C++ Modules in ROOT and Beyond

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Motivation

#include <vector>

Textual Include

✗ Expensive
Fragile

1. **Expensive**
   Reparse the same header
2. **Fragile**
   Name collisions

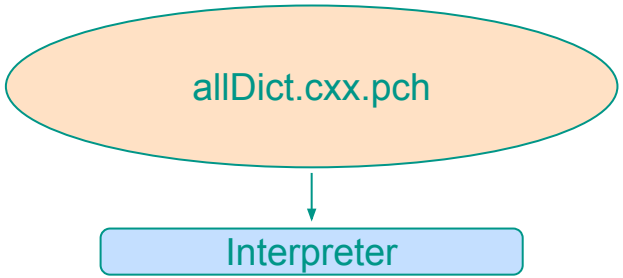
Rcpp library
#define PI 3.14
...

User Code
#include <header.h>
...
double PI = 3.14;
// => double 3.14 = 3.14;

Precompiled Headers (PCH)

✗ Inseparable

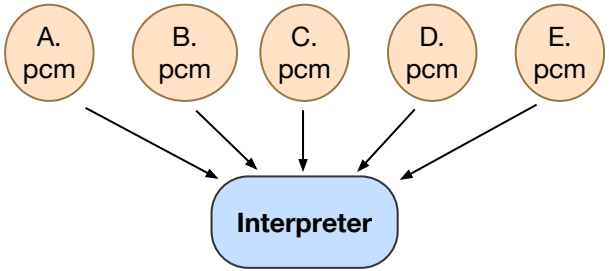
1. Storing precompiled header information (same as modules)
2. Stored in one big file
   - Inseparable



Modules

✓

- Pre compiled PCM files contain header information
- PCMs are separated

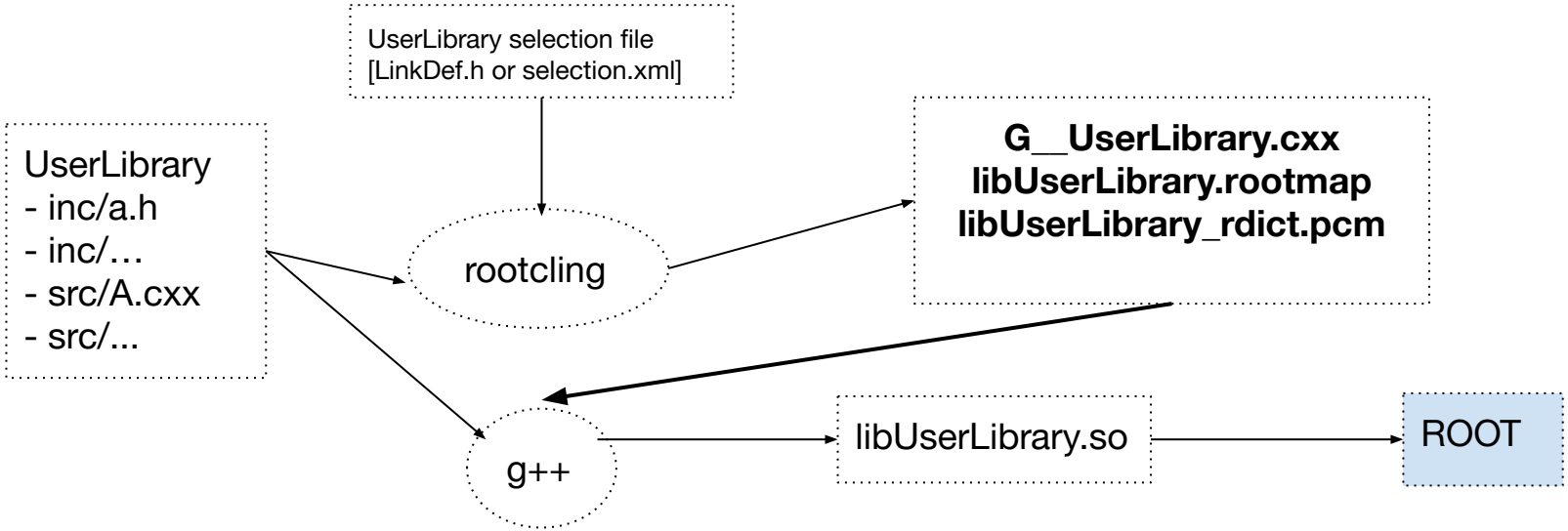


Motivation

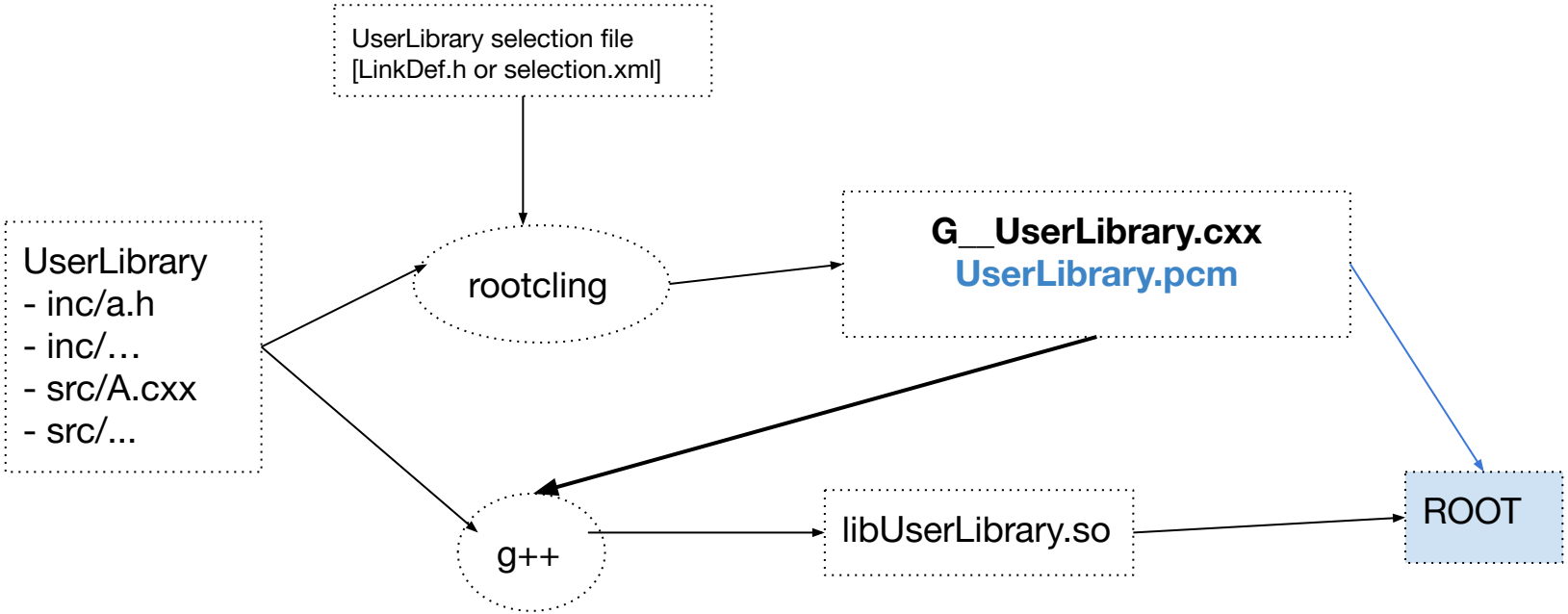
- ROOT sometimes requires parsing of sizeable chunks of C++ code to aid user actions at the prompt, dictionary setup, and various interpreter services
- **C++ Modules are designed to minimize the reparsing of the same header content** via an efficient on-disk representation of C++ Code

Dictionaries in ROOT

- ROOT provides **automatic generation of serialization information (I/O) and automatic header and dependency resolution (partially) *via dictionaries***
  - Dictionary is an extra file C++ needs to be synthesized and compiled into the defining library



Dictionaries in ROOT



Dictionaries in ROOT

G__UserLibrary.cxx has several sections which require reprocessing immutable headers in runtime

They are replaced by the much more efficient C++ Modules

```
Const char* foo = R”RAW(
-#include "TEveTrack.h"
-#include "TEveTrackEditor.h"
-#include "TEveTrackGL.h"
-#include "TEveTrackProjected.h"
-#include "TEveTrackProjectedGL.h"
-#include "TEveTrackPropagator.h"
-#include "TEveTrackPropagatorEditor.h"
-#include "TEveTriangleSet.h"
-#include "TEveTriangleSetEditor.h"
-#include "TEveTriangleSetGL.h"
...
-"TEveGedNameTextButton", payloadCode, "@",
-"TEveGeoManagerHolder", payloadCode, "@",
-"TEveGeoNode", payloadCode, "@",
-"TEveGeoNodeEditor", payloadCode, "@",
...
-class __attribute__((annotate(R"ATTRDUMP(An arbitrary polyline with fixed line and marker attributes.)ATTRDUMP"))) ..
)
```

C++ Modules in ROOT

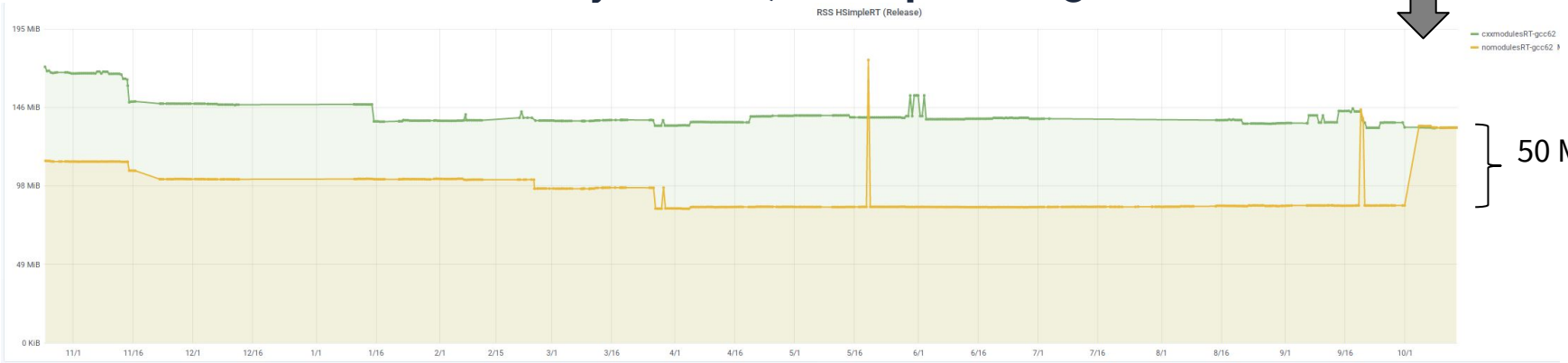
- Technology Preview released in ROOT 6.16
- **Default on UNIX in ROOT 6.20**

C++ Modules in ROOT. Loading strategies

- *Eager loading* of *pcm files at startup in ROOT 6.20
  - Small linear performance overhead depending on the number of modules
- *Delayed loading based on global module indexing (GMI)* planned for ROOT 6.22
  - **No overhead, pay only for what you use!**

C++ Modules become default on UNIX

Functionality is there, now optimizing!

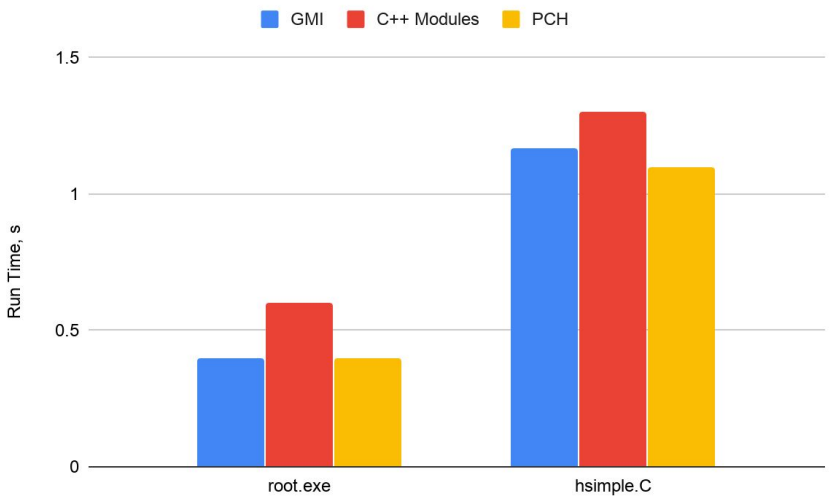


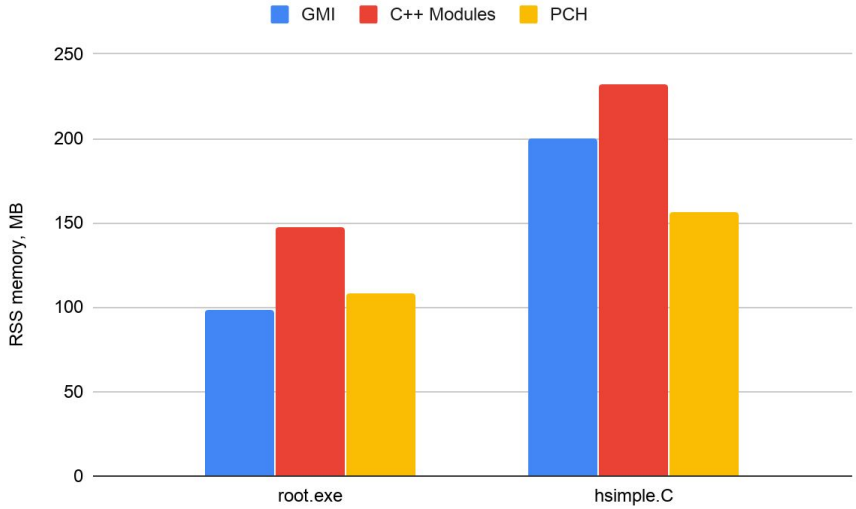
Global Module Index (GMI)

- Global Module Index (**`clang::GlobalModuleIndex`**) is **an aid for name lookup into modules**
- **Global Module Index returns a set of modules where a given identifier is present**
  - This allows us to avoid eager loading of all modules and load only necessary ones on demand

- It is using key-value store concept -> on-disk hash table
- Populated by scanning on demand all identifiers in all modules
- Created at build time (it is a on-disk file)

GMI measurements

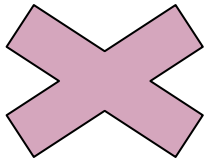


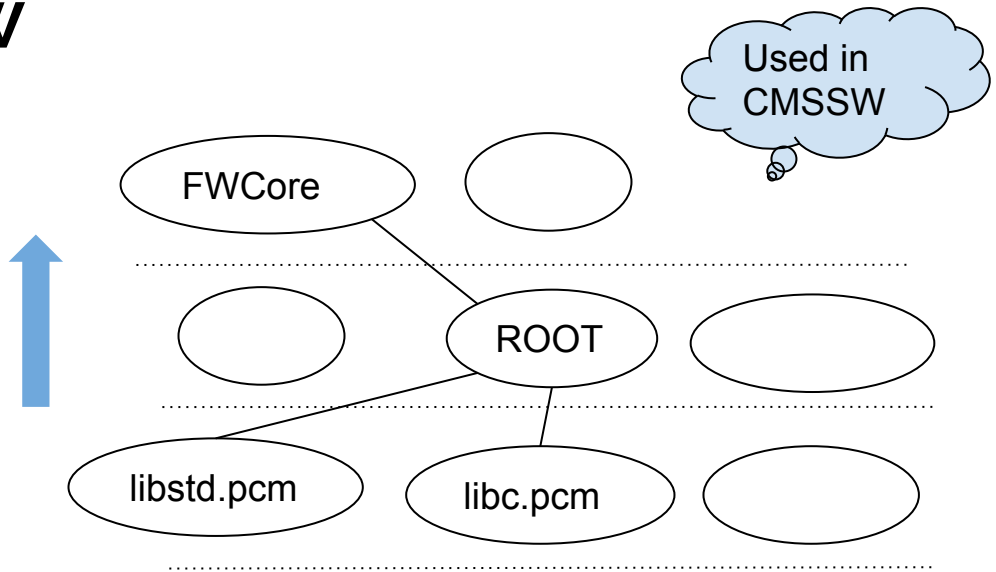


C++ Modules in CMSSW

- Available in CXXMODULE_IB

C++ Modularization in CMSSW





Top-down approach

Bottom-up approach

Library without modulemap

- Header file pollute the rest of the library dependencies
  - **The header duplication is problematic for performance but also triggers a lot of bugs when resolving the duplicate content**

Library with modulemap

- Headers are persisted in the PCM
  - **Header duplication is reduced by referencing the dependent module**

C++ Modules-aware dictionary generation in CMSSW

[module.modulemap]

- Definition file of headers to build a PCM in Clang
- Contain all “interface” headers, which are used by libraries

```
module "MathCore" {
  module “TComplex name” { header "TComplex.h" export * }
  module <name of the file> {
      header <relative path to the header file location> }
  export libMathCore.so
}
```

modulemap will contain all interface header files

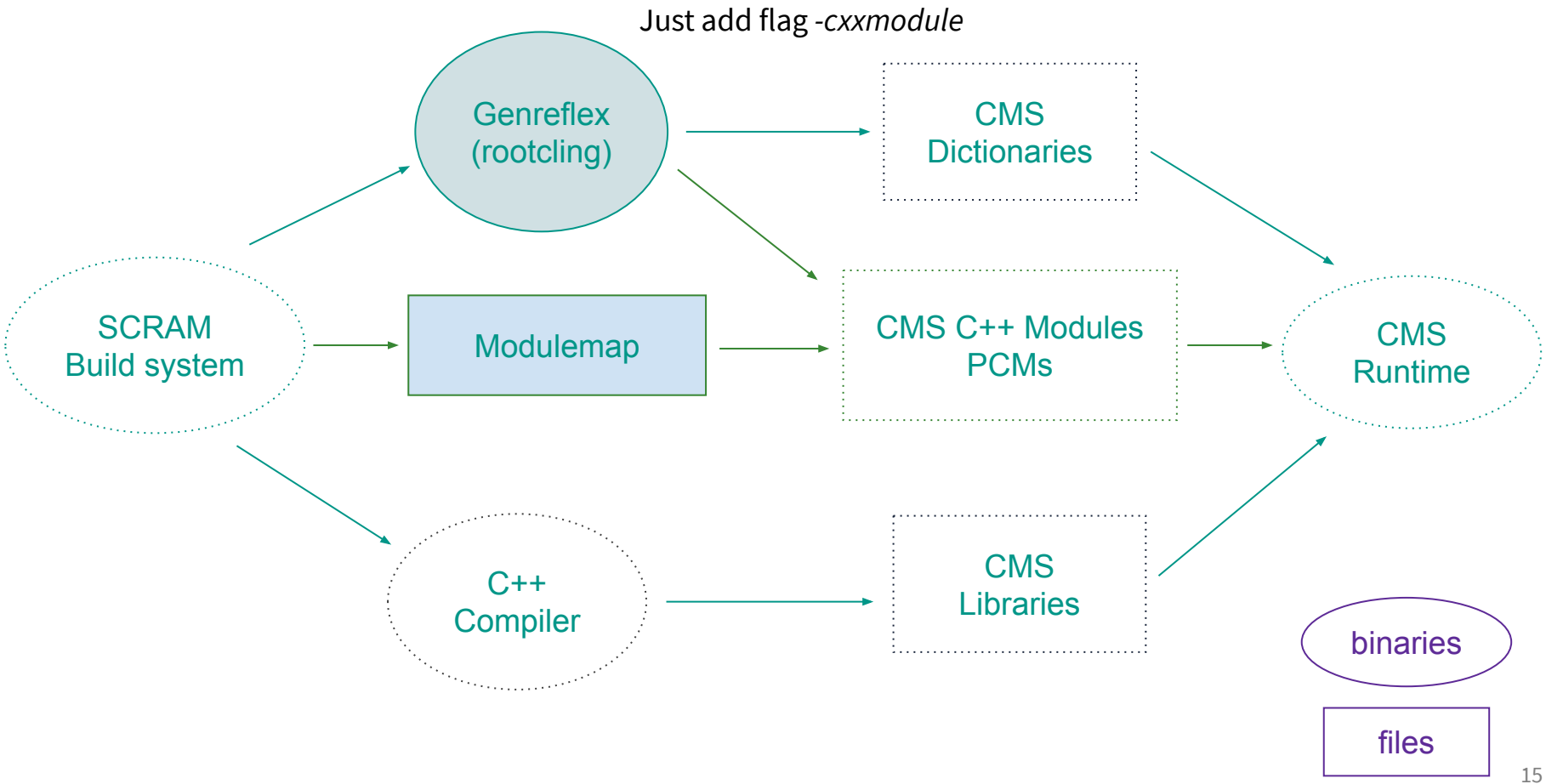
Automatic generation of modulemap

Dictionaries Using C++ Modules in CMSSW

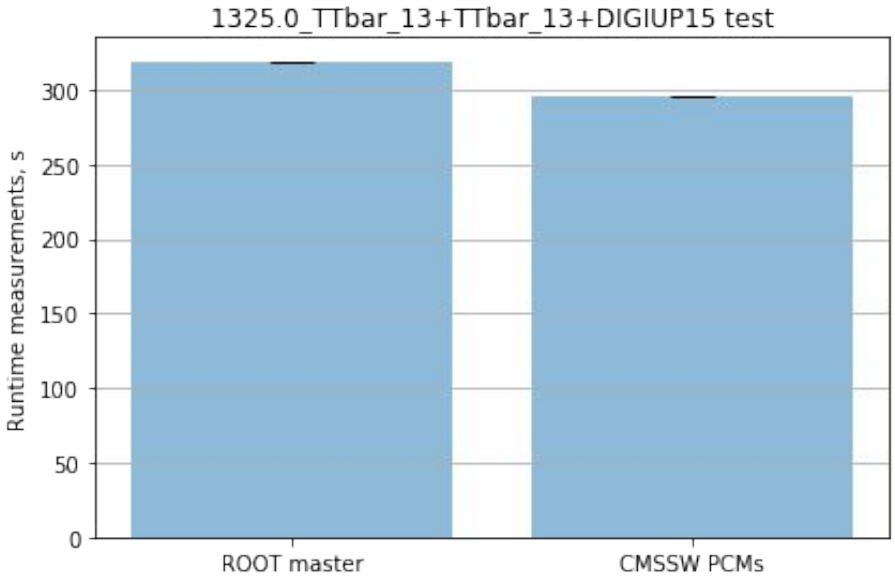
[Automatic generation of modulemap]

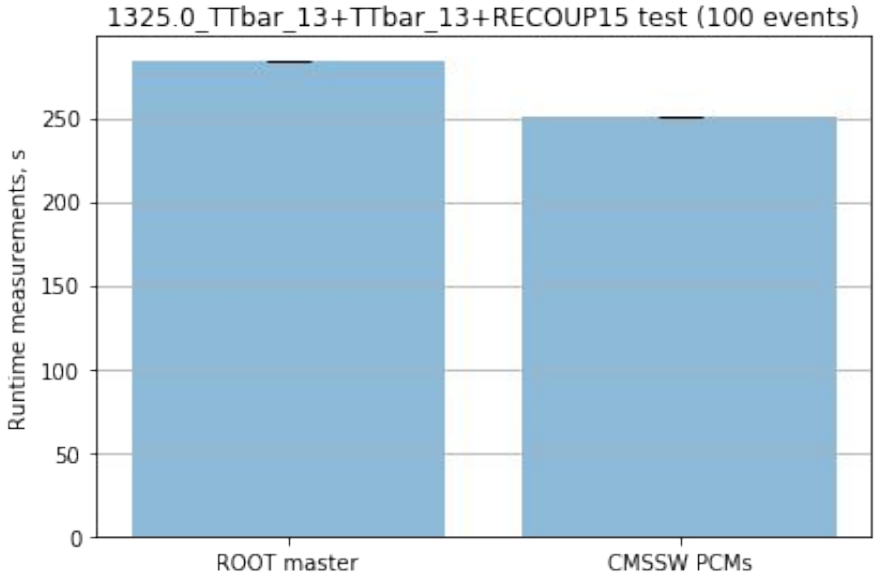
- CMSSW has “interface” headers
  - Exposed to libraries outside
- Automatically generate the modulemap by adding interface headers
  - Modulemap needs to be generated before the execution of genreflex
- *Design features*
  - *Headers can be easily vetoed from generation of modulemap via SCRAM settings*

C++ Modules-aware dictionary generation in CMSSW



C++ Modules in CMSSW. Preliminary measurements (104 modularised libraries)





The largest part of the speedup is in the initialization phase

C++ Modules in ROOT. Roadmap

C++ Modules in ROOT. Roadmap

- Modular ROOT and non-modular software stacks should work seamlessly but at no performance benefits (and costs)
- **ROOT 6.20 (January 2020):** C++ Modules will be default for all UNIX platforms (implementation based on eager module loading)
- **ROOT 6.22 (mid 2020):** C++ Modules by default for OS X (implementation based on global module indexing (GMI))

We are here to help to migrate your stack!

Thank you for your attention!

For more questions please contact: vvasilev@cern.ch
root-cxxmodules@cern.ch

Backup

Motivation of C++ Modules

```
#include "TVirtualPad.h"
#include <vector>
#include <set>

int main() {
…
```

original code

Preprocess

Textual Include

```
                                        ……
                                        ……
# 286 "/usr/include/c++/v1/vector" 2 3
namespace std { inline namespace __1 {
template <bool> class __vector_base_commo
  __attribute__ ((__visibility__("hidden"),
__always_inline__)) __vector_base_common
                                        ……
# 394 "/usr/include/c++/v1/set" 3
namespace std {inline namespace __1 {
template <…> class set {
public:
   typedef _Key key_type;
                                        ……

int main {
                                        ……
```

TVirtualPad.h

vector

set

one big file!

Compile

Parse

.o

C++ Modules in CMSSW. Mechanism of the modulemap

[modulemap, modulemap overlay file, virtual modulemap overlay]