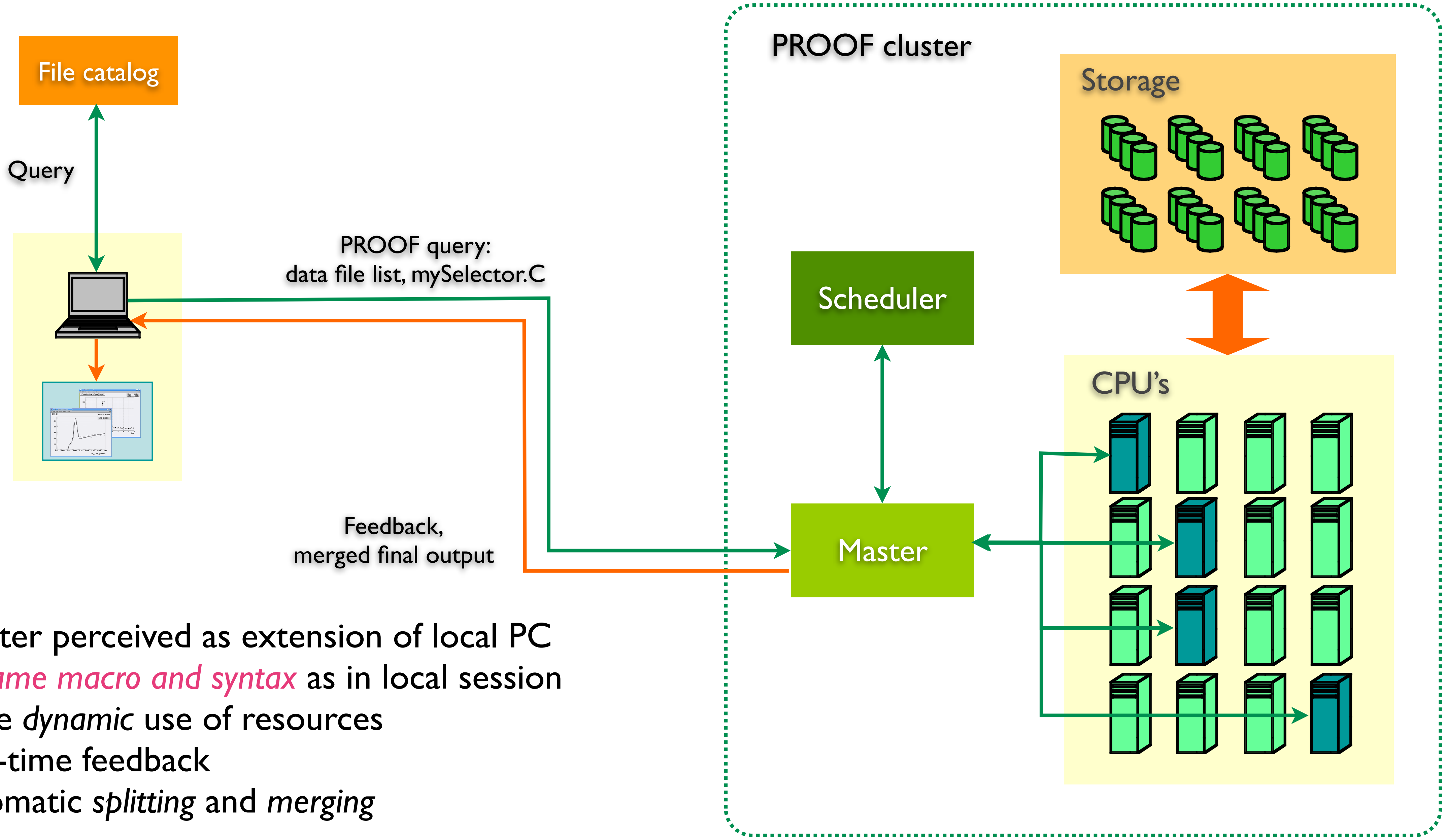
```
SELECT event
  FROM root:/data1/mbranco/ATLAS/*.root
  WHERE
  ( event.EF_e24vhi_medium1 OR event.EF_e60_medium1 OR
    event.EF_2e12Tvh_loose1 OR event.EF_mu24i_tight OR
    event.EF_mu36_tight OR event.EF_2mu13) AND
  event.muon.mu_ptcone20 < 0.1 * event.muon.mu_pt AND
  event.muon.mu_pt > 20000. AND
  ABS(event.muon.mu_eta) < 2.4 AND
....
```

- SQL makes querying fast
  - Column-stores & vectorized execution use h/w efficiently.

PROOF - The Parallel Query Engine

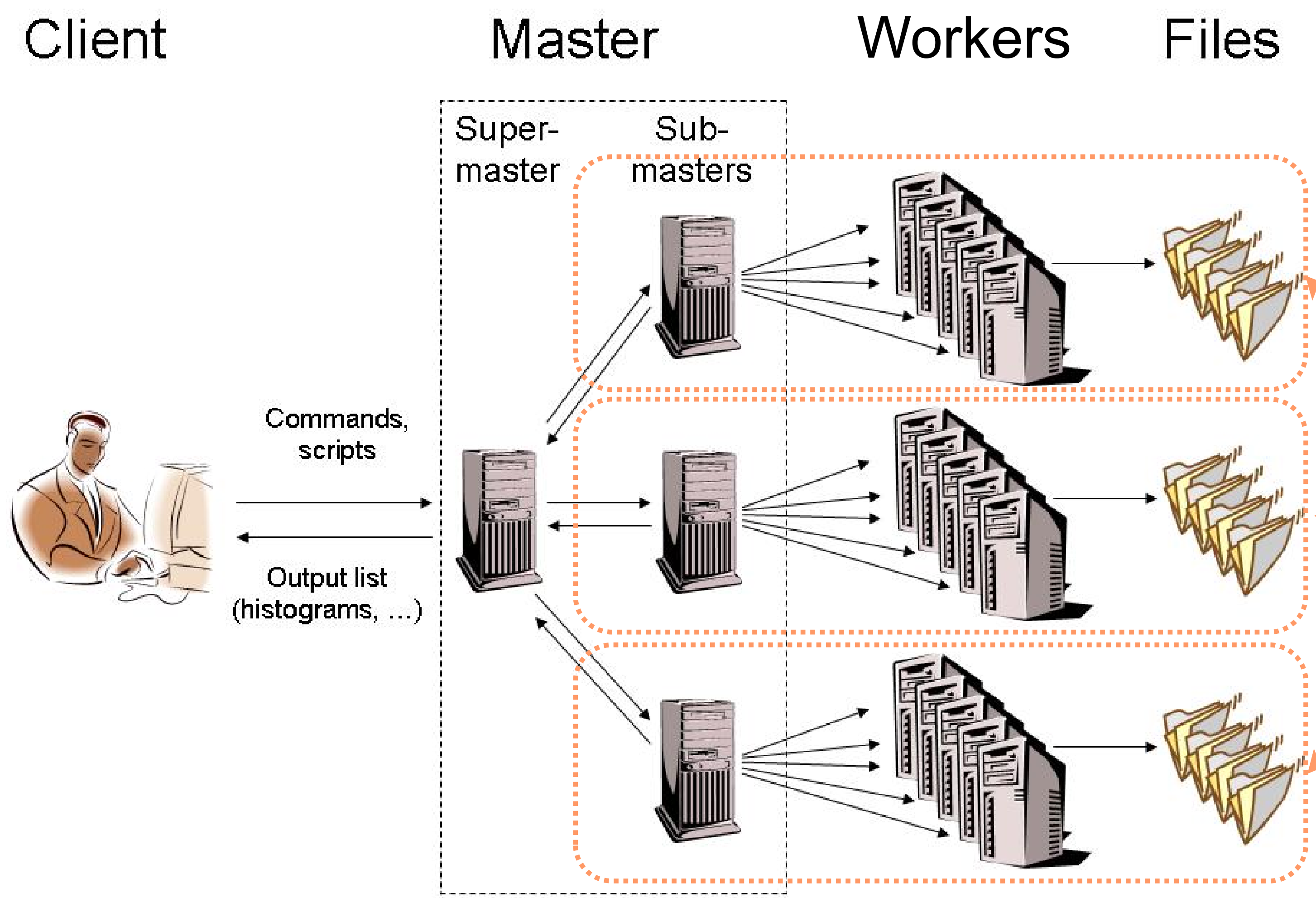
- A system for running ROOT queries in parallel on a large number of distributed computers or many-core machines
- PROOF is designed to be a transparent, scalable and adaptable extension of the local interactive ROOT analysis session
- Extends the interactive model to long running "interactive batch" queries
- Uses xrootd for data access and communication infrastructure
- For optimal CPU load it needs fast data access (SSD, disk, network) as queries are often I/O bound
- Can also be used for pure CPU bound tasks like toy Monte Carlo's for systematic studies or complex fits

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*

PROOF - A Multi-Tier Architecture



Adapts to wide area *virtual* clusters

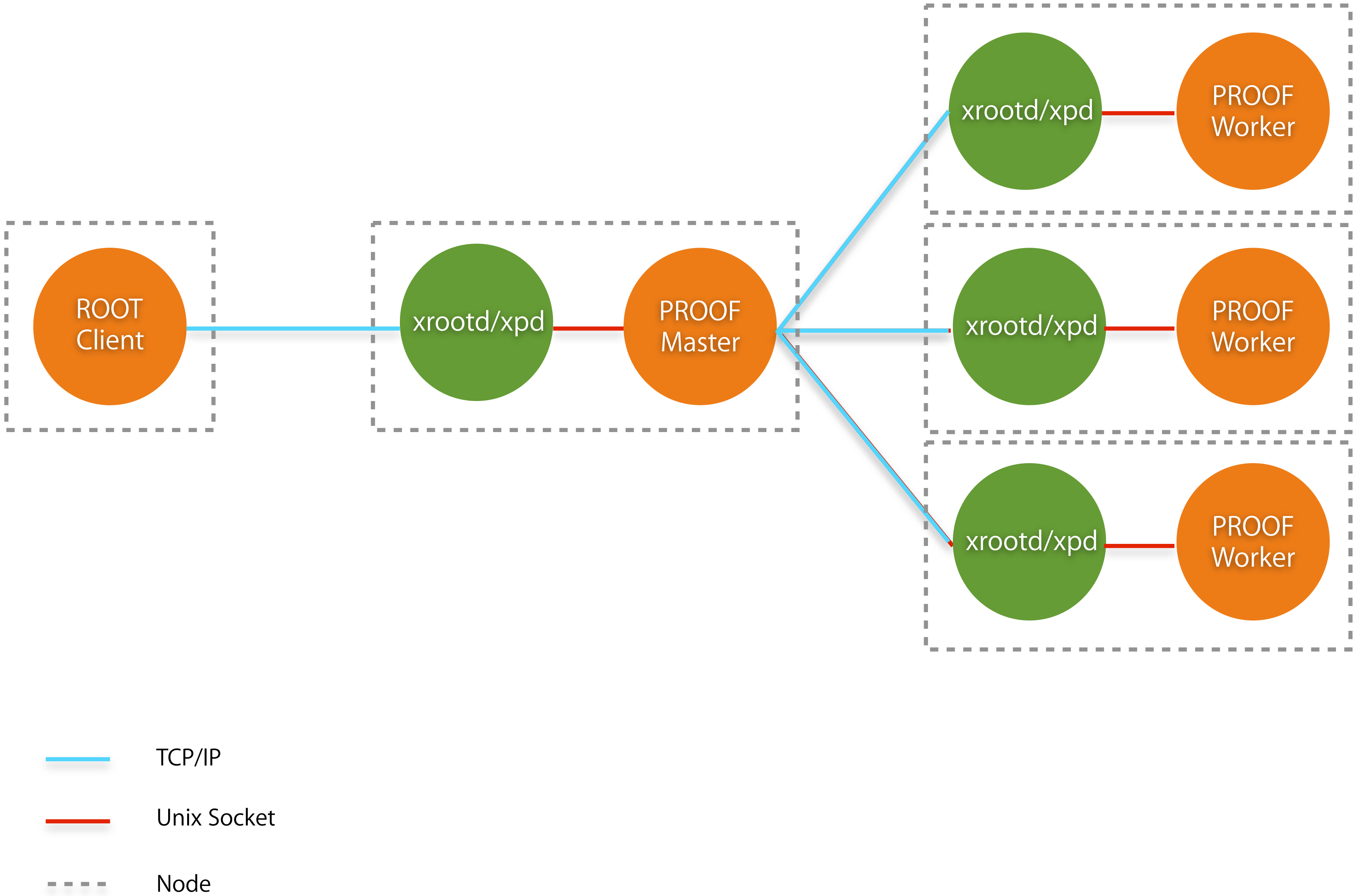
Geographically separated domains, heterogeneous machines

Network performance

Less important → VERY important

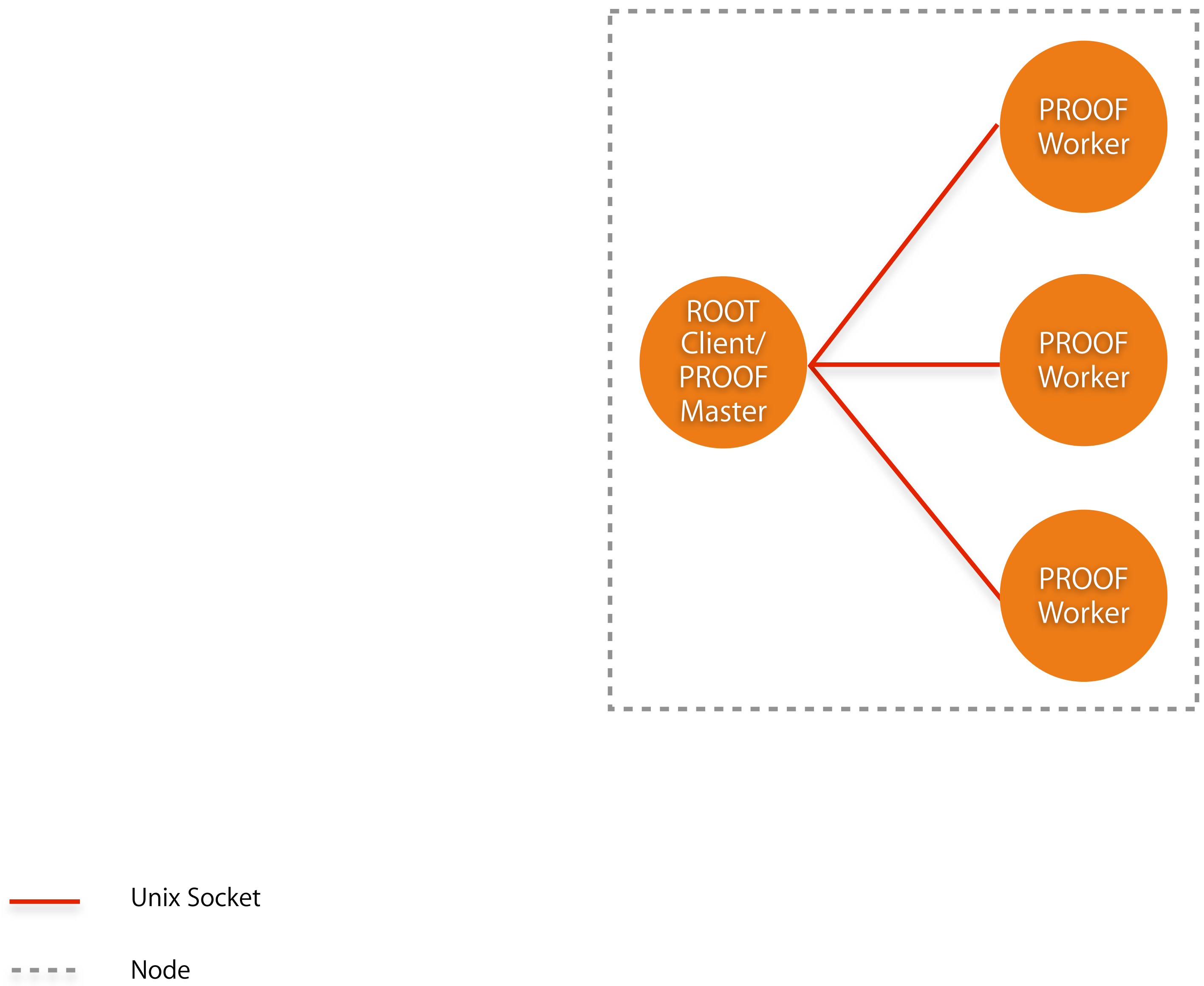
Optimize for data locality or high bandwidth data server access

From PROOF

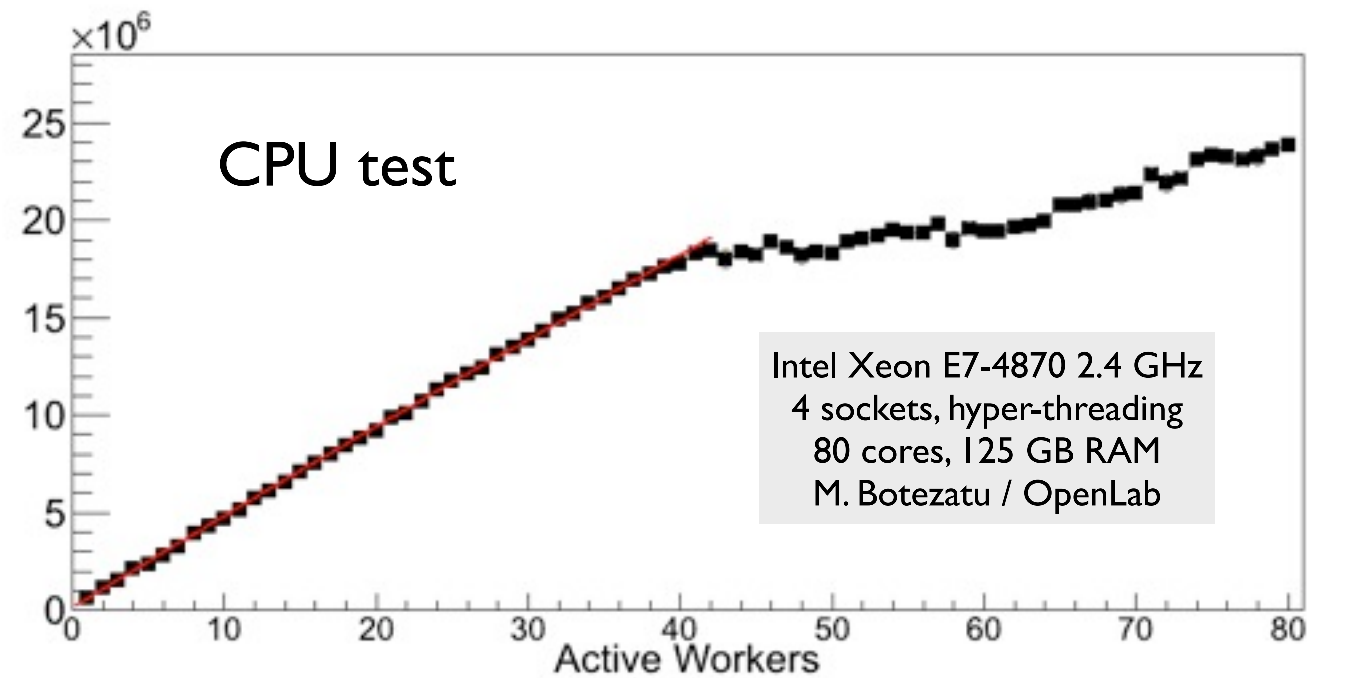


ROOT Client
xrootd/xpd
PROOF Master
xrootd/xpd
PROOF Worker
xrootd/xpd
PROOF Worker
xrootd/xpd
PROOF Worker
TCP/IP
Unix Socket
Node

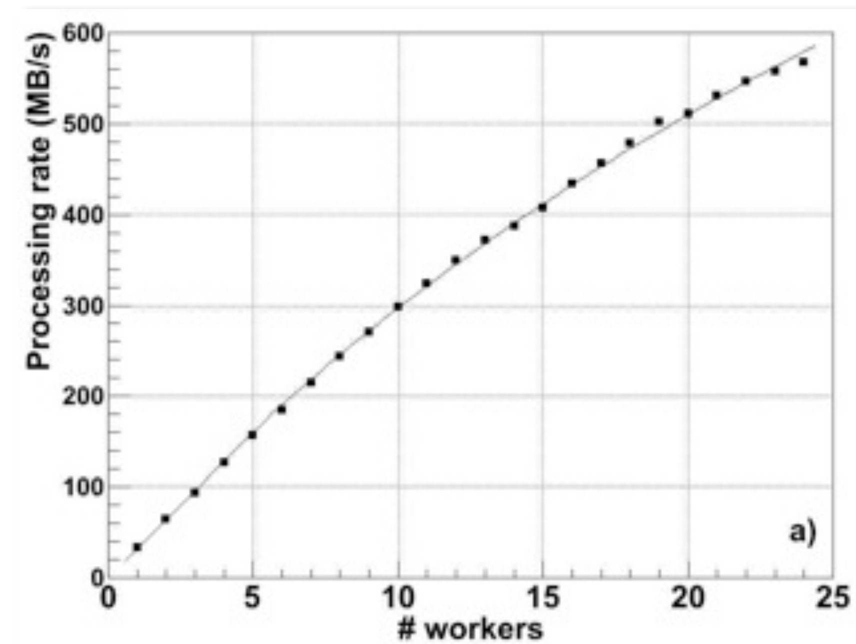
To PROOF Lite



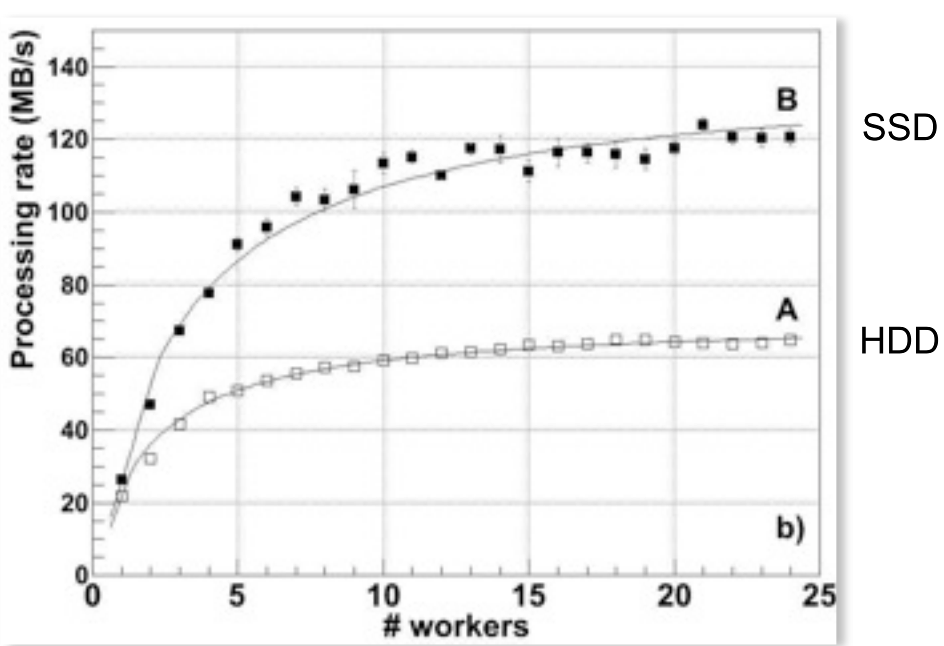
Benchmarking with PROOF-Lite



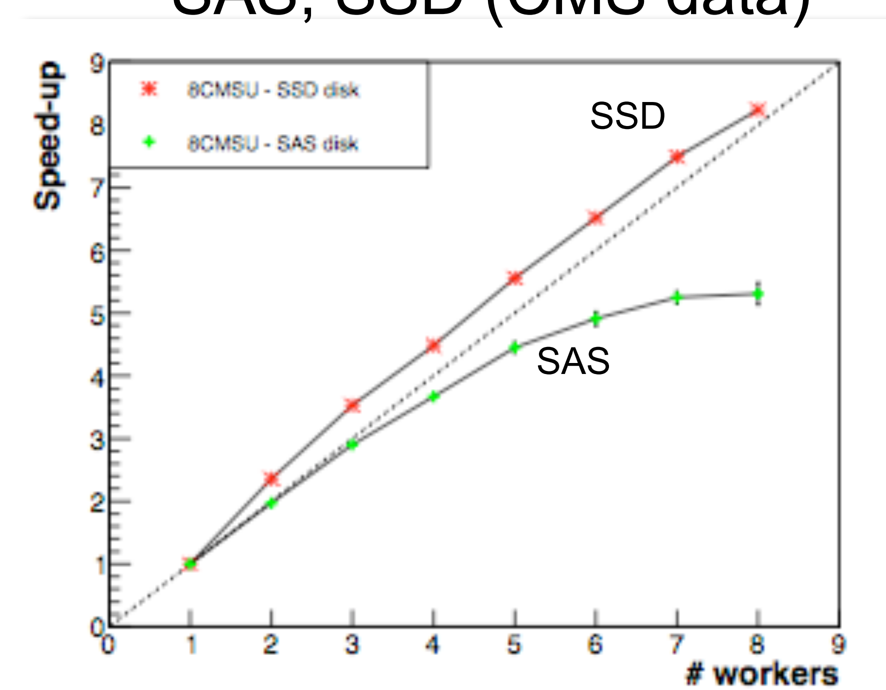
RAM



HDD, SSD



SAS, SSD (CMS data)



Barbone, Donvito, Pompilii CHEP2012

PROOF on Demand

- Use PoD to create a temporary dedicated PROOF cluster on batch resources
- Uses an Resource Management System to start daemons
  - Master runs on a dedicated machine
  - Easy installation
  - RMS drivers as plug-ins: gLite, PanDa, HTCondor, PBS, LSF, OGE
  - ssh plug-in to control resource w/o and RMS
- Each user gets a private cluster
  - Sandboxing, daemon in single-user mode (robustness)
  - Scheduling, auth/authz done by RMS

PROOF on Clouds

- A lot of computing resources available via clouds as virtual machines
- Several PROOF tests has been made on clouds
  - Amazon EC2, Google CE (ATLAS/BNL)
  - Frankfurt Cloud (GSI)
- Dedicated CernVM Virtual Appliance with the relevant services to deploy PROOF on cloud resources
  - PROOF Analysis Facility As A Service

ROOT Roadmap

- Current version is v5-34-05
  - It is an LTS (Long Term Support) version
  - New features will be back ported from the trunk
- Version v6-00-00 is scheduled for when it is ready
  - It will be Cling based
  - It will not contain anymore CINT/Reflex/Cintex
  - GenReflex will come in 6-02
  - It might not have Windows support (if not, likely in 6-02)
  - Several “Technology Previews” will be made available
    - Can be used to start porting v5-34 to v6-00

Conclusions

- HEP has a long experience in Big Data
- We have a number of interesting products on offer
- We should make a concerted effort to better promote and market our products
- EU Big Data projects could be used to extend and document our products for a much wider community