Monte Carlo Generators and Rivet Tutorial

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"The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory . . ."

– Richard Feynman and Rick Field, 1978

This Tutorial

- How to generate simulated events: Pythia8 (you already learned Herwig7)
- Analysis framework: RIVET for *particle level* analysis.
- Now is a good time to fire up the virtual machine (hope you have it :)

Pythia8

- ... is a leading order PS generator.
- One of the most widely used for many years.
- Relatively easy to install (along with its *friends*: HepMC, and LHAPDF6) and run, online user manual: http://home.thep.lu.se/~torbjorn/pythia82html/Welcome.html
- Run via various *mainXX* programs.

Generating events with Pythia8

- Start the terminal
- Pythia8230 is located at: > Documents/src/pythia8230
- We will use main42, a generic main program. It is inside examples directory.
- Compile: make main42, should result in a main42 executable in the directory.
- Input (which process to generate, how many events, collision energy, ...) are specified via a *runcard (cmnd files)*, we will use main42.cmnd
- > ./main42 main42.cmnd out.hepmc

Run Card

Change to 5000

```
! File: main42.cmnd
! This file contains commands to be read in for a Pythia8 run.
! Lines not beginning with a letter or digit are comments.
! Names are case-insensitive  -  but spellings-sensitive!
! The changes here are illustrative, not always physics-motivated.

! 1) Settings that will be used in a main program.
Main:numberOfEvents = 200          ! number of events to generate
Main:timesAllowErrors = 3          ! abort run after this many flawed events

! 2) Settings related to output in init(), next() and stat().
Init:showChangedSettings = on      ! list changed settings
Init:showAllSettings = off         ! list all settings
Init:showChangedParticleData = on  ! list changed particle data
Init:showAllParticleData = off     ! list all particle data
Next:numberCount = 1000            ! print message every n events
Next:numberShowLHA = 1             ! print LHA information n times
Next:numberShowInfo = 1            ! print event information n times
Next:numberShowProcess = 1         ! print process record n times
Next:numberShowEvent = 1           ! print event record n times
Stat:showPartonLevel = on          ! additional statistics on MPI

! 3) Beam parameter settings. Values below agree with default ones.
Beams:idA = 2212                   ! first beam, p = 2212, pbar = -2212
Beams:idB = 2212                   ! second beam, p = 2212, pbar = -2212
Beams:eCM = 14000.                 ! CM energy of collision
```

Change to 13000

Continued…

Run Card

```
! 4) PDF settings. Default is to use internal PDFs
! some pdf sets examples: cteq61.LHpdf cteq61.LHgrid MRST2004nlo.LHgrid
#PDF:pSet = LHAPDF5:MRST2001lo.LHgrid
! Allow extrapolation of PDF's beyond x and Q2 boundaries, at own risk.
! Default behaviour is to freeze PDF's at boundaries.
#PDF:extrapolate = on

! 5a) Pick processes and kinematics cuts.
! Colour singlet charmonium production of J/psi and chi_c.
Charmonium:gg2ccbar(3S1)[3S1(1)]g    = on,off
Charmonium:gg2ccbar(3PJ)[3PJ(1)]g    = on,on,on
Charmonium:qg2ccbar(3PJ)[3PJ(1)]q    = on,on,on
Charmonium:qqbar2ccbar(3PJ)[3PJ(1)]g = on,on,on
PhaseSpace:pTHatMin = 20.          ! minimum pT of hard process

! 5b) Alternative beam and process selection from a Les Houches Event File.
! NOTE: to use this option, comment out the lines in section 5a above
! and uncomment the ones below. Section 3 is ignored for frameType = 4.
#Beams:frameType = 4                ! read info from a LHEF
#Beams:LHEF = events.lhe             ! the LHEF to read from

! 6) Other settings. Can be expanded as desired.
! Note: may overwrite some of the values above, so watch out.
#Tune:pp = 6                        ! use Tune 4Cx
#ParticleDecays:limitTau0 = on      ! set long-lived particle stable ...
#ParticleDecays:tau0Max = 10        ! ... if c*tau0 > 10 mm
```

Change to process of interest (comment out or remove)

Uncomment

For Monash: Change to: Tune:ee =7 Tune:pp = 14

Example Run Cards

Z-boson production and leptonic decay

```
! 5a) Pick processes and kinematics cuts.
WeakSingleBoson:ffbar2gmZ =on
23:onMode = off
23:onIfAny = 11 13
23:mMin = 60
```

W-boson production and leptonic decay

```
! 5a) Pick processes and kinematics cuts.
WeakSingleBoson:ffbar2W = on
24:onMode = off
24:onIfAny = 11 -11 13 -13
```

ttbar production and semileptonic decay

```
! 5a) Pick processes and kinematics cuts.
Top:gg2ttbar = on
Top:qqbar2ttbar = on
24:onMode = off
24:onPosIfAny = 11 13
24:onNegIfAny = 1 2 3 4 5
```

Minbias Events

```
! 5a) Pick processes and kinematics cuts.
SofQCD:inelastic = on
```

So then …

Analyze the events

- ROOT is used extensively by the experiments
- But unless you are an experimentalist, it is probably too intimidating for you
- Many times, you just want to quickly look at simulated events...

RIVET

Based somewhat on Andy Buckley's LH13 tutorial

- A generator agonistic analysis system for generators (no direct data analysis!) in C++ (now in C++11)
- Physics plots from generator output (in HepMC format)
- Compare MC predictions with *built-in* actual (unfolded) data analyses from different experiments
- Everything defined in terms of stable final state objects
- Details: https://rivet.hepforge.org/

Important!

Analyses intended to be based on physical objects:

- Final state hadrons
- Jets (FastJet)
- Muons, Electrons (dressed)
- Bosons reconstructed from particles (rather than taken from event record)

Version 2.5 contains $\sim$ 350 Analyses (195 LHC)

- Monte Carlo validation and tuning, data preservation
- Lots of code examples to get inspired

Rivet for you!

- Super convenient bootstrap script to install (Rivet and all its dependencies) at rivet.hepforge.org
- Source codes of existing analyses serve as useful examples
- Helping the community by adding your analysis to the official library

Trying out RIVET

- ... it is setup for you, just do > source Documents/bin/activate
- > rivet --help
- > rivet --list-analyses (ATLAS_ or MC_)

Running a Data Analysis

- Since we are looking at Minbias events, lets try
  > rivet -a ATLAS_2016_I1467230 -a ATLAS_2016_I1468167 -a ATLAS_2017_I1509919 out.hepmc
- Output: Rivet.yoda
- Look inside the yoda file
- Plot with rivet-mkhtml Rivet.yoda (--mc-errs)
- View plots by firefox rivet-plots/index.html

Compare Pythia8 and Herwig7

- Run the same rivet command on the Herwig7 output hepmc file.
- Remember to remember the earlier output yoda file to say out_py8.yoda (otherwise it will get overwritten, or you can do -o out_her7.yoda here)
- Plot both yoda files together!

Plot File (example)

```
BEGIN PLOT /ATLAS_2015_I1343107/d18-x01-y01
XLabel=$E^{\rm{miss}}_T$ [GeV]
YLabel=Events
XMin=150
END PLOT
```

Labels, formatting controlled by corresponding .plot file

The data is present in corresponding reference .yoda file

Writing an Analysis

- The analyses named MC_ are pure MC based analysis, no reference data to compare with.
- Useful for testing generator predictions.
- You can make a template: rivet-mkanalysis MC_MyAna
- Find the MC_MyAna.cc file in the directory (also MC_MyAna.info and MC_MyAna.plot)
- Look inside the cc file!

There are many different analyses in Rivet code repository. Usually one or more examples should be close to what you are trying to do.

Walkthrough

1

```
// -*- C++ -*-
#include "Rivet/Analysis.hh"
#include "Rivet/Projections/FinalState.hh"

namespace Rivet {


  /// @brief Add a short analysis description here
  class MC_MyAna : public Analysis {
  public:

    /// Constructor
    DEFAULT_RIVET_ANALYSIS_CTOR(MC_MyAna);


    /// @name Analysis methods
    //@{
```

Basic include stuff, add new headers as required

Continued…

Walkthrough

2

Expect usual C++ init/execute/finalize type loop code structure

```
  /// Book histograms and initialise projections before the run
    void init() {

      // Initialise and register projections
      declare(FinalState(Cuts::abseta < 5 && Cuts::pT > 100*MeV),
"FS");

      // Book histograms
      _h_XXXX = bookProfile1D(1, 1, 1);
      _h_YYYY = bookHisto1D(2, 1, 1);
      _h_ZZZZ = bookCounter(3, 1, 1);

    }
```

Continued…

Walkthrough

2

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```

Projections and declaration of two types of histograms

Continued…

Walkthrough

2

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      // Book histograms
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    }
```

Projections and declaration of two types of histograms

Continued…

Projections

- Observable calculators - from an event, *project* out the *physical* observables.
- Already defined in the framework
- Registered with a name in *init*
- Applied to the current event in *analyze*
- Avoids unnecessary repetition in the code

Some Details

- ChargedFinalState
- NeutralFinalState
- UnstableFinalState
- IdentifiedFinalState
- VetoedFinalState
- DISFinalState
- VisibleFinalState
- HadronicFinalState

Histogramming

- Declare at *init* by bookHisto1D or bookProfile1D (usual name, binning)
- Can be *autobooked* from reference data!
- Usual fill method in *analyze*
- scale or normalize in *finalize*
- Declare the pointers

Walkthrough

3

```
/// Perform the per-event analysis
    void analyze(const Event& event) {

      /// @todo Do the event by event analysis here

    }


    /// Normalise histograms etc., after the run
    void finalize() {

      normalize(_h_YYYY); // normalize to unity
      scale(_h_ZZZZ, crossSection()/picobarn/sumOfWeights()); // norm to cross
section

    }

    //@}
```

Heart of the code: Fill histograms here

Normalize

Continued…

Some Other Details

`Particle` and **`Jet`** both have a **`momentum()`** method which returns a **`FourMomentum`**.

Some **`FourMomentum`** methods: **`eta()`**, **`pT()`**, **`phi()`**, **`rapidity()`**, **`E()`**, **`px()`** etc., **`mass()`**. Hopefully intuitive!

Walkthrough

4

```
   /// @name Histograms
    //@{
    Profile1DPtr _h_XXXX;
    Histo1DPtr _h_YYYY;
    CounterPtr _h_ZZZZ;
    //@}


  };


  // The hook for the plugin system
  DECLARE_RIVET_PLUGIN(MC_MyAna);


}
```

Histogram pointers declared

Task

- Modify this code to plot number of charged particles and their p_T

Add/Modify

```
#include "Rivet/Projections/ChargedFinalState.hh"
```

Added in headers

```
declare(ChargedFinalState(Cuts::abseta < 2.5 && Cuts::pT > 100*MeV), "CFS");
```

Projection definition changed

```
_h_Nchg = bookHisto1D("Nchg",20,0,100);
_h_pT = bookHisto1D("pT",40,0,200);
```

Histograms declared

```
const FinalState& cfs = apply<FinalState>(event, "CFS");
double mult = cfs.size();
_h_Nchg->fill(mult);
for (const Particle& p : cfs.particles()) {
   h_pT->fill(p.pT()/GeV);
}
```

In event-loop calculate variables and filled histograms

```
normalize(_h_Nchg); // normalize to unity
normalize(_h_pT);
```

Normalised

```
 Histo1DPtr _h_Nchg, _h_pT;
```

Histogram pointers

MC_MyAna

- Compile by: rivet-buildplugin RivetMC_MyAna.so MC_MyAna.cc
- export RIVET_ANALYSIS_PATH=$PWD (or use —pwd switch)
- Run over the same hepmc file and plot.

FIFO

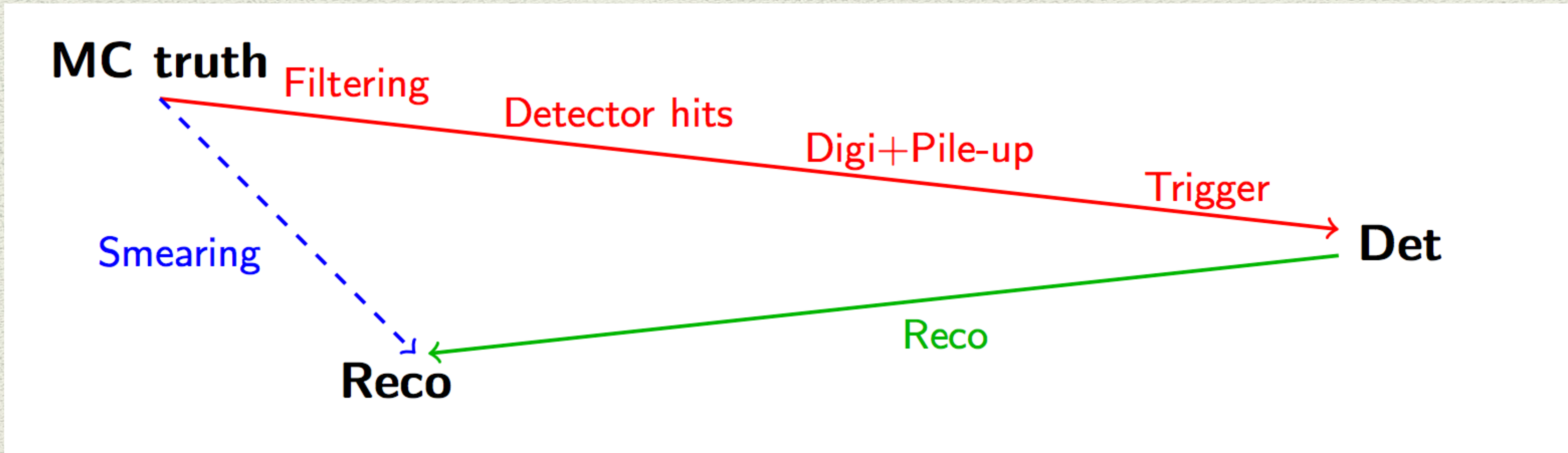
- HepMC files tend to become unmanageably large (5000 events ~ 1 GB)
- Often times, we need millions of events
- We use fifo (file in, file out), which is like a pipe. One event enters, gets processed, only then the second event is generated ...
- Look at Run.sh file (we will *run* that later)

Fifo Script

```
#Simple script to run pythia8 and rivet together via a fifo

export RIVET_ANALYSIS_PATH=$PWD  # Rivet needs to know where the analysis is
export RIVET_REF_PATH=$PWD
rm -rf my.hepmc                  # just a protection
mkfifo my.hepmc                  # create the fifo file

rm *.log                         # make sure log files are new

./main42 main42.cmnd my.hepmc > pythia.log &     # run Pythia, output goes to the pipe, always good to have a log file

rivet -a MC_MYANA  my.hepmc &> rivet.log           # run Rivet over, input comes from the pipe

rm my.hepmc
```

New Feature

- For searches, no unfolded data
- Approximate detector response/efficiencies can be made available
- Smearing of final state objects implemented (from v2.5.0)



Congratulations!