Intro to Efficient Programming

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HGS-HIRe power week

Limburg

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Lecture I

Introduction

Who we are

Mikolaj Krzewicki

- in ALICE since 2007
- ALICE High Level Trigger / ALICE O2
- Software validation
- TPC calibration
- Analysis (correlations and flow)

Patrick Huhn

- in ALICE since 2014
- PhD student since 2017
- former participant of this power week
- Analysis (charged particle R_{AA})

Sandro Wenzel

- at CERN since 2012; in ALICE since 2015
- Detector Simulation
- Previous experience in various computing activities (PhD: Quantum Monte Carlo; The Blue Brain Project)

Credits

Material of this course building on previous courses given by Jens Wiechula, David Rohr, Matthias Richter and Jochen Klein.

Outline / Goals of the week

Software development / computing in high energy physics is ubigous and essential knowledge. This week should help you to ...

- Be able to come up with efficient algorithms in C++ implementing software solutions to problems in (particle) physics.
- Be able to use ROOT as a library and to look into data using ROOT
- Be able to decompose problem into small pieces, structure code and work on software projects incrementally
- Understand tools and practices in the software development process
- Know about modern C++11 features and few optimization strategies
- Know about easy parallelism options and SIMD

Introduction

There are many aspects of *efficiency*

- Coding concepts
- Tools
- Fast development (prototyping)
- Fast code execution (optimization)
- Small memory imprint
- Code design
- Code flexibility / configurability
- ...

Programme

What we want to cover:

- Modern C++ features and concepts (C++11, C++14, ...)
- Tools
  - gcc
  - (c)make
  - git
  - doxygen
  - gdb
  - profilers: valgrind, perf, ...
- Methods
  - object orientation, templates
  - libraries
- Algorithms
- Parallelisation
- SIMD vectorisation

Outlook Programme 2

What we can't cover here but intend to do in part 2:

- GP-GPU
- Parallelization in more depth
- distributed computing and messaging
- ...

Course format

There will be some lectures but focus will be on practical side!

- Lot's of do-it yourself exercises/examples
- A real coding project touch typical high energy physics subject
- Possibility to do code reviews / interaction with lecturers

link to dynamic plan
https://tinyurl.com/hgspw1

A small project

- small groups (up to 5 people)
- work shall be carried out over the whole week,
  presentation of results on Friday (20+5),
  code reviews in between
- we want you to
  - use the tools
  - try the methods
  - test the algorithms

  which are discussed during the meeting
- you should learn something
  $\Rightarrow$ try and understand what you are doing

Computing I

- local servers (hostnames: power[1-4].power.week)
  personal user accounts:
  username: first letter of firstname + lastname,
  initial password: pwLimburg
  (reference environment, you can compare to your machine)

- Every groups gets assigned one server (please use it exclusively)

- separate network with WLAN access (or cable)
  SSID: PowerWeek_01
  pw: powerweek

- passwordless login
  often it is convenient to login using ssh keys

```
ssh-keygen
ssh-copy-id <you-user-id>@power[1-4]
```

Computing II

- examples and slides are provided via git

```
git clone https://github.com/hgspowerweek/powerweek1/
cd powerweek1
git pull
```

  do the last step before every session and you will get the latest examples and slides

- Slides are directly in this folder as pdfs

- Examples are in the folder *examples*

examples/bla

X

Lecture II

Introduction to code / document management using git – absolute basics

Code repository

Why would you use a code repository?

- keep control over your changes
- keep a history of changes and go back to any previous state
- add logging messages to individual changes
- develop different topics in parallel
- keep a working version as a reference
- create releases for distribution of the code
- synchronize several developers

A code repository can serves as

- back-up solution
- communication medium
- team and product management tool

git - the stupid content tracker

- Developed by Linus Torvalds and others in 2005 for the Linux kernel community
- Nobody knows what git stands for at least one does not get a real answer.
- Instead of beeing stupid - see manpage - it's a extremely powerful scalable, distributed revision control system.

In contrast to other versioning systems (CVS, subversion),

- git allows to use the full functionality of a code repository locally
- can be distributed
- does not require a central server, but can be used with a server

git commands in a nutshell

Basic operations:

- `git init`
- `git clone`
- `git add` – add something to staging area
- `git commit` – commit staging area to local reposity
- `git checkout <commit>` – retrieve certain state

Getting information

- `git log` – show commit history
- `git status`
- `git diff` – show differences (between commits)

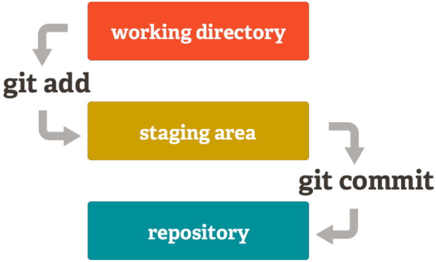
Advanced commands

- `git stash`
- `git push` – publish repo somewhere else (some URL)
- `git pull` – sync/get changes from somwhere else (some URL)
- `git rebase/merge` – integrate someone elses changes; change history

git - the stupid content tracker

How is a git repository structured:

- local copy (tree) - those are your files.
- staging area (intermediate store) - changes (diffs) staged for commit.
- local repository - full repository containing all changes to all branches. Everybody has a full copy, there is no concept of a central repository - you still may declare some repository the central one.



git - One time (identity) setup

- git config Configure git or query configuration
- Some essential setup: Give yourself a git identity:

```
git config --global user.name "Foo Bar"
git config --global user.email foo.bar@cern.ch
```

- `git config -l` will show you the whole configuration including your identity
- configuration is stored in a file `${HOME}/gitconfig` which can also be edited

git - Creating and cloning repositories

Creating an initial repository:

```
mkdir -p ~/src/project
cd ~/src/project
git init
Initialized empty Git repository in ~/src/project/.git
```

Cloning a repository:

```
git clone power1:/data/PowerWeek
Cloning into 'PowerWeek'...
Password:
remote: Counting objects: 6, done.
remote: Compressing objects: 100% (4/4), done.
remote: Total 6 (delta 1), reused 0 (delta 0)
Receiving objects: 100% (6/6), done.
Resolving deltas: 100% (1/1), done.
Checking connectivity... done
```

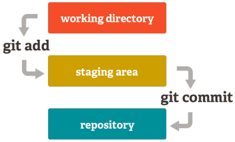
git - status of the local repository

Command: `git status`

```
richterm@power1 ~ git status
# On branch master
# Changes not staged for commit:
#   (use "git add <file>..." to update what will be committed)
#   (use "git checkout -- <file>..." to discard changes in working directory)
#
#       modified:   twoparticle.C
#
# Untracked files:
#   (use "git add <file>..." to include in what will be committed)
#
#       result.root
#       twoparticle_C.d
#       twoparticle_C.so
no changes added to commit (use "git add" and/or "git commit -a")
```

- information about the current branch
- files which are staged for commit
- tracked files whith local changes
- untracked files (can be masked by `.gitignore`)

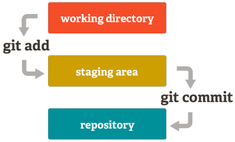
git - committing



Step 1: `git add` mark changes to be committed

```
richterm@power1 ~/src/example_01 $ git add twoparticle.C
richterm@power1 ~/src/example_01 $ git status
# On branch master
# Changes to be committed:
#   (use "git reset HEAD <file>..." to unstage)
#
#       modified:   twoparticle.C
#
# Untracked files:
#   (use "git add <file>..." to include in what will be committed)
#
#       result.root
#       twoparticle_C.d
#       twoparticle_C.so
```

git - committing



Step 2: `git commit` changes

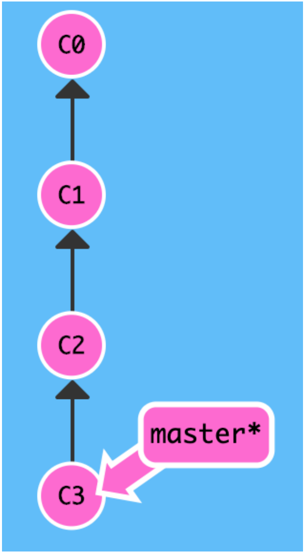
```
richterm@power1 ~/src/example_01  git commit -m "initial version
of particle class"
[master a56e827] initial version of particle class
```

Now it is locally committed, check the log

```
richterm@power1 ~/src/example_01  git log
commit a56e8270fd6f3c99d4cdbcdb0e45f287e1c71711
Author: Matthias Richter <richterm@power1.power.week>
Date:   Tue Nov 26 11:51:09 2013 +0100

    initial version of particle class

commit ea2c328e7ac3e21c5546480dad1a55af4a0f5e35
Author: Jochen Klein <jochen.klein@cern.ch>
Date:   Mon Nov 25 13:51:12 2013 +0100

    - initial commit of example
```

git commits; git checkout

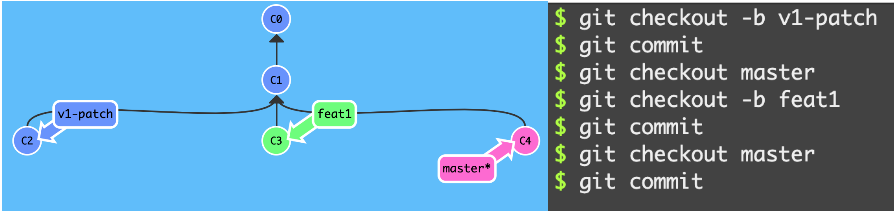
- git organizes commits in a connected **tree** of nodes; A git commit adds a new node
- each node consists of
  - The actual changeset/diff to files
  - Metadata (author, ...)
  - A commit message
  - A SHA-256 hash digest - This hash uniquely identifies the precise node and all its history!
- one can checkout specific nodes by using `git checkout <commit-sha>`
- pointer to last node – of main development line – is typically called `master`



The commit tree and branches

The git commit structure can be a tree. Pointers to leave nodes are called branches.

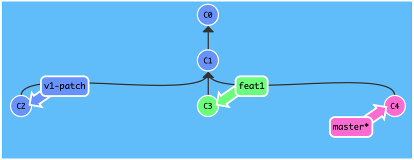
- The master branch is the main development line
- Other branches typically used for feature development in isolation (`Feat1`) or for releasing a certain stable version and patches (`v1-patch`)
- branches are started with `git checkout -b NewFeature` on the currently checked out commit
- one can switch between branches with `git checkout branchname`



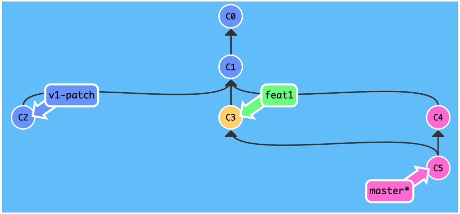
nice online learning platform: `https://learngitbranching.js.org/?NODEMO`

Short intro to merging and rebasing

- merging/rebasing : operations on the tree to bring together 2 branches
- used to integrate commits from one branch into the other
- for example when feature is fully developed

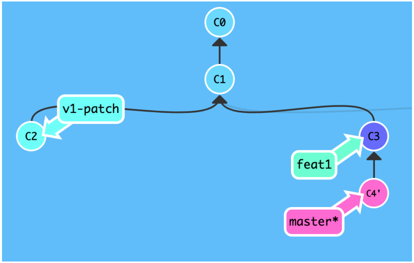


`git merge feat1`



- tree (old commits) stays intact
- merge creates adds a special commit

`git rebase feat2`



- branches are linearized
- no new commit; but old commits rewritten

git - looking at the difference

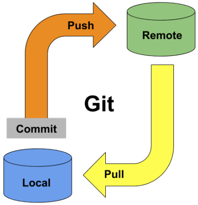
Command: `git diff`

```
richterm@power1 ~/src/example_01 git diff twoparticle.C
diff --git a/twoparticle.C b/twoparticle.C
index fdca6ac..77d77c5 100644
--- a/twoparticle.C
+++ b/twoparticle.C
@@ -1,7 +1,7 @@
 // a simple macro with surprises for the purpose of training usage of valgrind a

 // include header files for the porpose of compilation
-#ifndef __CINT__
+#if !defined(__CINT__) || defined(__MAKECINT__)
 #include "TParticle.h"
 #include "TSystem.h"
 #include "TH1.h"
```

- shows local differences in tracked files
- without arguments: for all tracked files
- can be used to show differences between revisions

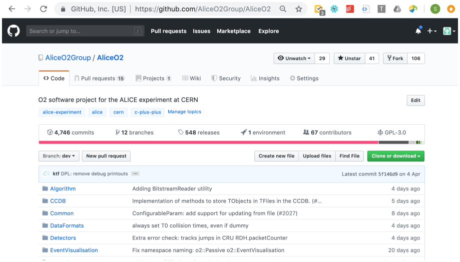
Distributed gits: push and pull

- A git repository can exist at various locations (or in multiple copies) at the same time (it's distributed); one speaks of local and remote repositories.
- the authorative version of a git repository is often hosted on some web server (remote)
  - if you cloned from the remote it is called 'origin'
  - otherwise you can declare a remote repo with `git remote add foo URL`
- Users syncronize local and remote repositories via git pull and git push commands.
  - git pull [–rebase] foo get all remote changes and apply locally
  - git push foo publish your own changes to the remote



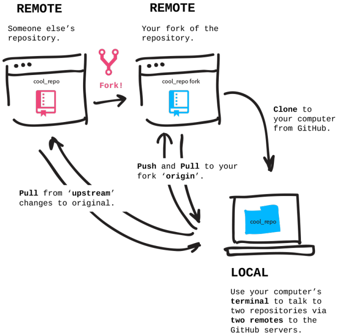
Github/Gitlab/Bitbucket

- many open source projects host git on platforms like Github, Gitlab or Bitbucket
- free git server and infrastructure
- collaborative code reviews
- integrations with other services
  - task tracking
  - continuous integration (CI) - automatic testing of new code and accepting only if good
  - documentation



Github/Gitlab/Bitbucket - workflow

- A typical workflow on those platforms uses 3 repositories
  - the authorative repo (remote)
  - a fork (a user copy remote)
  - the local user repository
- Changes are integrated via push to fork and pull requests to real repo



git - Further reading

We found the following nice looking pages ... but there are tons other really

- https://rogerdudler.github.io/git-guide/index.de.html
- https://try.github.io/ – resources to learn git;
- https://www.atlassian.com/git/tutorials
- https://www.edureka.co/blog/git-tutorial/
- `git help`

git - stash

You are in the middle of developing and get a request to fix something or update your clone

⇒ `stash` allows to save your current status

```
> git pull
# ... pull fails due to merge conflicts ...
> git stash save
> git pull
> git stash pop
```

git - checking logs revisited

tig; gitk; etc

Exercises

- Create a git repo; Do some add-commit cycles
- Play with branching merging:
  - locally
  - as an interactive game `https://learngitbranching.js.org/`
- Get familiar with github by forking or cloning the PowerWeek github repo `https://github.com/hgspowerweek/powerweek1`.
  - Look around
  - Contribute to the documentation of F.A.Q. section
- In order to contribute to an github repo, you need to create a github account
- For the coding project, we suggest to use gitlab.cern.ch in a private repository
  - needs CERN lightweight account account.cern.ch
  - keeps code private (also for future power weeks participants)
  - enables code review features

Lecture III

Code compilation

What is GCC

- Originally ‘only’ GNU C Compiler
- Release in March 1987 as the first **free** ANSI C optimizing compiler
- C++ support was added in December of that year
- Now, many other languages are supported as well, e.g. Objective-C, Objective-C++, Fortran (gfortran), Java (gcj), ...
- In addition, many different CPU architectures supported, e.g. Intel, ARM, Alpha, PowerPC, ...
- Today GCC stands for GNU Compiler Collection

Compilers

A compiler translates the human readable code into machine executable code

The main compilers of the GCC suite we are interested in are the GNU C and C++ compilers: gcc and g++

Brian Gough
`http://www.network-theory.co.uk/docs/gccintro/`

`examples/gcc`

First steps with g++

```cpp
#include <iostream>
int main()
{
  std::cout << "hello world" << std::endl;
  return 0;
}
```

The hello world example above (hello_world.cpp) can be compiled using

```
g++ -Wall hello_world.cpp -o hello_world
```

-o specifies the name of the executable (default it is *a.out*)

-Wall turns on most commonly used compiler warning → **highly recommended to use**

To run the program simply type

```
./hello_world
```

Try it!

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⇒

Try it!

Splitting code

Often it is useful to split the code into separate logical files

- Enhances readability and maintenance
- Enables to compile code parts independently
  - Saves compilation time, not all code needs to be recompiled if somethings changes
- Allows to compile code using the functionality of other code without knowing the actual implementation

We split the hello_world example into three files:

- main.cpp
- hello_fn.h
- hello_fn.cpp

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We split the hello_world example into three files:

- main.cpp
- hello_fn.h
- hello_fn.cpp

Splitting code - example

main.cpp

```cpp
#include "hello_fn.h"
int main()
{
  hello("world");
  return 0;
}
```

hello_fn.h

```cpp
void hello(const char* to);
```

hello_fn.cpp

```cpp
#include <iostream>
void hello(const char* to)
{
  // function to print hello to someone on the command line
  std::cout << "Hello " << to << std::endl;
}
```

Splitting code - header files

- Separate the *declaration* of classes / functions from the actual *implementation*
- The declaration is given in the *header file* ending on `.h`
- When using external code in an own class, during compilation only the declaration is needed
- A declaration should not be included several times (compilation time), this is handled by a pre-compiler directive (*header guard*)

```
#ifndef MYCODE_H
#define MYCODE_H
void myfunction(int x, float y);
#endif
```

Compile multiple source files

To compile the code run

```
g++ -Wall main.cpp hello_fn.cpp -o hello_world
```

⇒ Try it!

Not won too much, still all code is compiled all the time

- compile parts of the code into separate *object files*
- *link* the *object files* to the executable

Compile multiple source files

To compile the code run

```
g++ -Wall main.cpp hello_fn.cpp -o hello_world
```

⇒ Try it!

Not won too much, still all code is compiled all the time

- compile parts of the code into separate *object files*
- *link* the *object files* to the executable

Creating object files

We create one *object file* per input file:

```
g++ -Wall -c main.cpp hello_fn.cpp
```

- `-c` tells the compiler to create an object
- object files are machine code, but not yet executable

Produces the object files *main.o* and *hello_fn.o*

This can also be run separately for each file

```
g++ -Wall -c main.cpp
g++ -Wall -c hello_fn.cpp
```

⇒ Try it!

Creating object files

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```
g++ -Wall -c main.cpp hello_fn.cpp
```

- `-c` tells the compiler to create an object
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Produces the object files *main.o* and *hello_fn.o*

This can also be run separately for each file

```
g++ -Wall -c main.cpp
g++ -Wall -c hello_fn.cpp
```

⇒ Try it!

Linking objects to an executable

Now the objects can be *linked* together to the executable:

```
g++ main.o hello_fn.o -o hello_world
```

NOTE:

The code is already compiled → You don't need warning options

⇒ Try it!

- Modify something in one of the files (e.g. world → moon in main.cpp)
- Recompile only main.cpp
- Link all files to one executable

⇒ Try it!

Linking objects to an executable

Now the objects can be *linked* together to the executable:

```
g++ main.o hello_fn.o -o hello_world
```

NOTE:

The code is already compiled → You don't need warning options

⇒ Try it!

- Modify something in one of the files (e.g. world → moon in main.cpp)
- Recompile only main.cpp
- Link all files to one executable

⇒ Try it!

Makefiles

- The steps mentioned above can be automatized using the *make system*
- Define dependencies (e.g. the executable can only be built if all objects files are available)
- Only compiles code which changed

Documentation:
`https://www.gnu.org/software/make/manual/make.html`

Makefiles – An example

```
CXX         = /usr/bin/g++
CXXFLAGS    = -Wall -Wextra -Wconversion -Wshadow -g
LDFLAGS     =

OBJ       = hello_fn.o main.o

split: $(OBJ)
        $(CXX) -o $@ $(OBJ) $(LDFLAGS)

main.o: main.cpp hello_fn.h
        $(CXX) -o $@ -c $< $(CXXFLAGS)

%.o: %.cpp %.h
         $(CXX) $(CXXFLAGS) -c $< -o $@


clean:
        @rm -f ${OBJ} split
```

Makefiles – Primer

Makefiles consist of rules that tell the make system what to do. A rule has the form:

```
target ... : prerequisites ...
<tab> recipe
<tab> ...
<tab> ...
```

`target` is usually an output file name, `prerequisites` can be other targets or e.g. file names

NOTE: A `recipe` MUST be started with a $< tab >$

When the `make` command is called, it looks for a file called *Makefile* or *makefile* in the present directory and processes the first target (*default target*).

Makefiles – Primer

A few important automatic variables are defined in the `make` system:

- `$@` The target name
- `$<` The first prerequisite
- `$^` The names of all the prerequisites, with spaces between them

For more see `https://www.gnu.org/software/make/manual/make.html#Automatic-Variables`

⇒ Try it!

CMake - introduction

- treatment of dependencies and automatic re-compilation
  covered by Makefiles and make
- manual maintenance of Makefiles can become tedious and error-prone
- configuration for specific setup of SDK and external dependencies
  covered by autotools suite or CMake

CMake - introduction

CMake is an open-source, cross-platform family of tools designed to build, test and package software.

- universal (toolchain agnostic) description of build flow in CMakeLists.txt
- automated creation of Makefiles depending on configuration options environment found
- automatic re-evaluation when needed
- possibly add testing and packaging steps

here: CMake with Makefiles

typical build layout

- separate build into different directories:
  - source: no generated files
  - build: generated files, object files, libraries, executables
    possibly more than one with different build options
  - install: final files only
- test stage
- delivering/deploying stage

a minimal CMake project

```
cmake_minimum_required(VERSION 3.9)
project(MyPowerProject CXX)

add_executable(testExe test.cc)
```

- always specify minimum version of CMake (depending on the features you use)
- declare project and language used
- add targets (here just one executable)

---

example project:

```
examples/cmake_simple
```

a CMake run

```
cd <build directory>
cmake <source directory>
make -j$(nproc)
```

bu

happens in phases:

- configuration:
  evaluation of CMakeLists.txt files, additional options, toolchain probing
- generation:
  generation of build files (depending on selected generator)
- compilation:
  actual build using Makefiles

libraries

```
...

add_library(power power.cc)
add_executable(main main.cc)
target_link_libraries(main power)
```

- add target for library and source files needed to build it
- link executable against library
- include directories are propagated to the targets using the library

using lists

```
...

set(SOURCES s1.cc s2.cc s3.cc)
add_library(s ${SOURCES})

set(EXECUTABLES e1 e2 e3)
foreach(EXE ${EXECUTABLES})
  add_executable(${EXE} ${EXE}.cc)
  target_link_libraries(${EXE} power)
endforeach()
```

- define lists that can be reused
- avoid overly repetitive code

ROOT integration

```
...

find_package(ROOT)
include(${ROOT_USE_FILE})
if(ROOT_FOUND)
  message(STATUS "Using ROOT: ${ROOT_VERSION} <${ROOT_CONFIG}>")
  target_compile_definitions(power PUBLIC "-DUSE_ROOT")
  target_include_directories(power PRIVATE ${ROOT_INCLUDE_DIRS})
  target_include_directories(power PRIVATE .)
  ROOT_GENERATE_DICTIONARY(G__Power ${CMAKE_CURRENT_SOURCE_DIR}/power.h LINKDEF Li
  target_sources(power PRIVATE power_rooted.cc G__Power)
  target_link_libraries(power ROOT::Core ROOT::Gui ROOT::Tree)
endif(ROOT_FOUND)
```

- ROOT comes with additional tools to build dictionaries

warnings and errors

```
message("something important")
message(STATUS "just a status message")
message(WARNING "something's fishy here")
message(ERROR "this is plain wrong")
message(FATAL_ERROR "this is too wrong, I rather die ...")
```

- use messages to check on your build,
  don't be blind on what is happening

language options

```
...

set(CMAKE_CXX_STANDARD 14)
set(CMAKE_CXX_STANDARD_REQUIRED ON)
message(STATUS "Using C++${CMAKE_CXX_STANDARD}")

enable_language(CUDA)
```

- compiler-agnostic settings of language standard
  N.B.: you can also request specific language features
- enabling of additional programming languages

build types and compiler options

```
set(CMAKE_CXX_FLAGS_DEBUG "-O0 -ggdb -DDEBUG -D__DEBUG")
set(CMAKE_CXX_FLAGS_RELWITHDEBINFO "${CMAKE_CXX_FLAGS_RELEASE} -ggdb")
set(CMAKE_CXX_FLAGS_RELEASE "-O3 -march=native -ftree-vectorize -ffast-math -DNODEB
message(STATUS "Using CXX flags for ${CMAKE_BUILD_TYPE}: ${CMAKE_CXX_FLAGS_${CMAKE_
```

- compiler options/flags are controlled by build types
- can be changed separately for different build types
- don't put target-specific stuff here

```
cmake -DCMAKE_BUILD_TYPE=DEBUG <source dir>
```

default build type

```
# by default build optimized code with debug symbols
if(NOT CMAKE_BUILD_TYPE AND NOT CMAKE_CONFIGURATION_TYPES)
  set(CMAKE_BUILD_TYPE RELWITHDEBINFO)
endif()

set(CMAKE_ALLOWED_BUILD_TYPES DEBUG RELEASE RELWITHDEBINFO)
if(NOT CMAKE_BUILD_TYPE IN_LIST CMAKE_ALLOWED_BUILD_TYPES)
  message(FATAL_ERROR "Invalid build type ${CMAKE_BUILD_TYPE}. Use one of: ${CMAKE_
endif()
```

- explicit control over default build type

install

```
install(TARGETS main power
  LIBRARY DESTINATION lib
  RUNTIME DESTINATION bin
)
```

- this should install only the final build products
- try and adhere to conventions about installation paths

some more involved stuff

- nested projects
- tests

nested projects

```
add_subdirectory(sub1)
add_subdirectory(sub2)
```

- include sub-projects in sub-directories, hierarchical layout
- sub-directories can contain project, this allows to build the sub-project independently
- different directories:
  - CMAKE_SOURCE_DIRECTORY: directory from which cmake was run
  - CMAKE_PROJECT_SOURCE_DIRECTORY: (sub-)project directory
  - CMAKE_CURRENT_SOURCE_DIRECTORY: current directory in source tree

CTest

- you can add tests which can be run programatically

```
enable_testing()

add_test(NAME MyPowerTest COMMAND echo done)
```

```
ctest
```

You can also run this using the *make* process by

```
make test
```

summary

- surely not an extensive coverage of CMake,
  but it should get you started
- extensive documentation on project pages
  but not always good explanation of the underlying concepts

Lecture IV

Project

The problem

- consider an experiment to measure the X particle
- a renowned theorist told us some expectations:
  - decay to three charged pions
  - mass $50 - 100$ GeV, known lifetime $c\tau = 0.5$ mm
  - production flat in η and $\propto p_{\mathrm{T}}^{-5}$
  - in every n-th event (poisson around that mean), n most probably 5
- available detector covers $|\eta| < 2$ and full azimuth,
  provides one point at $R = 5$ cm with $\sigma = 0.1$ mm in z and $r\varphi$ direction,
  θ with a resolution of 1 degree and p_{T} with a resolution of
  $\Delta p_{\mathrm{T}}/p_{\mathrm{T}} = 0.5\ \%/(\mathrm{GeV}/c) \cdot p_{\mathrm{T}}$,
- on average 10 (poisson with mean 10) other primary particles (pions) produced, flat in η and $\propto p_{\mathrm{T}}^{-8}$
  exploit the known lifetime
- find a way to prove (or falsify) the existance of the X, which properties can be measured

Your task

Write the code to

- simulate the production of the X particle
  and its decay according to the specified properties
- simulate background particles produced in association with X
- smear the measured track properties ($\vec{x}$, p_{T}, η)
  (fast detector simulation)
- reconstruct the X particle
- analyze the performance of the reconstruction
- develop clever cuts on the analysis level

Simulation, smearing, reconstruction, and analysis should be kept separated!

Some thoughts

- IO is usually quite slow, but might be important, optionally, for debugging purposes $\Rightarrow$ use root trees
- simulation writes information to memory structure(s)
  what information needed? how structured?
- smearing runs on these data / tree input
  modify? copy? extend? file structure?
- reconstruction runs on these in memory structure(s) / tree input
  what information is needed? what is produced?
- analysis runs on these in memory structure(s) / tree input
  what information is needed?
- for specific problems (e.g. three-body decay) you might want to use external libraries (ROOT – e.g. TGenPhaseSpace)

You are free to do what you want.

Details

- Primary particles are created at the origin (exact position, no smearing).
- All spectra are flat in η and follow a power law in p_{T}, cut of at 100 MeV.
- We have a cylindrical barrel detector with 4 layers: 3 tracking layers at R = 5cm, 6cm, and 7cm, and one calorimeter layer at R = 10 cm.
- The η coverage of all layers is $\eta = 2$, they have full azimuthal coverage. This means that the z-extent of the different layers is different. Consider that decaying particles with $\eta > 2$ can still have decay products in the detector coverage.
- The resolution of the tracking layers is $\sigma = 1\ \mathrm{mm}$ in z and in $r\varphi$ direction (Gaussian). There is no error in r.
- The detector has full acceptance, every particle crossing a layer produces exactly one hit.
- For generating the hits, assume perfectly cylindrical detector layers. For fitting the particles from the hits, assume the error on the plane tangential to the respective hit on the cylinder.
- The resolution of the calorimeter layer is $\sigma = 1\ \mathrm{cm}$ in z and in $r\varphi$. The energy resolution is $\sigma_E = 0.5\% \cdot E^2$ (in GeV).
- Mass of particles: X: $50 - 100\ \mathrm{GeV}$, Y: ....
- Lifetime of particles: X: $c\tau = 0.5\ \mathrm{mm}$, Y: ....
- The mean number of background particles is $dN/d\eta = 2.5$, the mean number of X particles is $dN/d\eta = 0.25$ (Poissonian Distribution).
- The p_{T} spectrum of the X is proportional to p_{T}^{-5}, the p_{T} spectrum of the background is proportional to p_{T}^{-8}.