Rivet/Professor

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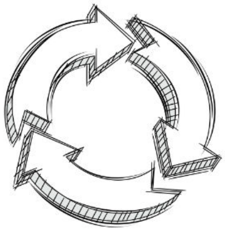
rivet.hepforge.org

professor.hepforge.org

Introduction

- **Recent big changes in LHC experiment/theory interaction**
  - ⇒ more direct collaboration to improve methods and modelling, starting from SM & QCD, now also Top, Higgs, and BSM
- **Rivet** analysis library is part of this: a lightweight way to exchanging analysis details and ideas
- Implementing a Rivet analysis to complement the data analysis is increasingly expected of LHC analyses. **Everyone benefits!**



Introduction

Rivet is an analysis system for MC events, and *lots* of analyses

427 built-in, at today's count! 54 are pure MC, and some double/triple-counting

- *Generator-agnostic* for physics & pragmatics
- A quick, easy and powerful way to get physics plots from lots of MC gens
  - Only requirement: use **HepMC** event record
  - Usually via ASCII, but in-memory exchange is faster
- Rivet has become the LHC standard for archiving LHC data analyses
  - Focus on *unfolded* measurements, esp. QCD and EW+QCD, rather than searches
  - But there are BSM studies using it! **And detector simulation now possible**
  - Key input to MC validation and tuning – increasingly comprehensive coverage
  - Also "recasting" of SM and BSM data results on to new/more general BSM model spaces
  - **Add your analyses, too!**

Design philosophy / pragmatics

Rivet operates on HepMC events, intentionally unaware of who made them…so don't "look inside" the event graph.
⇒ reconstruct resonances, dress leptons, avoid partons, etc.

cf. q/g jet discrimination: LO picture is an implementation-dependent cartoon; a useful motivator but incomplete and ill-defined until after hadronization

This "hard work" way is actually simpler – fewer gotchas.
Makes you think about physics & helps find analysis bugs/ambiguities

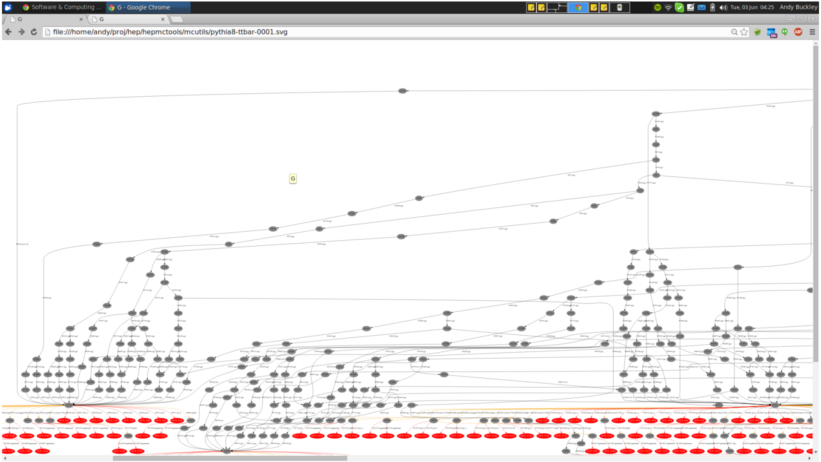
Tech stuff:

- C++ library with Python interface & scripts
- "Plugins" ⇒ write your analyses without needing to rebuild Rivet
  Trivial from user / analysis author point of view
- Tools to make "doing things properly" easy and default
- Computation caching for efficiency
- Histogram syncing: *keep code clean and clear*

+ helpful developers! New contributors always welcome

Why wouldn't we want to look at the event graph?!

A Pythia8 $t\bar{t}$ event!



Most of this is not standardised: Herwig and Sherpa look *very* different.
But final states and decay chains have to have equivalent meaning.

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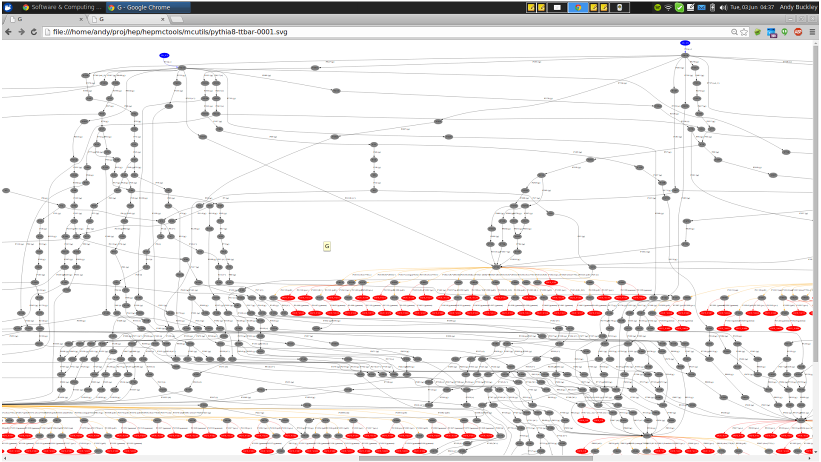

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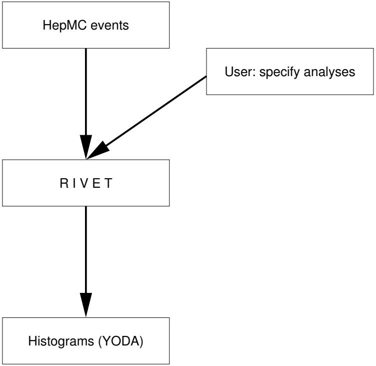
Basic principle



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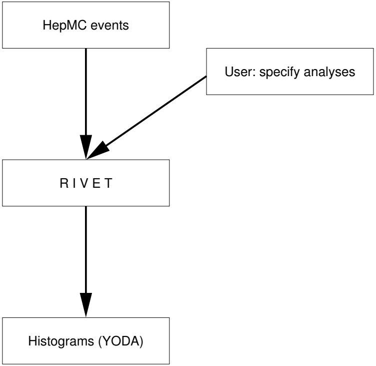

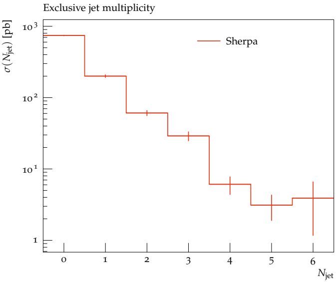

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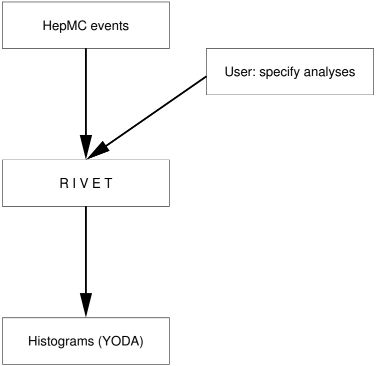
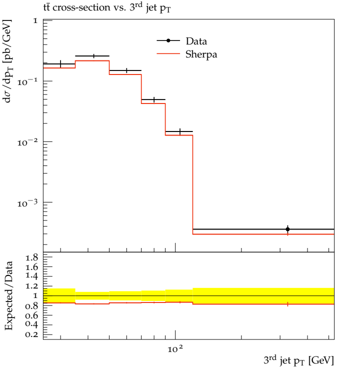




Getting Rivet

Rivet is readily available on the MC4BSM virtual machine.
Some event files are available in `tutorial/Rivet/Events`

Easy to install using our *bootstrap script*:

```
wget http://rivet.hepforge.org/hg/bootstrap/raw-file/2.5.3/rivet-bootstrap
bash rivet-bootstrap
```

Latest version is 2.5.3 Requires C++11

Docker image available:

```
docker pull hepstore/rivet:2.5.3
```

http://rivet.hepforge.org/trac/wiki/Docker

`CVMFS` installations on lxplus.

Getting Rivet

- **`rivet`** command line tool to query available analyses
- Can be used as a library (e.g. in big experiment software frameworks)
- Can also be used from the command line to read HepMC ASCII files/pipes: very convenient
- Helper scripts like **`rivet-mkanalysis`**, **`rivet-buildplugin`**
- Histogram comparisons, plot web albums, etc. very easy

Docs online at **http://rivet.hepforge.org** – PDF manual, HTML list of existing analyses, and Doxygen. Entries in HEPdata point to existing rivet analyses.

Writing an analysis

Writing an analysis is of course more involved. But the C++ interface is pretty friendly: most analyses are short, simple, and readable – details handled in the library + expressive API functions.

A single C++ file is sufficient. Rivet comes with scripts that generate analysis templates and compile the new code into a shared library (plugin).

Mostly “normal”:

- Typical init/exec/fin structure
- Histogram titles, labels, etc.: use **`.plot`** file
- Rivet’s own Particle, Jet and FourMomentum classes: some nice things like **`abseta()`** and **`abspid()`**, sorting and filtering
- Use of *projections* for computations, with a bit of magic – this is where the caching happens
- Projections are *declared* with a string name, and later are *applied* using the same name
- Final state projections are central: compute from final state or physical decayed particles

Projections

Major idea: **projections**. They are just observable calculators: given an `Event` object, they *project* out physical observables.

They also automatically cache themselves, to avoid recomputation. This leads to slightly unfamiliar calling code.

Projections were *declared* with a name in `init()` they are then *applied* to the current event in `analyze()`, by the same name.

E.g.

- Final states (Identified, Charged, Visible, ...)
- Jets (All native FastJet algorithms)
- Event shapes (Thrust etc.)
- Missing momentum and DIS kinematics

Selection cuts

Combinable `Cut` objects:

- `FinalState(Cuts::pT > 0.5*GeV && Cuts::abseta < 2.5)`
- `fs.particles(Cuts::absrap < 3 || (Cuts::absrap > 3.2 && Cuts::absrap < 5), cmpMomByEta)`

Can also use cuts on PID and charge:

- `fs.particlesByPt(Cuts::abspid == PID::ELECTRON)`, or
- `FinalState(Cuts::charge != 0)`

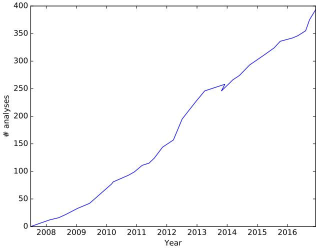
Use of functions/functors for ParticleFinder filtering is coming…

Rivet + fast-sim for BSM searches

BSM analysis coverage

Currently $\sim$ 427 analyses total & $\sim$ 230 LHC alone

- Until recently only 27 dedicated BSM searches – and BSM-sensitive SM measurements , cf. CONTUR talk
- SM focus on unfolded observables, not sufficient for most BSM studies
- Rivet 2.5.0 introduced detector smearing machinery. *For BSM only!*



NB. glitch is Rivet 1.x → 2.x migration.
Note recent acceleration!

- ⇒ 9 more BSM routines in last few months:
  - ATLAS: ICHEP 2016 3-lepton & same-sign 2-lepton, 1-lepton + jets, 1-lepton + many jets, jets + MET; 2015 jets + MET and monojet
  - CMS: ICHEP 2016 jets + MET; 8 TeV α_T + b-jets
  - *Partially* validated – not many cutflows available!
  - Also added tools to help with object filtering, cutflows, etc.
  - Important as real-world examples of how to write BSM routines
- **Rivet is in good shape for preserving new physics searches!**

BSM & detector effects

Explicit fast detector simulation vs. smearing/efficiencies

MC truth

BSM & detector effects

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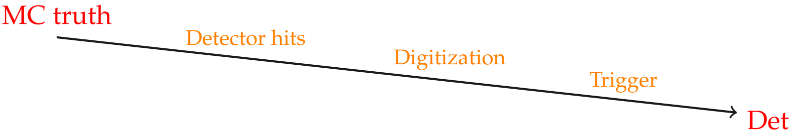

BSM & detector effects

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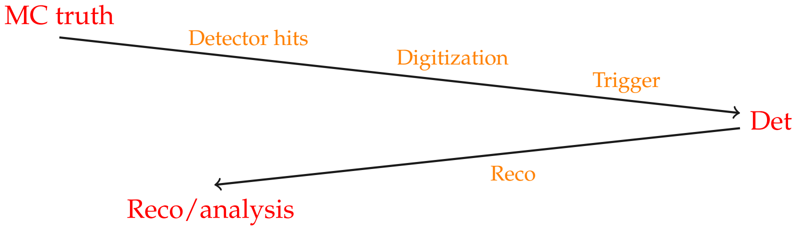

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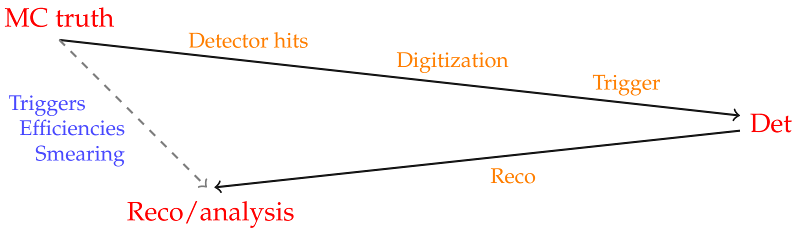

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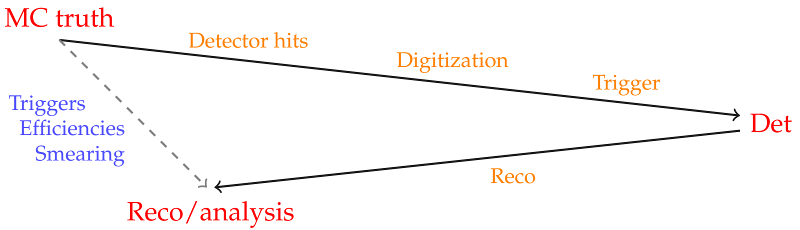
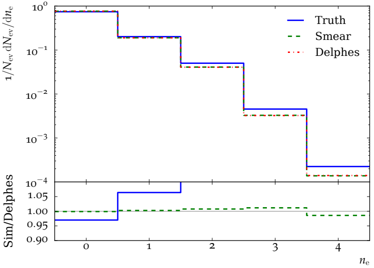


- **Explicit fast-sim takes the "long way round".**
- **Reco already reverses most detector effects!**
- Reco calibration to MC truth: smearing is a few-percent effect
- (Lepton) efficiency & mis-ID functions dominate – and are tabulated in both approaches
- Smearing is more flexible: effs change with phase-space, reco version, run, ... and need to guarantee *stability* for preservation

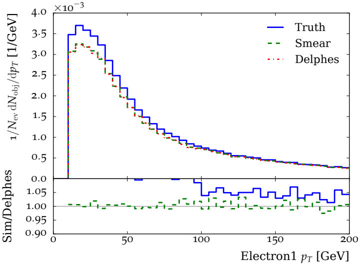
Smearing vs. fast sim vs. MC truth

CMSSM eff/smearing effects from Rivet, in turn using some DELPHES and paper/note calibration functions:

Electron multiplicity



Leading electron p_T



Note major lepton shifts from blue truth to green smeared: difference w.r.t red DELPHES very small

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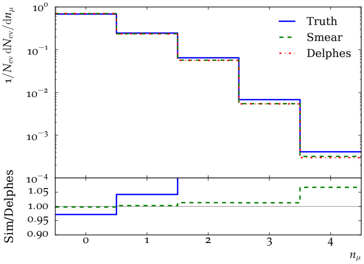
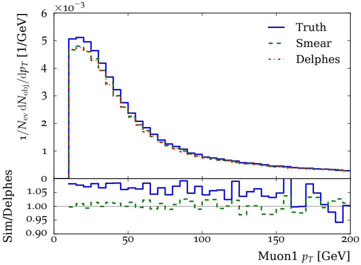
Muon multiplicity



Leading muon p_T



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BSM & detector effects (II) ⇒ Rivet 2.5

In addition to last slides, *flexibility* of det-sim is important:

- "Global" fast-sims hence difficult for coverage of multiple experiments, multiple runs, multiple reco calibrations, etc.
- Analysis-specific efficiencies and smearings are more precise and allow use of multiple jet sizes, tagger & ID working points, isolations, … ⇒ **many variations in real analyses**

⇒ Rivet det-sim as effs+smearing, localised per-analysis

Rivet internally caches results, so global effect sim still efficient

- Functions for generic ATLAS & CMS performance in Runs 1 & 2
- Inline or analysis-specific functions easy to write & *chain*
- Eff/smearing functions can be used directly, e.g. for object filtering
- Working on embeddability for multithreaded fitters/samplers.

Selection tools for search analyses

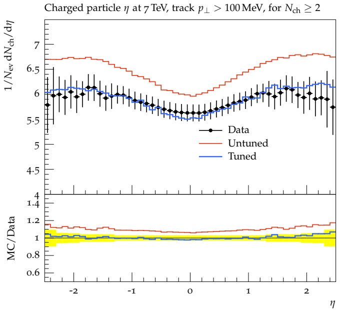
Search analyses typically do a lot more "object filtering" than measurements. Rivet 2.5 provides a lot of tools to make this complex logic expressive:

- Filtering functions: **`filter_select`**, **`filter_discard`** + **`ifilter_*`** in-place variants
- Lots of *functors* for common "stateful" filtering criteria: **`PtGtr(10*GeV), EtaLess(5), AbsEtaGtr(2.5), DeltaRGtr(mom, 0.4)`**
- Cut-flow monitor via **`#include "Rivet/Tools/Cutflow.hh"`**

```
Particles elecs = apply<ParticleFinder>(event, "Electrons").particles(Cuts::pT > 10*GeV);
Jets jets = apply<JetAlg>(event, "Jets").jetsByPt(Cuts::pT > 20*GeV && Cuts::abseta < 2.8);
// Remove electrons within dR = 0.2 of a b-tagged jet
for (const Jet& j : jets)
  if (j.abseta() < 2.5 && j.pT() > 50*GeV && j.bTagged(Cuts::pT > 5*GeV))
    ifilter_discard(elecs, deltaRLess(j, 0.2, RAPIDITY));
// Remove any |eta| < 2.8 jet within dR = 0.2 of a remaining electron
for (const Particle& e : elecs)
  ifilter_discard(jets, deltaRLess(e, 0.2, RAPIDITY));
```

Professor

- Established tool for MC generator tuning, heavily taylored to Rivet
- Replace MC generator response with polynomials in χ^2 minimisation using **`Minuit`**
- $\chi^2(\vec{p}) = \sum_{b}^{\text{Nbins}} w_b \cdot \left(\frac{I_b(\vec{p}) - D_b}{\Delta(\vec{p})} \right)^2$

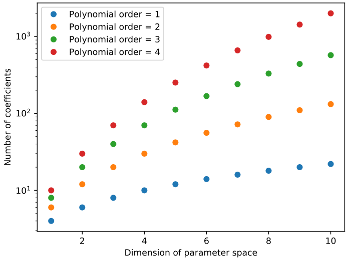


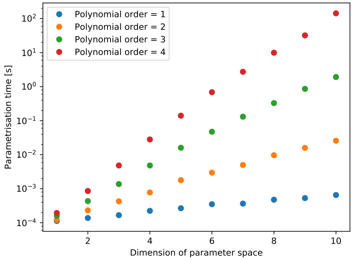
Getting Professor

- Prerequisits: Eigen3 headers, C++ 11 compiler, Python 2.7
- professor.hepforge.org
- Docker image: `docker pull iamholger/professor:2.2.1`
- Try out at http://mybinder.org/repo/iamholger/professor

Professor technicalities

- C++ core functionality, python bindings for everything else
- Least-squares fits of general polynomials to input data in a certain parameter space
- Technically, solving of matrix equation by means of Singular Value Decomposition
- In case of MC, input generation trivial to do in parallel (different points in parameter space)
- Result is fast analytic pseudo-generator

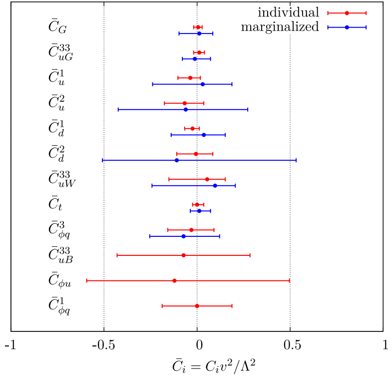




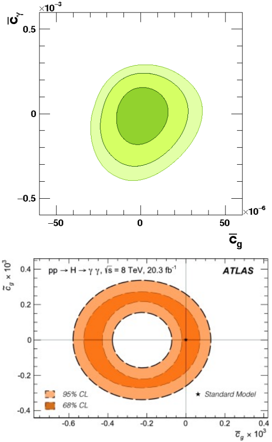
Professor beyond tuning

- Instead of fiddling with say hadronisation model parameters, explore BSM parameter space
- Lots of experience can be transferred from tuning to BSM

TopFitter

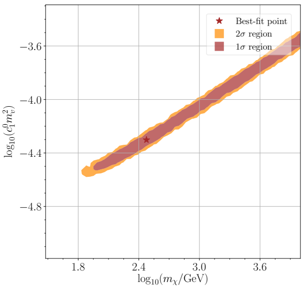


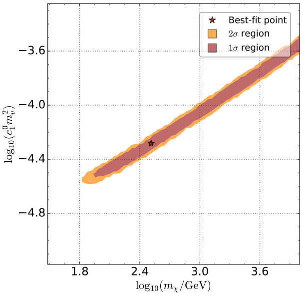
HEFT



Professor beyond collider physics

- Recently got foothold in neutrino MC community, **`Genie`**
- Triggered containerisation of Professor with Docker
- Similarly, Dark Matter direct detection codes: Professor in likelihood evaluation (MultiNest)





BSM challenges for Professor

- More careful checks of validity of polynomial approximation.
  - Partitioning of parameter space in case parameter space too big
  - Need to allow to drop inputs in case of vanishing cross-sections (avoid discontinuities in polynomial fit)
  - Resolutions, jack-knifing
- Usage of other parameterisations, e.g. Gaussian Processes for $\frac{1}{x}$, exponential behaviour

Summary

- **Rivet is a user-friendly MC analysis system for prototyping and preserving data analyses**
- Allows theorists to use analyses for model development & testing, and BSM recasting: impact beyond "get a paper out"
- Also a very useful cross-check: quite a few ATLAS analysis bugs have been found via Rivet!
- Strongly encouraged/required by ATLAS (and CMS?) physics groups. Integrated with ATLAS and CMS software
- Now supports detector simulation for BSM search preservation
- Multi-weights, NLO counter-events, and multi-threading all in the pipeline
- **Feedback, questions and getting involved in development all very welcome!**

- Professor:
  - Parametrisation of computationally expensive functions
  - Inputs can always be parallelised in a trivial way
  - Seamless integration into numerical tools **`iminuit`**, **`pymultinest`** through python bindings
  - Immediately available through **`docker`**
- Professor development used to be driven by Rivet/YODA and MC tuning needs.
- BSM requires more care in parametrisation than tuning.