Rivet for Heavy Ions

introduction & tutorial

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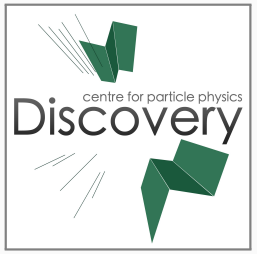


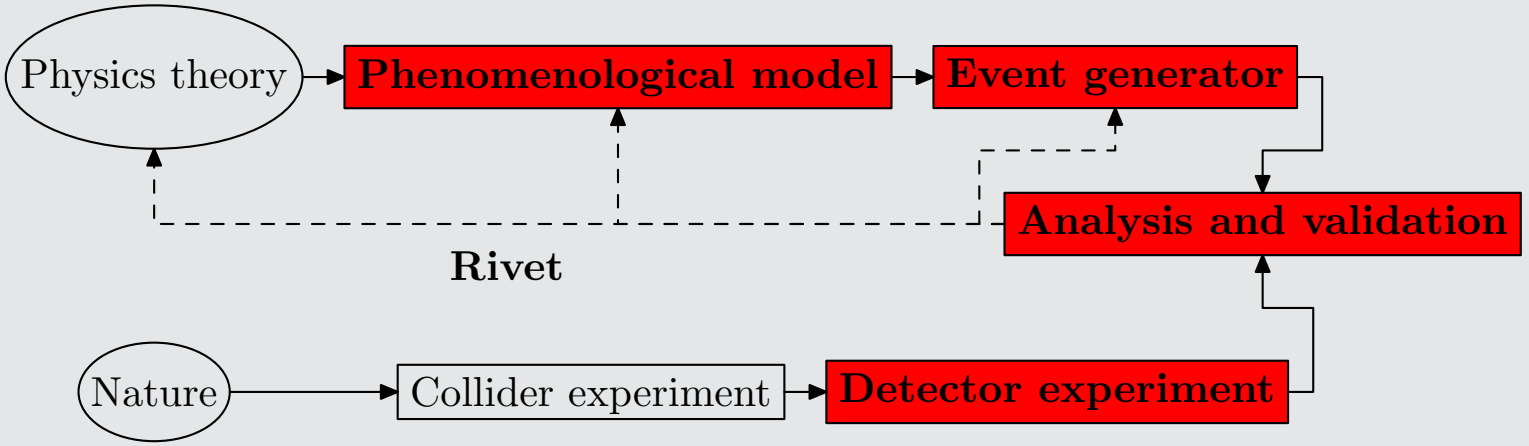
Before we start...

- Prepare your laptops for the tutorial while I talk.
- `if experienced with rivet:`
  1. Download the latest version of Rivet from `https://rivet.hepforge.org/`.
  2. Remember to also upgrade YODA from `https://yoda.hepforge.org/`.
  3. Run with your favourite generator.
- `else:`
  1. Download and install VirtualBox from `https://www.virtualbox.org/`.
  2. Load up the VM distributed on usb-sticks.
  3. Username: `mcnet`, password: `jetset`.
  4. Rivet 2.7.0 and Pythia 8.240 installed (+ dependencies).
  5. Also contains small prerun samples in HepMC format.

Rivet

- Analysis system for Monte Carlo events. (Buckley *et. al.*: arXiv:1003.0694.)
  1. Data preservation.
  2. Monte Carlo validation.
- Generator independent, HepMC events, many analysis tools.
- C++ library with analyses as "plugins", optimally written by the analyser.

The biggger picture



What is a "rivet analysis"?

- Unfolded data + analysis code.
- Data and code is delivered in a format such that one can easily compare to a HepMC compatible generator.
- Simple example `ALICE_2010_I880049.cc`.

Rivet for heavy ions

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  - Lack of common interest (few MCs for HI).
  - Lack of specialized functionality $\rightarrow$ High threshold.

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That has changed!

- ◇ Experimental community:
  pilot project lead by J. F. Grosse-Oetringhaus, P. Karczmarczyk, J. Klein (ALICE: CERN).
- ◇ MC community:
  efforts by C. Bierlich, L. Lönnblad (Pythia, DIPSY: Lund).
- ◇ Efforts joined 2018:
  supported by Rivet core group and University of Copenhagen, resulting in release 2.7.0.

New features

1. Centrality selection $\rightarrow$ analysis options.
2. Comparing to pp $\rightarrow$ re-entrant finalize.
3. Flow observables $\rightarrow$ generic framework.
4. Several shorthand projections for specific experiments.
5. 20 new analyses using these features, *pp*, *p*Pb, AuAu and PbPb.

Centrality selection

- Centrality is ubiquitous, but not directly measurable.
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- MC: Not always feasible to fold prediction with "forward central" correlation.

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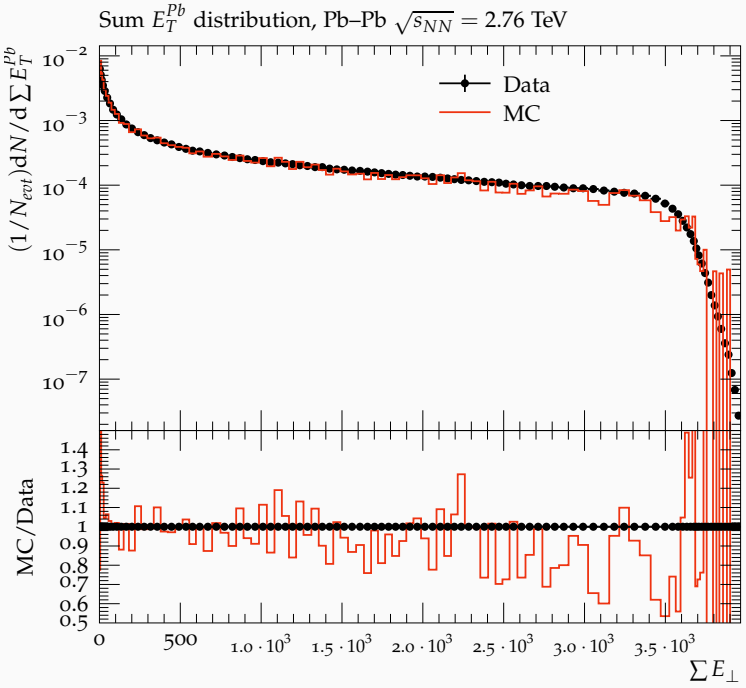
Solution: Users' choice between several options

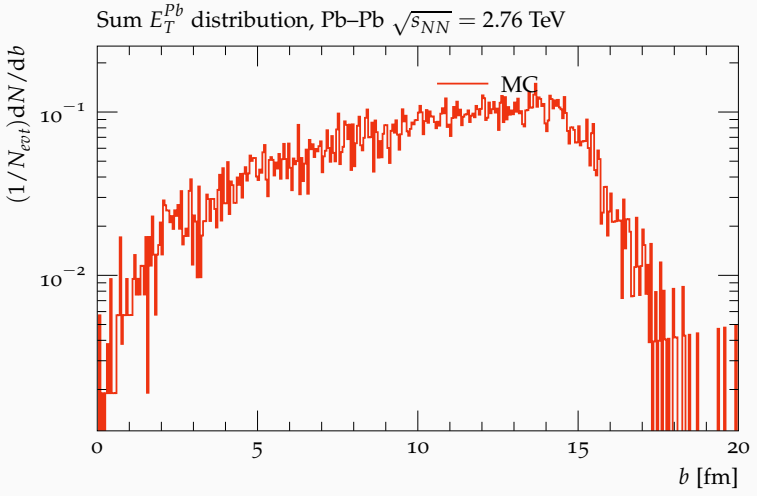
1. Experimental measure (if existing).
2. Generated version of experimental measure.
3. Impact parameter distribution.
4. MC supplies centrality number.

- Three latter requires a "calibration run".

Centrality selection, calibration

- Example calibration: `ATLAS_PBPB_CENTRALITY`.
- (data points extracted from paper, not unfolded).

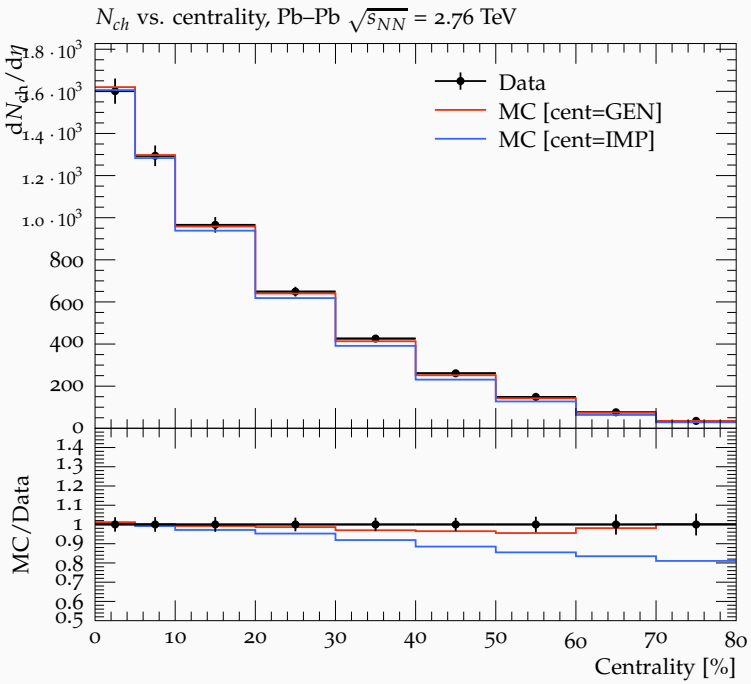


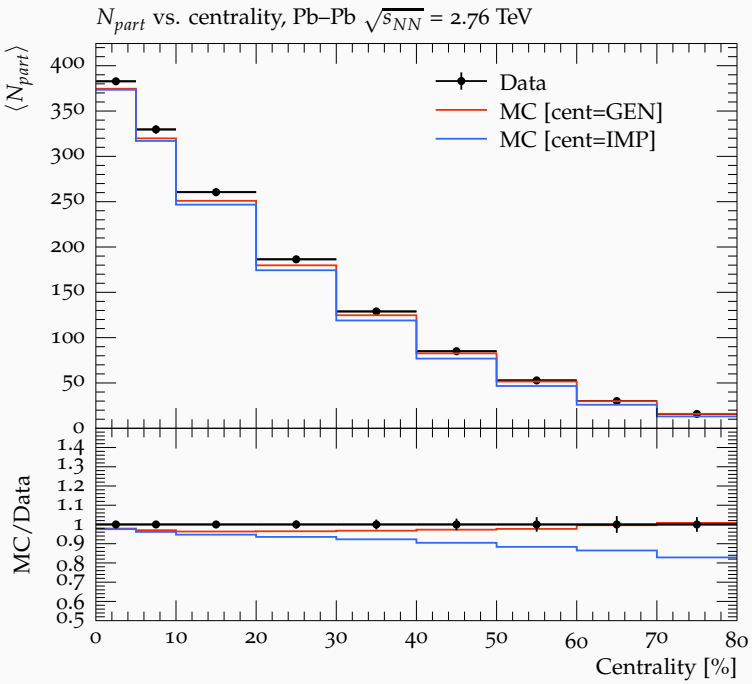


- Generated histograms are preloaded into Rivet: new `preload` option.

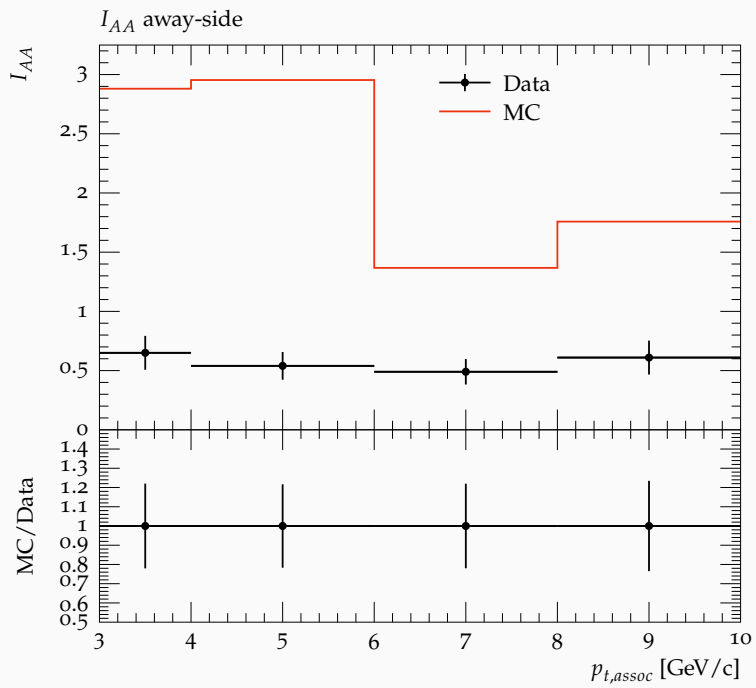
Centrality and Rivet options + live demo

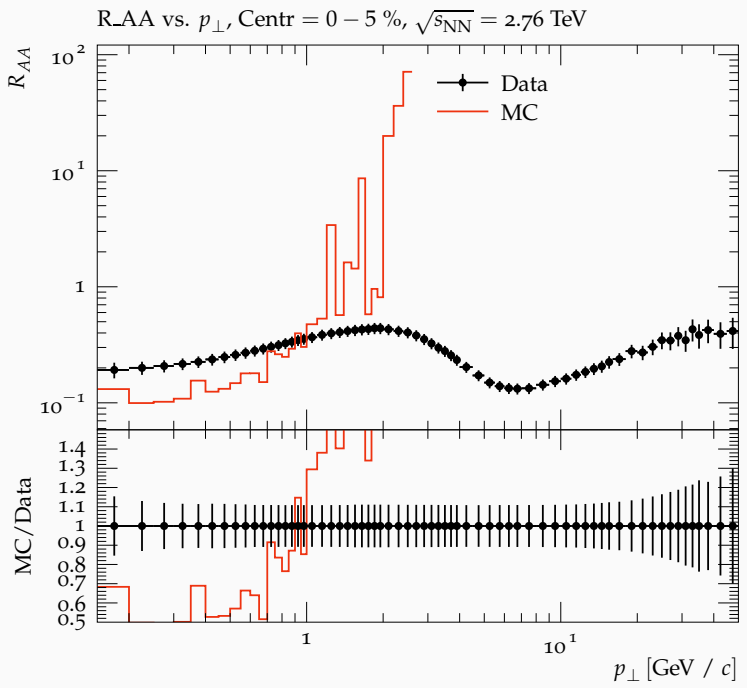
- New Rivet functionality: Analysis options, selected at run time.
- Run the same analysis, with different options.
- Example: `ALICE_2010_I880049`.
- Live demo: `ATLAS_pPb_Calib` and `ATLAS_2015_I1386475`.





Ratios to pp – ”nuclear modification factors”





`ALICE_2012_I930312, ALICE_2012_I1127497.`

New feature: `rivet-merge`

1. Read in histogram files, and re-generate analysis objects (must be `.yoda` streamable).
2. Run `void finalize()` again.

Flow observables – generic framework

- Piecewise inclusion of HI observables, first: Flow coefficients and cumulants.
- Generic framework (the flow equivalent of FastJet!) and add-ons implemented. (1010.0233, 1312.4572).
- Functionality, calculate any $\langle\langle M \rangle\rangle_{m,n}$.
- Automatic subtraction of lower orders and error calculation.

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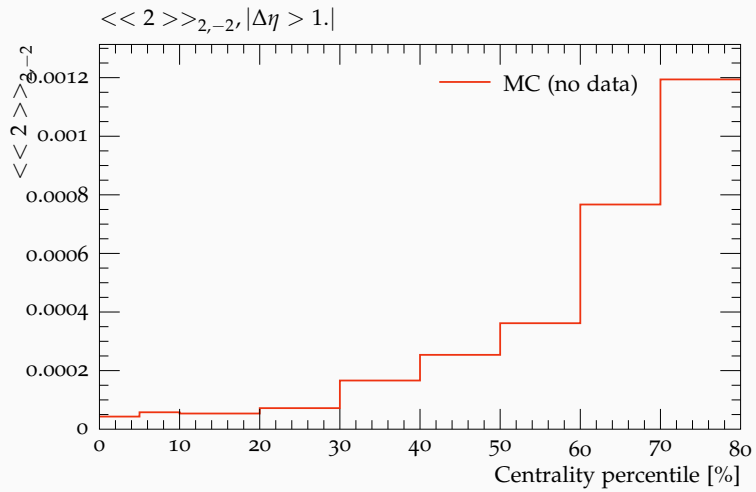
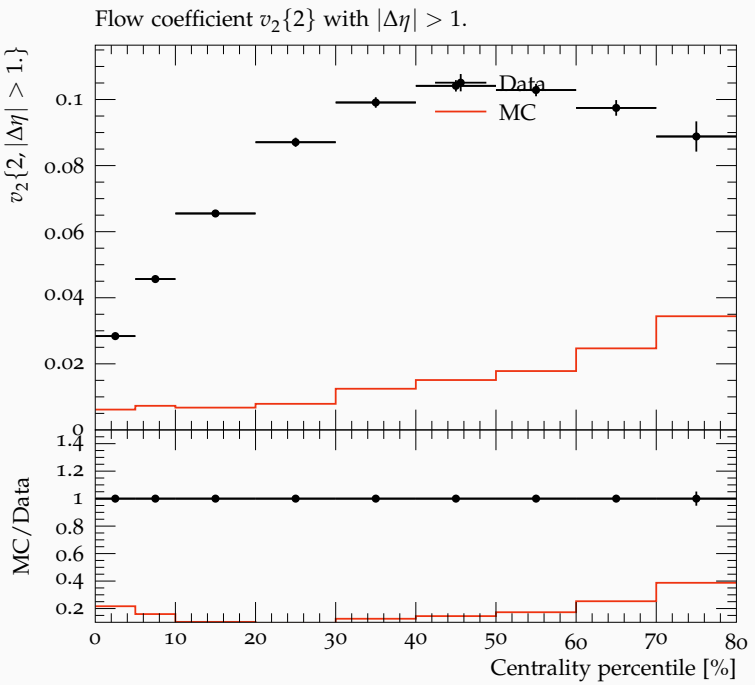
```
1        hc24 = bookScatter2D("c24",120,0,120);
2        ec22 = bookECorrelator<2,2>("ec22",hc22);
3        ec24 = bookECorrelator<2,4>("ec24",hc24);
4        ...
5        ec22->fill(...);
6        ec24->fill(...);
7        ...
8        // c_n{4} = <<4>>_{n,-n} - 2 * <<2>>_{n,-n}
9        cnFourInt(hc24, ec22, ec24);
```

Sample results

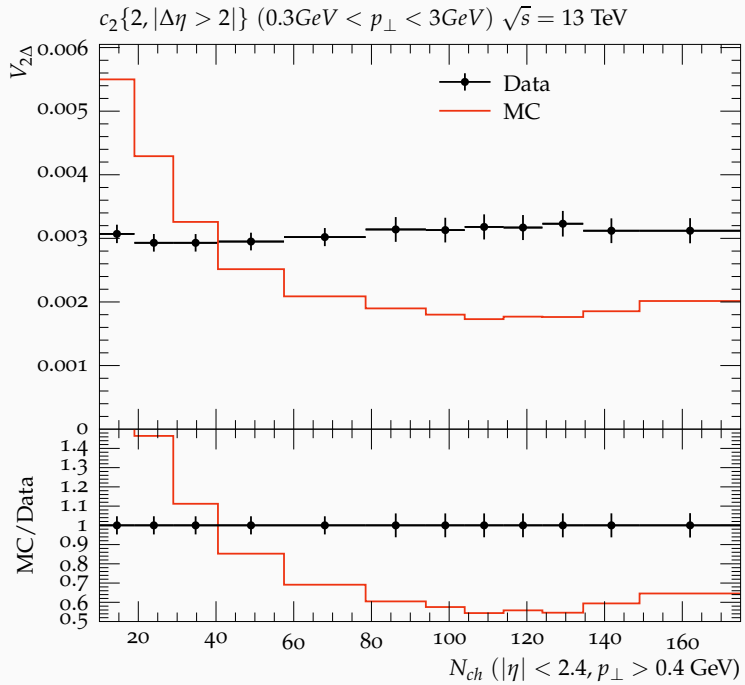
- Some HI analyses implemented, here: `ALICE_2016_I1419244`.
- Correlators and cumulants can be plotted, also without data.
- Data not well reproduced by this MC.

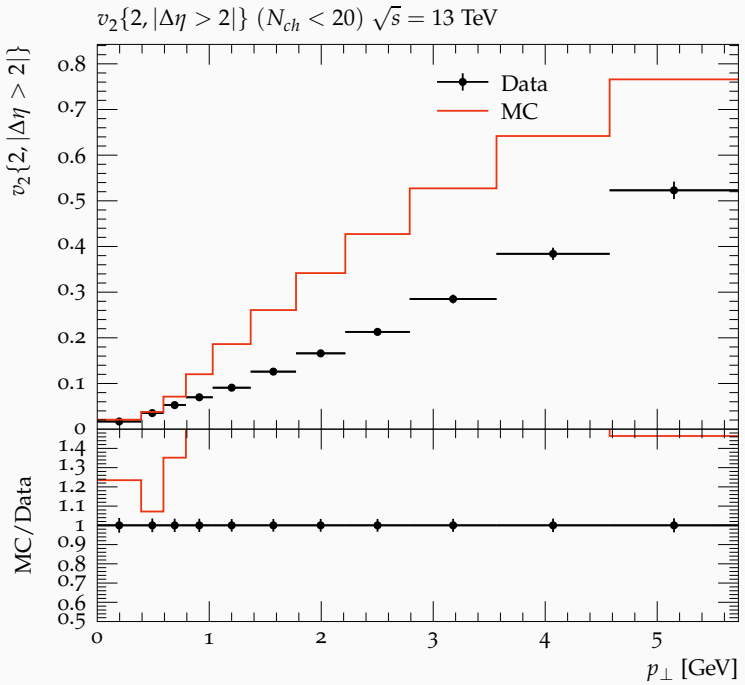




Perspective: HI methods in pp (CMS: Evidence for collectivity in pp collisions at the LHC)

- Heavy ion methods also available for pp analyses.
- Allows for new types pp analyses in Rivet.
- Example: `CMS_2017_I1471287`.





- (subtraction procedures still unclear – analyser help needed!)

Reference: List of analyses

Analyses with data:

ALICE_2010_I880049, PbPb: Multiplicity
ALICE_2012_I127497, PbPb: Nuclear mod. factor
ALICE_2012_I930312, PbPb: Di-hadron correlations
ALICE_2012_I1126966, PbPb: π, K, p
ALICE_2013_I1225979, PbPb: Multiplicity
ALICE_2014_I1243865, PbPb: Multistrange baryons
ALICE_2014_I1244523, pPb: Multistrange baryons
ALICE_2015_PBPBCentrality, PbPb: Energy flow
ALICE_2016_I1394676, PbPb: Multiplicity
ALICE_2016_I1419244, PbPb: Flow
ALICE_2016_I1471838, pp: Multistrange baryons
ALICE_2016_I1507090, PbPb: Multiplicity
ALICE_2016_I1507157, pp: Particle correlations
ATLAS_2015_I1386475, pPb: Multiplicity
ATLAS_PBPB_CENTRALITY, PbPb: Energy flow
ATLAS_2015_I1360290, PbPb: Mult + spectra
ATLAS_pPb_Calib, pPb: Energy flow
BRAHMS_2004_I647076, AuAu: π, K, p
CMS_2017_I1471287, pp: Flow
LHCF_2016_I1385877, pPb: Forward region $p_\perp$
STAR_2016_I1414638, AuAu: Flow

Analyses without data:

ALICE_2015_PPCentrality, Any: Calibration
BRAHMS_2004_CENTRALITY, Any: Calibration
STAR_BES_CALIB, Any: Calibration
MC_Cent_pPb_Calib, Any: Calib. example
MC_Cent_pPb_Eta, Any: Calib. + mult example
MC_OPTIONS, Any: Analysis options example
MC_REENTRANT, Any: Reentrant finalize example

What should I do now? (instead of a summary)

- This is a hands–on session, so you should get your hands dirty!
- We can stay here for a long time, pizza dinner provided.
- Use google doc (`CLICKME!`) to coordinate.

I am new to all this!

Use the virtual machine, and run a couple of analyses.

Possible goal: Using the demonstrated analysis as a template to write a simple one yourself.

I am experienced!

Install the newest version of Rivet, and run one or more HI analyses.

Take an analysis you know, and implement it! Use existing analyses as a template.