HEP Software Foundation

Key4HEP - The Common Turnkey Software Stack

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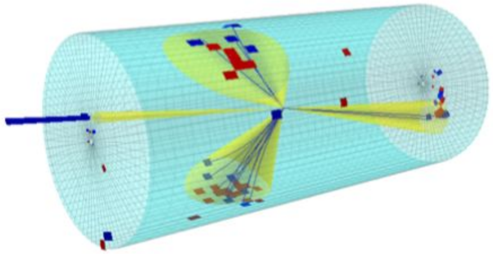
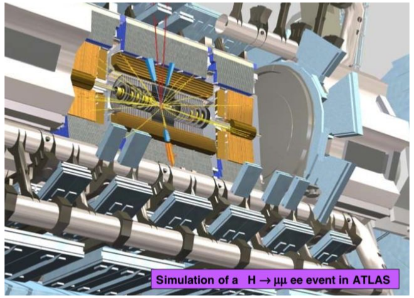
Experiment Software Lifecycle I

- First ideas and inspiration...
  - Cool idea... would that work?
- Concepts
  - Very fast approximate methods, e.g. Delphes (smeared tracks, etc.)
- Design
  - Still need to be flexible to decide between alternatives
  - Ultimately need to pay a lot of attention to details for accurate performance evaluation
    - Accurate geometry, full simulation, realistic digitisation, ...

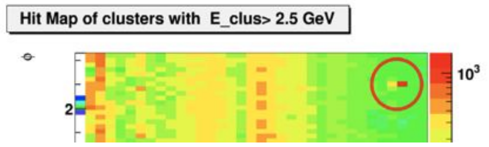


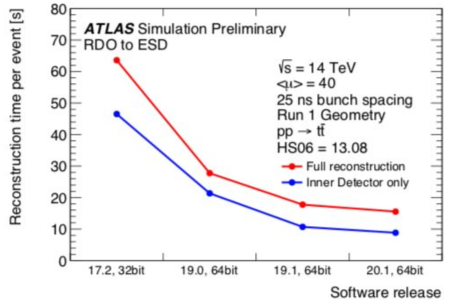


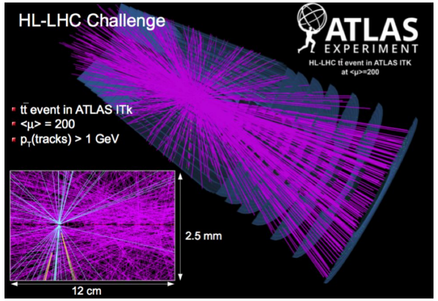
Experiment Software Lifecycle II

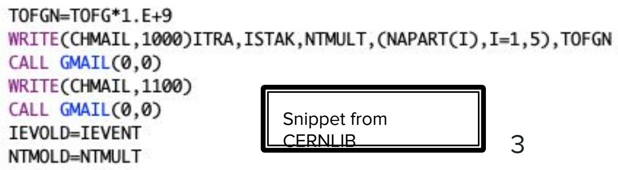
- Production
  - Dealing with the real world - calibration, alignments, dead and noisy elements
  - Learn about the detector, need stability but also continual improvements
- Upgrade
  - Design better sub-detectors for the next version
- Preservation
  - How can I make sure we can look at the data in the future?

For new experiments not everything needs to, or should be, solved up-front, but forgetting about the next step entirely will cause problems down the line (**technical debt!**)





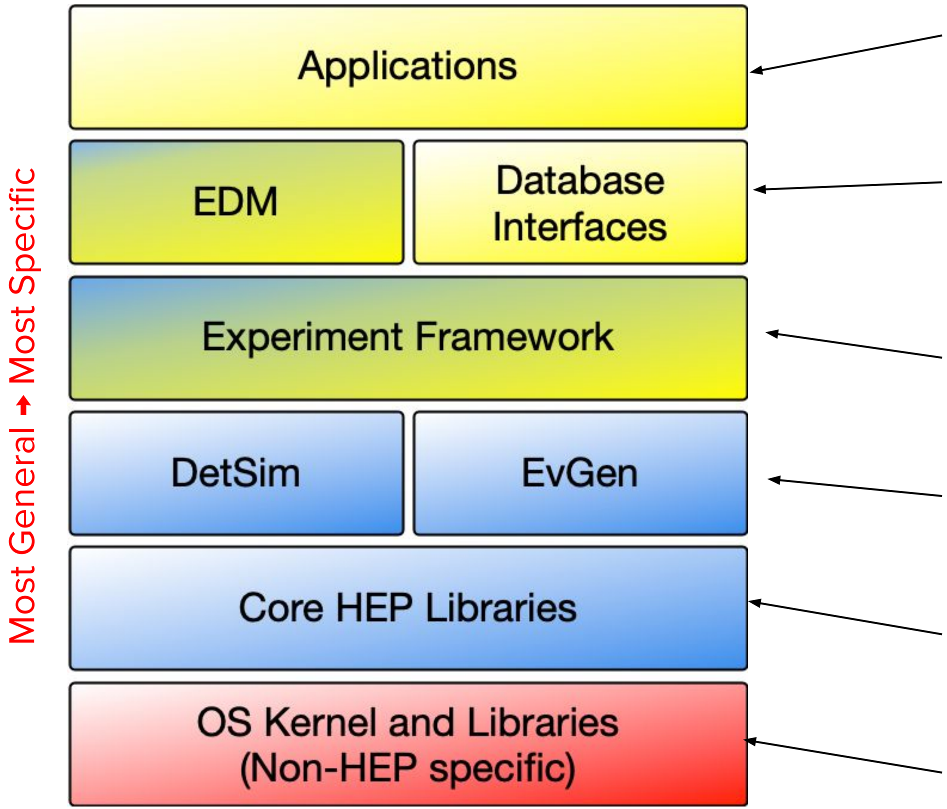

HL-LHC Challenge
ATLAS EXPERIMENT
HL-LHC $t\bar{t}$ event in ATLAS ITK at <μ>=200
$t\bar{t}$ event in ATLAS ITk
<μ> = 200
p_T(tracks) > 1 GeV
2.5 mm
12 cm



```
TOFGN=TOFG*1.E+9
WRITE(CHMAIL,1000)ITRA,ISTAK,NTMULT,(NAPART(I),I=1,5),TOFGN
CALL GMAIL(0,0)
WRITE(CHMAIL,1100)
CALL GMAIL(0,0)
IEVOLD=IEVENT
NTMOLD=NTMULT
```

Snippet from CERNLIB

HEP Application Software



Application layer of modules/algorithms/processors that perform physics tasks (some generic examples like FastJet and PandoraPFA)

Usually experiment specific libraries for data representation and access: xAOD (but LCIO!); also detector specific conditions data

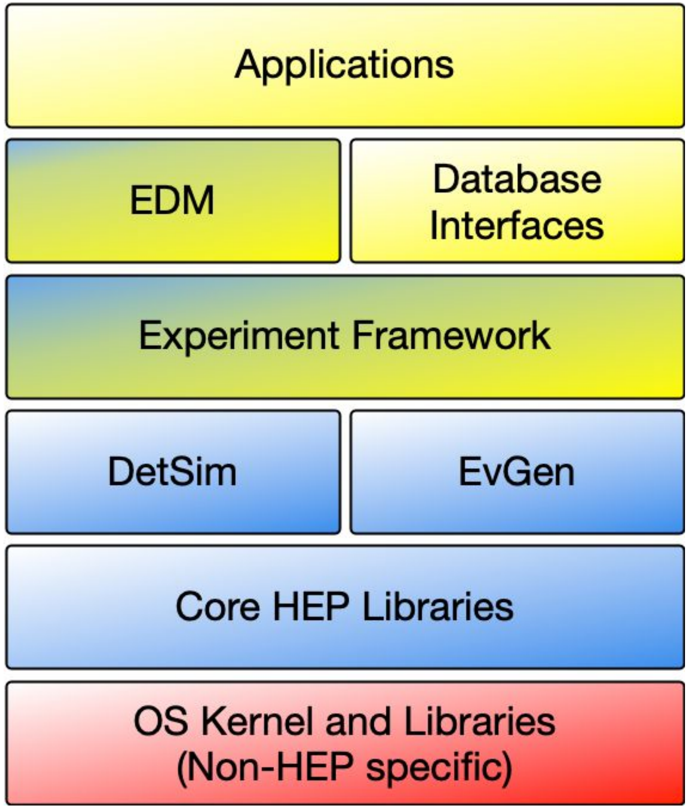
Experiment core orchestration layer, where everything else plugs in: Gaudi, CMSSW, Marlin

Specific components used by many experiments: Geant4, DELPHES, Pythia, ...

Provide core functionality widely used: ROOT, HepMC, HepPDT, DD4hep, ...

Many widely used non-HEP libraries: Boost, Python, Zlib, CMake, ...

Building HEP Applications



- Each piece of software does not live in isolation
- There is an ecosystem of interacting pieces
- Compatibility between the elements doesn’t usually come for free
  - Common standards do help a lot
- Building a consistent set of software for an experiment is a task in itself
  - But the software used to do it benefits from commonality
  - LCGCMake, Spack, etc.

Constituent Components

- Foundation Libraries
  - Basic types
  - Utility libraries
  - System isolation libraries
- Mathematical Libraries
  - Special functions
  - Minimization, Random Numbers
- Data Organization
  - Event Data
  - Event Metadata (Event collections)
  - Detector Description
  - Detector Conditions Data
- Data Management Tools
  - Object Persistency
  - Data Distribution and Replication
- Simulation Toolkits
  - Event generators
  - Detector simulation
- Statistical Analysis Tools
  - Histograms, N-tuples
  - Fitting
- Interactivity and User Interfaces
  - GUI
  - Scripting
  - Interactive analysis
- Data Visualization and Graphics
  - Event and Geometry displays
- Distributed Applications
  - Parallel processing (concurrency)
  - Distributed computing (grid/cloud/...)

Motivation

- Future detector studies critically rely on well-maintained software stacks to model detector concepts and to understand a detector's limitations and physics reach
- We have a scattered landscape of specific software tools on the one hand and integrated frameworks tailored for a specific experiment on the other hand
- Aim at a low-maintenance common stack for FCC, ILC/CLIC, CEPC with ready to use "plug-ins" to develop detector concepts
- Identified as an important project in the CERN EP R&D initiative
- Reached consensus among all communities for future colliders to develop a common turnkey software stack at recent Future Collider Software Workshop

Goals

- Put together a stack of the software packages covering the different domains
  - most commonly used, avoiding as much as possible functionality overlaps
- The turnkey stack connects and extends the individual packages to enable a complete data processing ecosystem
  - **converting a set of disconnected packages into a 'turnkey' system**
- and should be
  - easy to use: for librarians, developers, users
  - easy to set up
  - easy to deploy (CVMFS and containers)
  - easy to extend
  - full of functionality
- Plenty of examples/templates for simulation and reconstruction of detectors

Interoperability I

- Level 0 - Common Data Formats
  - Allows interoperability between different programs, even running on different hardware
  - E.g., HepMC event records, LCIO, GDML, ALFA messages
- Level 1 - Callable Interfaces
  - Basic calling interfaces defined by the programming language
    - Cross language calls are, of course, possible
  - Can be dependent on the compiler and language version (C++ in particular)
  - Details are important
    - how to handle errors and exceptions, is it thread safe, are objects const, dependent libraries and runtime setup
  - E.g., FastJet, Eigen, Boost

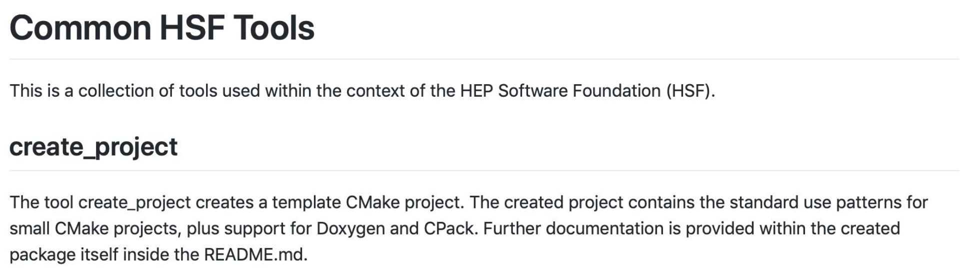
Interoperability II

- Level 2 - Introspection Capabilities
  - Software elements to facilitate the interaction of objects in a generic manner such as Dictionaries and Scripting interfaces
  - Example: PyROOT, which is a Python extension module that allows the user to interact with any ROOT (C++) class from the Python interpreter
- Level 3 - Component Model
  - Software components of a “common framework” offers maximum re-use
  - ‘standard’ way to configure its parameters, to log and report errors, manage object lifetime and ownership rules, ‘standard’ plug-in management, etc.
  - Unfortunately, no single Framework has been generally adopted

The right interoperability point between packages varies, but fixing it correctly eases life a lot for other developers and users

HSF Project Template

- To enable interoperability and long term maintainability
  - Build system
    - Share build results, but also knowledge of how to build
    - HSF Packaging working group studying various options
  - Testing
  - Licensing and Copyright
  - Documentation
    - If it is not documented, does it exist?
- Ensure as much uniformity as reasonable
  - https://github.com/HSF/tools

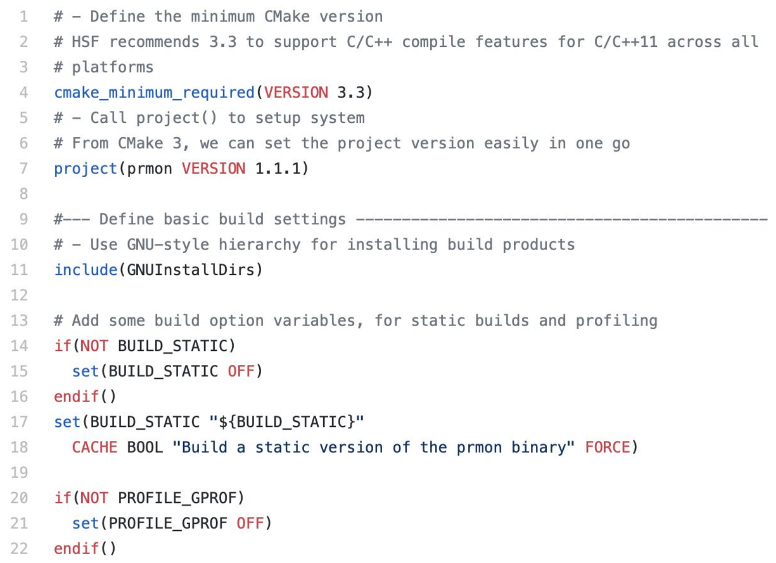


Common HSF Tools

This is a collection of tools used within the context of the HEP Software Foundation (HSF).

create_project

The tool create_project creates a template CMake project. The created project contains the standard use patterns for small CMake projects, plus support for Doxygen and CPack. Further documentation is provided within the created package itself inside the README.md.

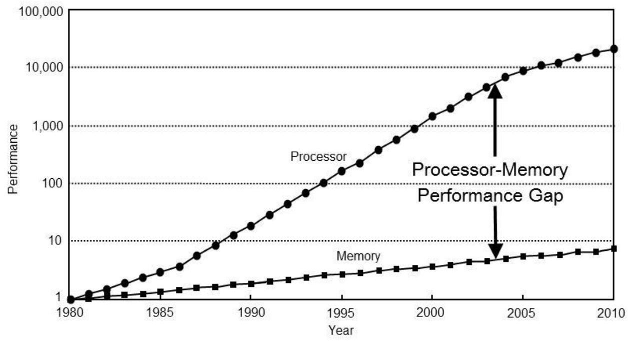


```
# - Define the minimum CMake version
# HSF recommends 3.3 to support C/C++ compile features for C/C++11 across all
# platforms
cmake_minimum_required(VERSION 3.3)
# - Call project() to setup system
# From CMake 3, we can set the project version easily in one go
project(prmon VERSION 1.1.1)

#--- Define basic build settings ---------------------------------------------
# - Use GNU-style hierarchy for installing build products
include(GNUInstallDirs)

# Add some build option variables, for static builds and profiling
if(NOT BUILD_STATIC)
  set(BUILD_STATIC OFF)
endif()
set(BUILD_STATIC "${BUILD_STATIC}"
  CACHE BOOL "Build a static version of the prmon binary" FORCE)

if(NOT PROFILE_GPROF)
  set(PROFILE_GPROF OFF)
endif()
```

EDM4HEP

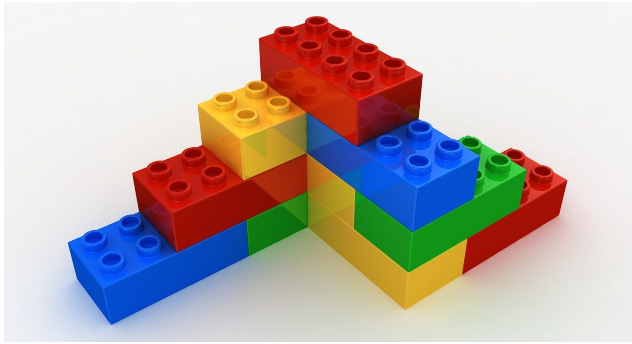
- To achieve the highest levels of interoperability components should directly talk the same language
    - For HEP this is the *Event Data Model*, EDM
- The experience of the ILC/CLIC community in sharing an EDM has been a very positive one
    - Defining it may not be easy
    - But once achieved it pays off handsomely
- As an outcome of the Future Collider Software Workshop a small working group is being setup (ILC/CLIC/FCC/CECP) to discuss this
    - Our baseline is the highly successful LCIO from the linear collider community

Implementing the EDM



- Original HEP C++ Event Data Models were heavily inspired by the Object Oriented paradigm
    - Deep levels of inheritance
    - Access to data through various indirections
    - Scattered objects in memory
- In practice access to the data in this way can be very slow
    - LHC experiments needed to optimise this a lot during Run 2
- Challenges in this area are only growing
    - As well as increasing memory latency, we look more and more towards accelerated computing devices
- **Use PODIO EDM generator**
    - Data model described at a high level in YAML
    - Code is then generated for target languages and different persistency backends
    - Insulates users from implementation details and allows for common optimisation

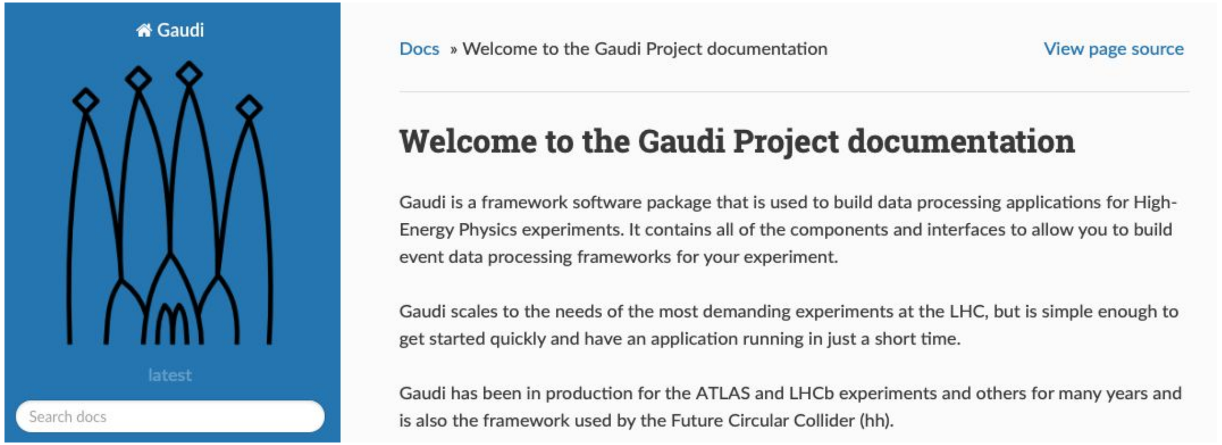
Experiment Framework



- Data processing **frameworks are the skeleton** on which HEP applications are built
- To get software to ‘click’ in the best way possible it’s a huge advantage to share a software framework
  - In HEP we have traditionally not done so well here - many frameworks and a lot of duplication of effort
- Marlin was used by the LC community and was very successful as a common project
  - Unfortunately very far behind in conversion to modern concurrency needs
  - It does have a lot of well liked features (e.g. configuration)
- Gaudi is another shared framework, used by LHCb and ATLAS, as well as smaller experiments
  - Supports concurrency and has all hooks needed for data taking
- We will **base Key4HEP on Gaudi** and contribute to development where needed

Gaudi Modernisation Project

- A lot of the very hard things are done
- Improved documentation coming
- CMake build system being rewritten this summer



Welcome to the Gaudi Project documentation

Gaudi is a framework software package that is used to build data processing applications for High-Energy Physics experiments. It contains all of the components and interfaces to allow you to build event data processing frameworks for your experiment.

Gaudi scales to the needs of the most demanding experiments at the LHC, but is simple enough to get started quickly and have an application running in just a short time.

Gaudi has been in production for the ATLAS and LHCb experiments and others for many years and is also the framework used by the Future Circular Collider (hh).

Practical Progress

- To help integrate ILCsoft algorithms into Key4HEP a Marlin➔Gaudi wrapper has been developed (André Sailer) ➔ Next talk
  - https://github.com/andresailer/GMP
  - Prototype for now, but proves that framework transition is quite practical to achieve
- As part of the AIDA2020 project LCIO has been re-implemented using PODIO (Frank Gaede)
  - This demonstrates, as expected, that PODIO can implement a generic data model like LCIO
  - Some interface changes, e.g. shift from pointer to by-value semantics
    - These can probably be temporarily masked

Next Steps and Conclusions

- General **agreement on moving to a common HEP software stack** from future experiments
  - A lot to be learned from ILC/CLIC experiments in how to do this and the benefits
    - N.B. ILCsoft and Marlin will keep working for LC
- Move build infrastructure to Spack tool
  - Sustainable build orchestrator with wide support for scientific software packages (developed by LLNL)
  - Many elements of HEP software are already supported
- Progress on EDM4HEP
  - Begin by looking at LCIO and FCC EDM
- Provide common and popular HEP package sets and ensure their interoperability
- Gaudi framework to bind elements together
- Shims to form a plugin system of software that really works coherently

Key4HEP will support ILC/CLIC software development