

MC analysis with Rivet

Analysis prototyping, preservation & re-interpretation

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University of Glasgow

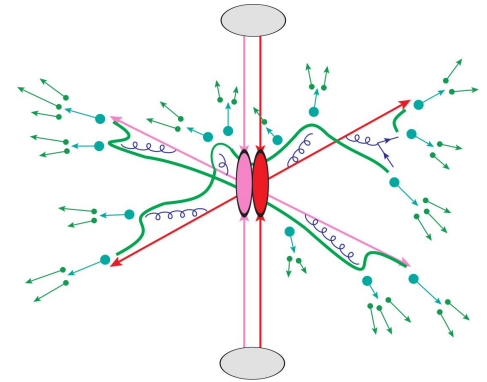
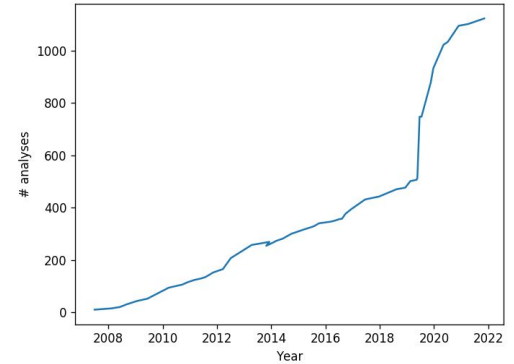
23rd MCnet workshop
7 Dec 2021



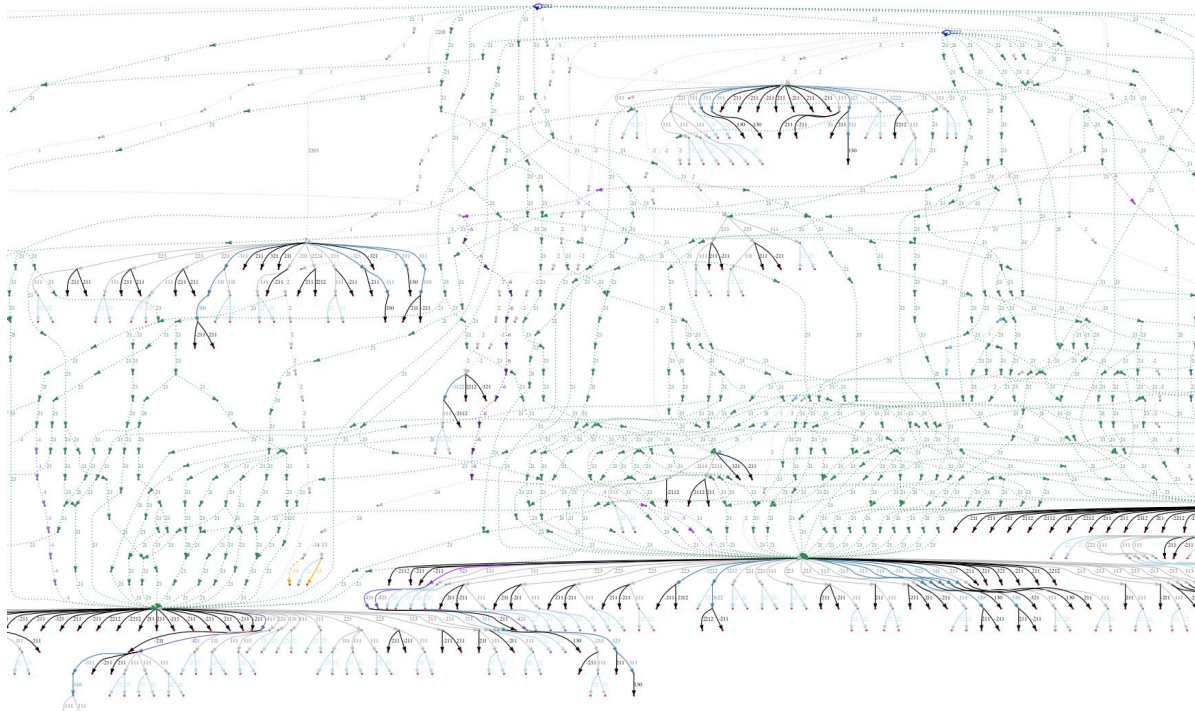
University
of Glasgow

What is Rivet?

- ❖ The “LHC standard” MC analysis toolkit
- ❖ More broadly a project to preserve the logic of HEP data analyses and further expt-pheno collaboration
⇒ the MCnet CEDAR meta-goal
- ❖ Code-wise, a C++ core and Python tools
 - Fiducial / [generator-independence](#) emphasis
 - Integration with [HepData](#)
 - Transparent [weight-stream handling](#)
 - **1000+ analyses!**
- ❖ Central to a community of analysis reinterpretation tools, linking experiment to theory
- ❖ **But why? Event loops are trivial...**



Because of this:



We want to avoid all physicists needing to rediscover graph algorithms, conventions, pitfalls, physical/debug distinctions, ...

Lessons learned

❖ A simple/obvious idea, with surprising impact:

- Reproducing a key plot (or not) is *powerful*
⇒ *understand physics, communicate issues, improve MCs*
- A *common language* for phenomenology and experiment

❖ But...

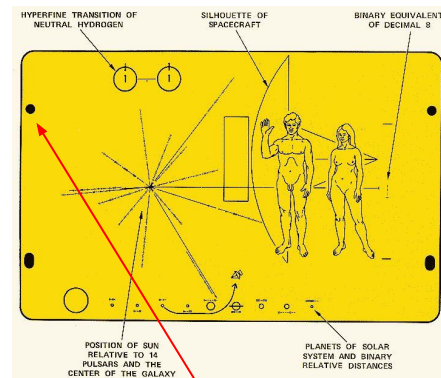
- “Obvious” to use partons, bosons, etc. direct from the event graph
- Frequently unphysical, depend on approximations. May not even exist!
 - (While I’m here... can’t we make event records minimal by default?!)
- Scalability of many analyses to new MCs means avoiding gen-dependence
⇒ predict “real” observables, from well-defined final states

❖ Standardisation: boring but important

- (physical) event format conventions, statuses, PDG particle numbering, weights...

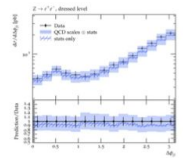
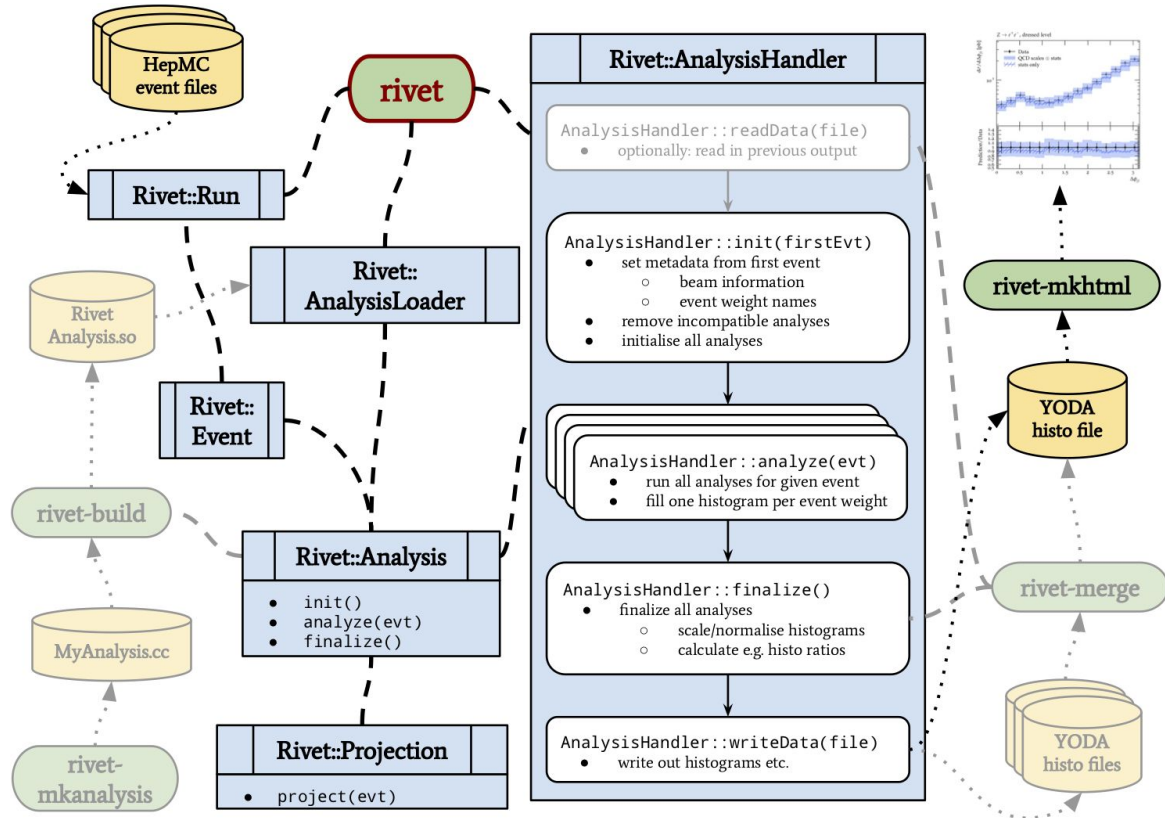
❖ Scalability

- Lots of expensive operations are repeated: sharing calculations is essential



The result

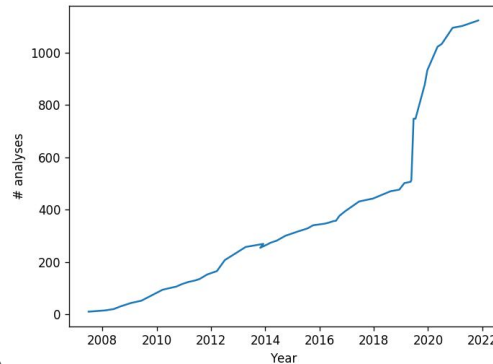
- ❖ Rivet v3 structure [arXiv:1912.05451](https://arxiv.org/abs/1912.05451)
- ❖ Streamlined set of tools from analysis coding to event processing to plotting (and other applications)
- ❖ And a key gateway to connect data analysis to theory (and back again)



The state we're in

❖ Version 3.1.0 (2019) → 1000+ analyses!

A steady 50/yr flow of analysis submissions, plus a deluge of (mainly identified-hadron) routines from Herwig ⇒ v3.1.5 in Nov 2021



❖ Official support from the (LHC) experiments is crucial

preservation = standard part of “how we science”, but still imperfect! We monitor coverage:

❖ “New” features since the v1 vision: systematics multiweights, “perfect merging”, heavy ions, detector smearing functions, analysis options

Rivet analysis coverage (no searches, no heavy ion)

Rivet analyses exist for 845/4241 papers = 20%. 153 priority analyses required.

Total number of Inspire papers scanned = 7280, at 2020-07-02

Breakdown by identified experiment (in development):

Key	ALICE	ATLAS	CMS	LHCb	Forward	HERA	$e^+e^- (\geq 12 \text{ GeV})$	$e^+e^- (\leq 12 \text{ GeV})$
Rivet wanted (total):	72	111	126	183	43	461	765	647
Rivet REALLY wanted:	17	42	61	9	0	13	1	3
Rivet provided:	14/86 = 16%	135/246 = 55%	77/203 = 38%	13/196 = 7%	8/51 = 16%	9/470 = 2%	166/931 = 18%	344/991 = 35%

Show greylist Show blacklist

ALICE **ATLAS** CMS LHCb Forward HERA $e^+e^- (\geq 12 \text{ GeV})$ $e^+e^- (\leq 12 \text{ GeV})$ Tevatron RHIC SPS Other

- ATLAS: Measurement of the $t\bar{t}$ production cross-section in the lepton+jets channel at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS experiment
Inspire ID: 1802524 arXiv ID: 2006.13076 Report IDs: CERN-EP-2020-096
Links: Inspire arXiv
- ATLAS: Measurements of top-quark pair single- and double-differential cross-sections in the all-hadronic channel in pp collisions at $\sqrt{s} = 13 \text{ TeV}$ using tt
Inspire ID: 1801434 arXiv ID: 2006.09274 Report IDs: CERN-EP-2020-063
Links: Inspire CDS arXiv
- ATLAS: Measurements of the Higgs boson inclusive and differential fiducial cross sections in the 4ℓ decay channel at $\sqrt{s} = 13 \text{ TeV}$
Inspire ID: 1790439 arXiv ID: 2004.03969 Report IDs: CERN-EP-2020-035
Links: Inspire CDS arXiv HepData ATLAS_2020_11790439
- ATLAS: Measurement of the Lund Jet plane using charged particles in 13 TeV proton-proton collisions with the ATLAS detector
Inspire ID: 1790256 arXiv ID: 2004.03540 Report IDs: CERN-EP-2020-030
Links: Inspire DOI/Journal CDS arXiv HepData ATLAS_2020_11790256
- ATLAS: Measurements of the production cross-section for a Z boson in association with b -jets in proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS
Inspire ID: 1788444 arXiv ID: 2003.11960 Report IDs: CERN-EP-2020-022
Links: Inspire CDS arXiv
- ATLAS: Measurement of isolated-photon plus two-jet production in pp collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector
Inspire ID: 1772071 arXiv ID: 1912.09866 Report IDs: CERN-EP-2019-210
Links: Inspire CDS arXiv
- ATLAS: A measurement of soft-drop jet observables in pp collisions with the ATLAS detector at $\sqrt{s} = 13 \text{ TeV}$

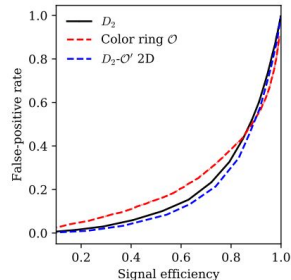
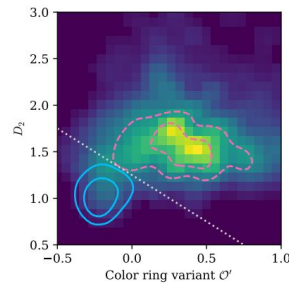
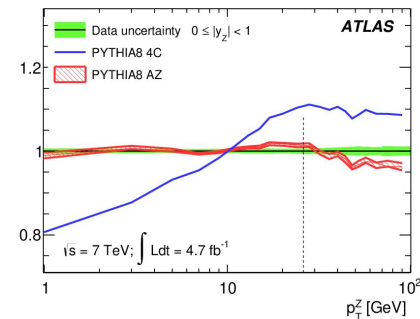
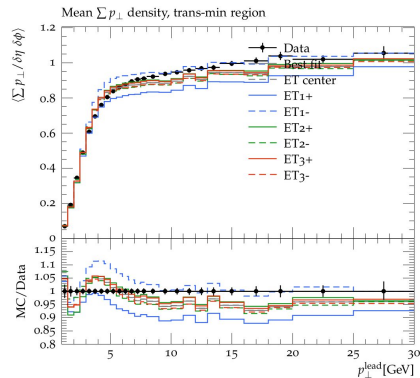
Applications: from tuning to...

First “killer app”: huge pre-LHC soft-QCD uncertainties:

- ❖ Tuning required Rivet analyses from expt
- ❖ Feed in to underlying event, pile-up, etc. modelling
 - Better tunes \Rightarrow better analysis, better results
 - **Impact:** LEP and Tevatron analyses published for ~ 10 years suddenly got used! **And cited...**
 - \Rightarrow ATLAS tunes, CMS tunes, **eigentunes**
 - \Rightarrow Rapid responses to preliminary data
 - **Model development:** matching & merging, addition of energy evolution & colour-reconnection to Herwig, ...

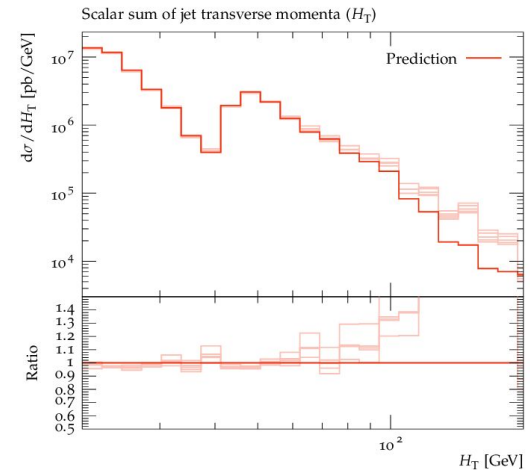
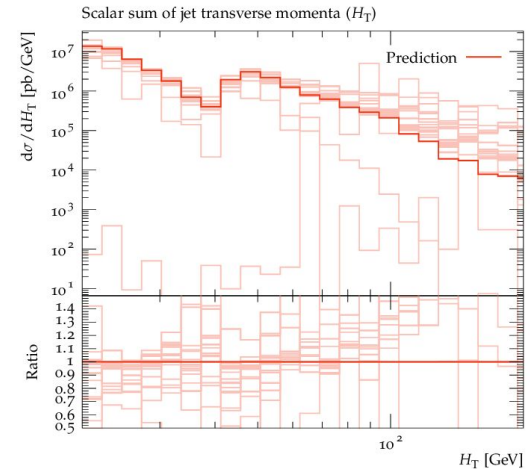
❖ Recently, also use of Rivet’s large analysis collection for *BSM* (see *Contur*) & *Higgs*

- Uptake still growing, e.g. in CMS



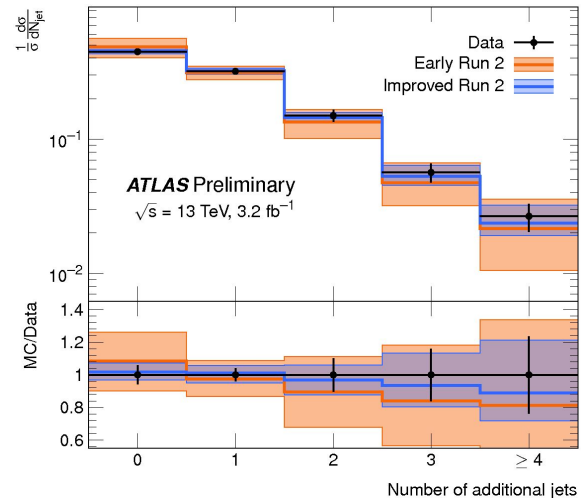
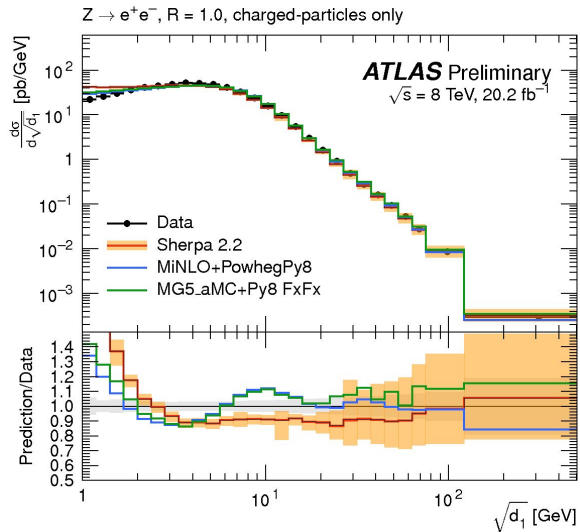
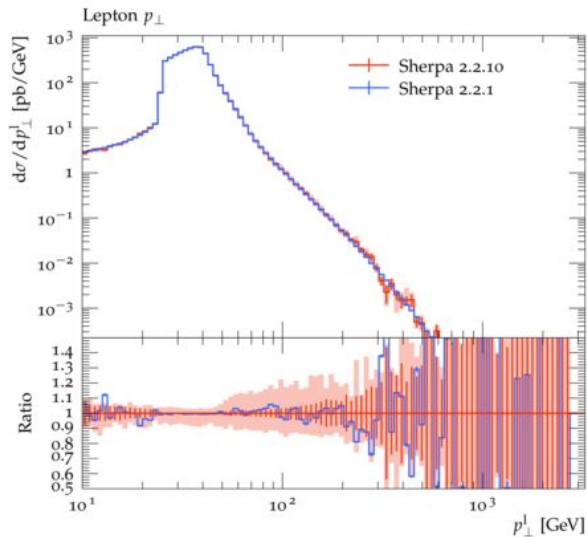
Multiweights and re-entry

- ❖ MC weight vectors allow expression of increasingly complex theory uncertainties. But a burden for analysis chains: have to propagate and correctly combine O(200) weight streams!
- ❖ Rivet 3: complex automatic handling of weights
~invisible to users: data objects *look* like histograms etc. but are secretly multiplexed
- ❖ Can now re-call finalisation to combine runs:
RAW histogram stage preserves pre-finalize objects
⇒ “re-entrant” perfect rivet-merge-ing
Key for e.g. pA/pp or W/Z ratios, + BSM recasting
- ❖ Data types are important: glimpses of a fully coherent separation of semantics from presentation



MC systematics bands via multiweights

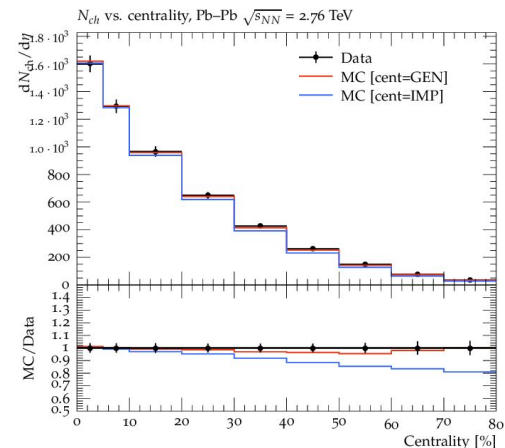
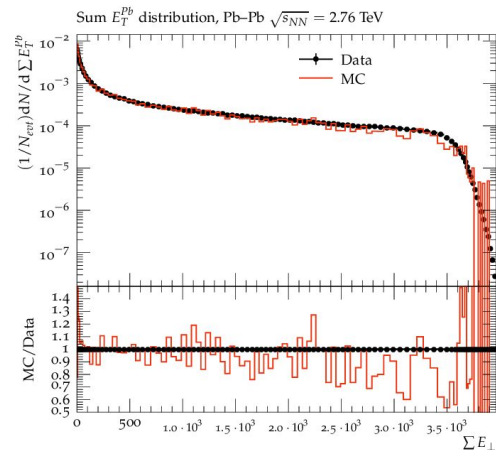
ATLAS MC studies have been a significant driver of this feature (thanks to Chris Gutschow)



Weight-naming standardisation **underway** concluding!

Heavy-ion physics preservation

- ❖ “Adding heavy-ion support” sounds trivial!
- ❖ Actually nuanced \Rightarrow lots of structural impacts
 - HI observables often require centrality-fraction calibration curves: we need a 2-pass run.
 - Flow observables, event/event correlations... all centrality-binned!
 - Swappable definitions: few HI generators are general-purpose enough to do “everything”
- ❖ All supported “out of the box” since v3
 - Paper: <https://arxiv.org/abs/2001.10737>
 - Core development tool for Pythia/Angantyr: authors and ALICE (etc.) collaborators providing analyses
- ❖ HI experience \Rightarrow updated pp primary particle defns



HI community engagement!

- ❖ Great “spontaneous” engagement from within HI. Several productive workshops

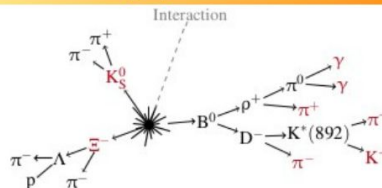
Summary

1. Data getting into HEPData

2. Build your own undergraduate army

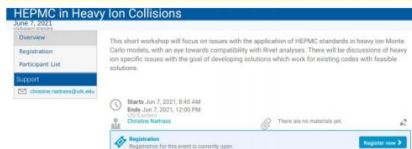


3. Primary particle definition



4. Validation Procedure

5. HEPMC output may have some issues



HEPMC in Heavy Ion Collisions

Overview

Registration

Participant List

Support

Starts Jun 7, 2021, 9:45 AM

Ends Jun 7, 2021, 12:00 PM

Christine Nattress

Registration for this event is currently open.

<https://indico.bnl.gov/event/10966/>

- ❖ HepData, Rivet
- ❖ Better ex/ph communication
- ❖ Faster model/data comparisons
- ❖ Addressing issues with formats and incomplete models
- ❖ Undergrad army!
- ❖ <https://indico.cern.ch/event/1022351/>

Also for EIC: ep /DIS/photoproduction

❖ Recent pushes to include more ep analyses

- Remember Rivet's origins in HERA HZTool?
- 2 analyses and DIS boosted frames since the beginning
- Older attempt to port HZTool analyses to Rivet flopped: ~little interest → semi-useful RivetHZTool package
- Now changing, largely due to EIC

❖ 8+2 new HERA routines in v3.1.5

- Supplied via preservation effort by Andrii Verbytskyi
- More to come...

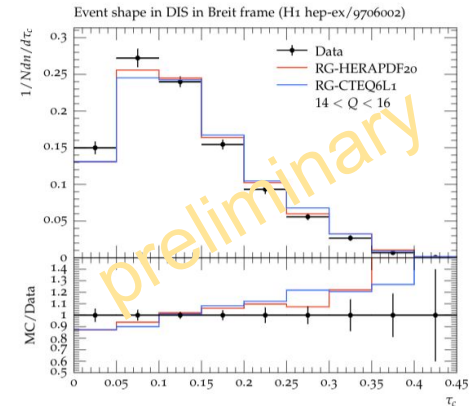
❖ 18 more from DESY summer students

- 2019 Rivet/DESY preservation workshop: refinements in fiducial machinery for DIS
- Rivet-based preservation programme in summer 2021
- Coming soon... v3.1.6 in ~Feb 2022?

Rivet, RivetHZTool and HERA

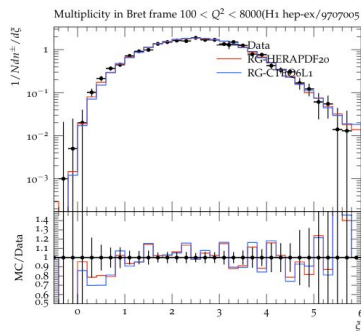
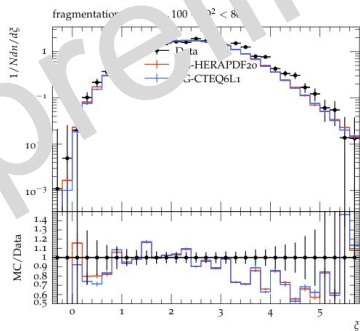
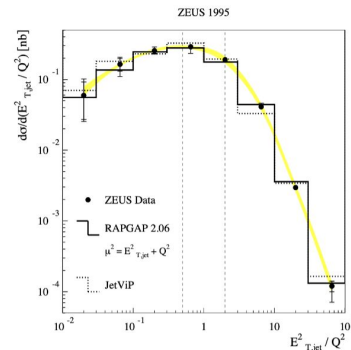
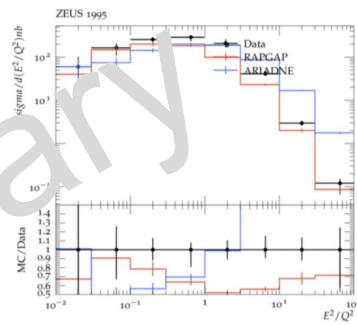
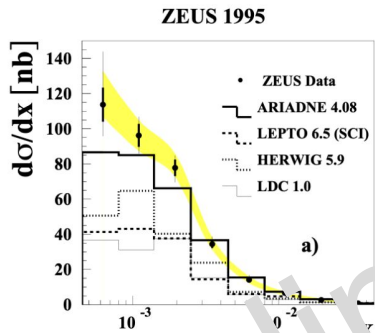
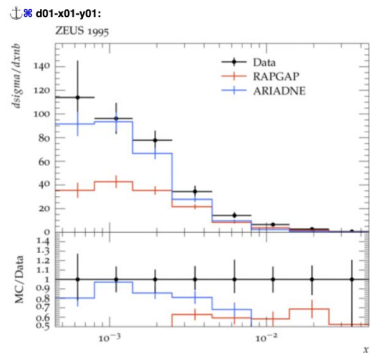
A validation effort for coding HERA measurements for Rivet

Muhammad Ibrahim Abdulhamid⁸, Andrea Achilleos,
Giorgia Bonomelli, Aryan Borkar¹⁴, Madhav Chithirasreemadam,
Maksim Davydov¹⁶, Keila Moral Figueroa, A. Arjan Iro B. Galván,
Susie Kim, Kritsanon Koennick, Luca Marsili¹³,
Ariadna León Quirós, Narmen Kaimova, Jacob Shannon,
Suraj Singh¹⁴, Can Süslü¹², Nataporn Trakulphorm, Danielle Wilson,
Wenting Zhang¹⁸,
A. Bernabede, Martínez², A. Buckley⁹, C. Bierlich¹⁵,
J. M. Butterworth¹⁴, L.I. Estevez Banos², C. Gütschow¹¹, H. Jung²,
M. Mendizabal², S. Taheri Monfared², S. Plätzer¹⁰, S. Schmitt, P. van
Mechelen⁴, Q. Wang^{2,7}, G. Watt¹⁷, M. Wing¹¹, H. Yang^{2,7}



More prelim HERA ep outputs

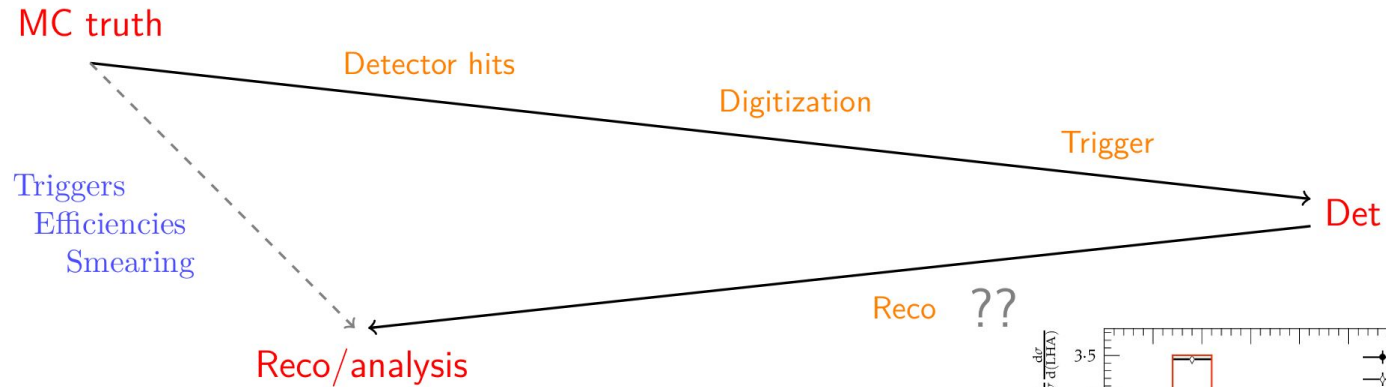
Analyses on everything from jet rates, to event shapes, E_T flow, K rates, b production, D and inclusive fragmentation, ...



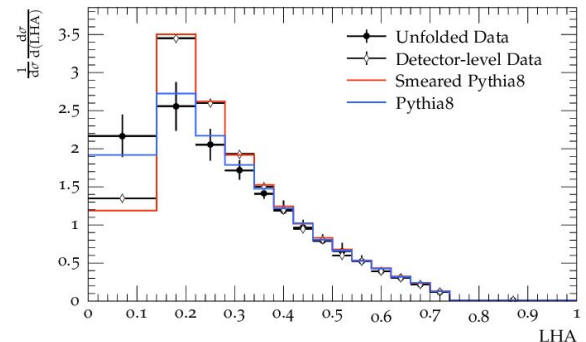
Detector emulation (but please unfold by preference!)

❖ Detector smearing built on Rivet's projection system — for reco-level analyses

- developed based on Gambit ColliderBit experience: no need for “full fast-sim”

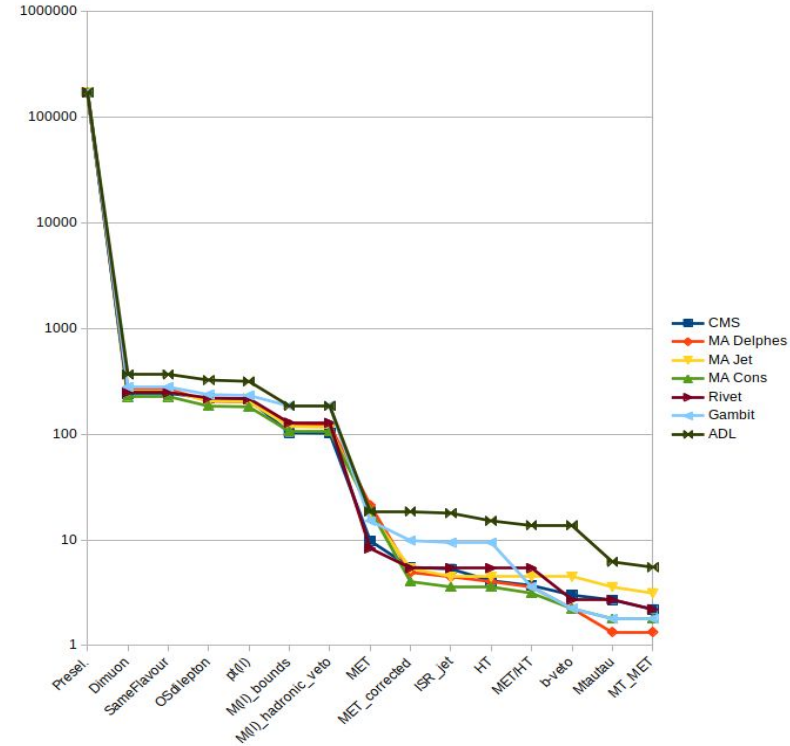


- like Delphes, but more flexible & can be *analysis-specific* \Rightarrow MA5 “SFS” mode
- flexibility allows e.g. “tuned” jet-substructure smearing, systematics studies, ...



Rivet and BSM-search recasting

- ❖ Rivet's main emphasis *isn't* BSM direct searches, but there's no reason not to
 - lots of experiment experience and support
 - efficient scaling-up to hundreds of analyses, with distinct phase-space specific detector/efficiency functions
- ❖ Can we do for BSM preservation what we did for measurement analyses?
 - Hasn't been a major focus: mechanisms are useful anyway, experiments (at least ATLAS) have focused on home-grown solutions
 - But... recent CMS interest via Si Hyun Jeon. Watch this space 👍



Les Houches 2019 CMS soft-lepton recasting-tools comparison

BSM from “Standard Model”

- ❖ **Not being focused on *direct* searches doesn’t mean no interest in BSM!**
- ❖ **Particle-level measurements *can* achieve high model-independence**
 - Careful definition of fiducial cross-section
 - Control distributions of “hidden variables” which are cut on
 - Reduce model sensitivity in unfolding
- ❖ **Rivet used directly in e.g.**
 - TopFitter top quark EFT fits;
 - at core of ATLAS *VH* EFT fits;
 - being integrated into Gambit global fits; and...
- ❖ **Contur is getting particular uptake**
 - Inject signal to “SM” measurements: **if it’d be statistically distinct, the model is eliminated**
 - Rivet gives huge coverage from “many angles”: views on not all, but most BSM signatures
a new result with Rivet code can be in Contur (or other) BSM fits within *hours*

Try doing this with full-sim recast in finite time...

❖ Contur VLQ review requested a scan of realistic multiplets:

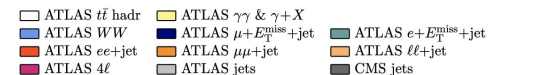
7 multiplets, each with 3 generational couplings, each with 4 W/H/Z-couplings,
300 points per scan, x 30,000 events \Rightarrow 750M events!

(a) *BT* 0:0:1 (b) *BT* 0:1:0 (c) *BT* 1:0:0 (d) *BT* $\frac{1}{2}:\frac{1}{4}:\frac{1}{4}$

(e) *XT* 0:0:1 (f) *XT* 0:1:0 (g) *XT* 1:0:0 (h) *XT* $\frac{1}{2}:\frac{1}{4}:\frac{1}{4}$

(i) *BY* 0:0:1 (j) *BY* 0:1:0 (k) *BY* 1:0:0 (l) *BY* $\frac{1}{2}:\frac{1}{4}:\frac{1}{4}$

(m) *BTXY* 0:0:1 (n) *BTXY* 0:1:0 (o) *BTXY* 1:0:0 (p) *BTXY* $\frac{1}{2}:\frac{1}{4}:\frac{1}{4}$

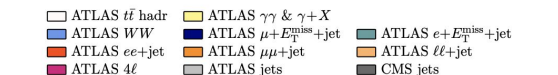


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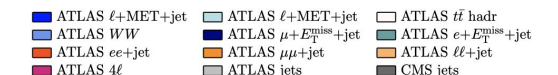


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The future of Rivet

- ❖ **Vision: Rivet as a standard for “truth-level” observables, across collider physics**
 - *Already used this way inside CMSSW truth definitions* 
- ❖ Not just standalone, but as a library in pheno & experiment frameworks, too: *leverage analysis collection, standardise MC-observable definitions, seamless systematics handling, etc.*
- ❖ At its core: a **physics-oriented** system for physicists to **compare MC predictions to one another and to data, on many simultaneous observables, in myriad ways**

We don't know all the use-cases yet.

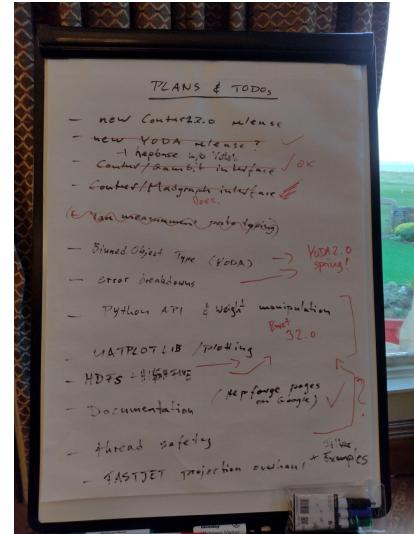
Practical tasks and challenges

❖ Tasks:

- Extension of HepData and other community infrastructure for ever-more precise data. Even our compressed data format is struggling with the volume of analyses and data
GSoC+follow-up on generalised binned containers, static/dynamic object distinction, and multiweight-oriented data formats (HDF5)
- **Improved, modernised visualisation and exploration**
⇒ **matplotlib GSoC+follow-up to make public**
- Preserving MVAs: [BDI](#) and NN in vanilla C++? Or avoid?

❖ Challenges:

- So much progress has happened at/because of in-person developer workshops ⇒ Covid had a big impact. **Events in Dec 2020 and more recently have re-invigorated developments**
- **Need to find ways to continue this without MCnet funding...**



Getting & using Rivet

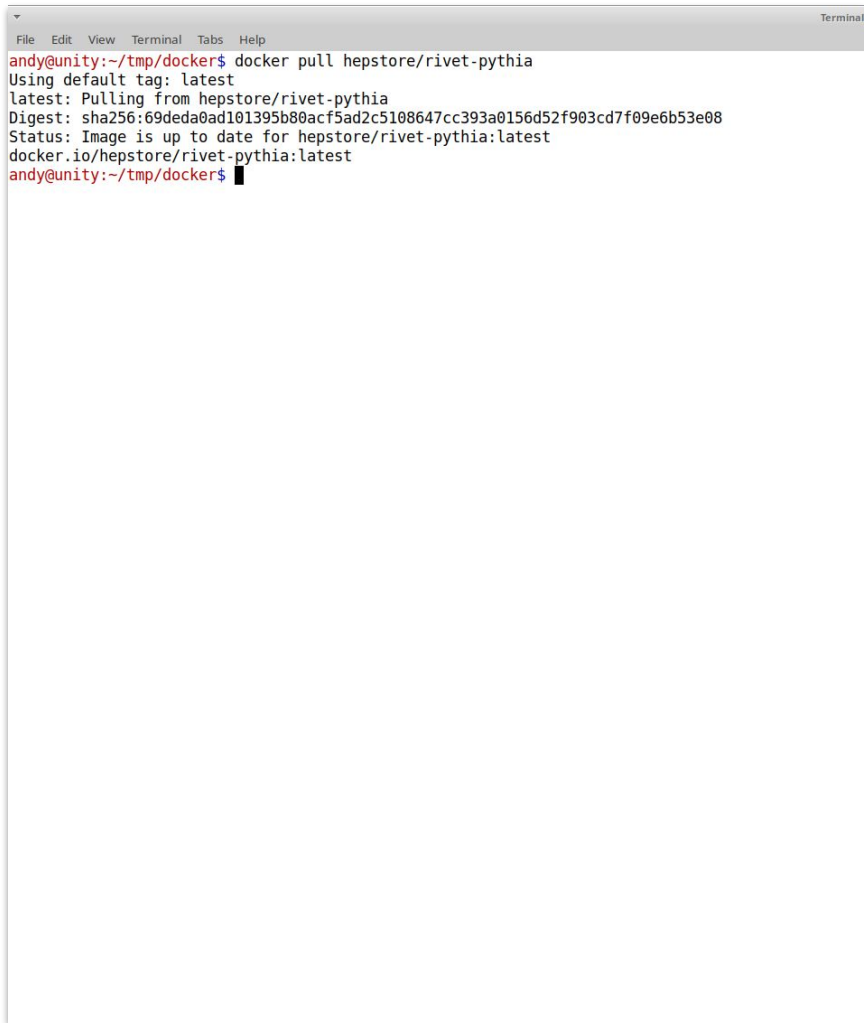
Lightweight analysis preservation
is valuable... and easy to start

As either a “user” or analysis
author, the barrier is lower than
ever: we recommend using our
Docker images to get started

Ideal for student projects!

Tutorials available from the
[Rivet website](#), a **walkthrough** in
the [R3 paper](#)

Imitation the highest form of
flattery ⇒ copy an existing analysis!

A terminal window titled "Terminal" with a menu bar (File, Edit, View, Terminal, Tabs, Help). The terminal shows the following output for the command 'docker pull hepstore/rivet-pythia':

```
andy@unity:~/tmp/docker$ docker pull hepstore/rivet-pythia
Using default tag: latest
latest: Pulling from hepstore/rivet-pythia
Digest: sha256:69deda0ad101395b80acf5ad2c5108647cc393a0156d52f903cd7f09e6b53e08
Status: Image is up to date for hepstore/rivet-pythia:latest
docker.io/hepstore/rivet-pythia:latest
andy@unity:~/tmp/docker$
```

Getting & using Rivet

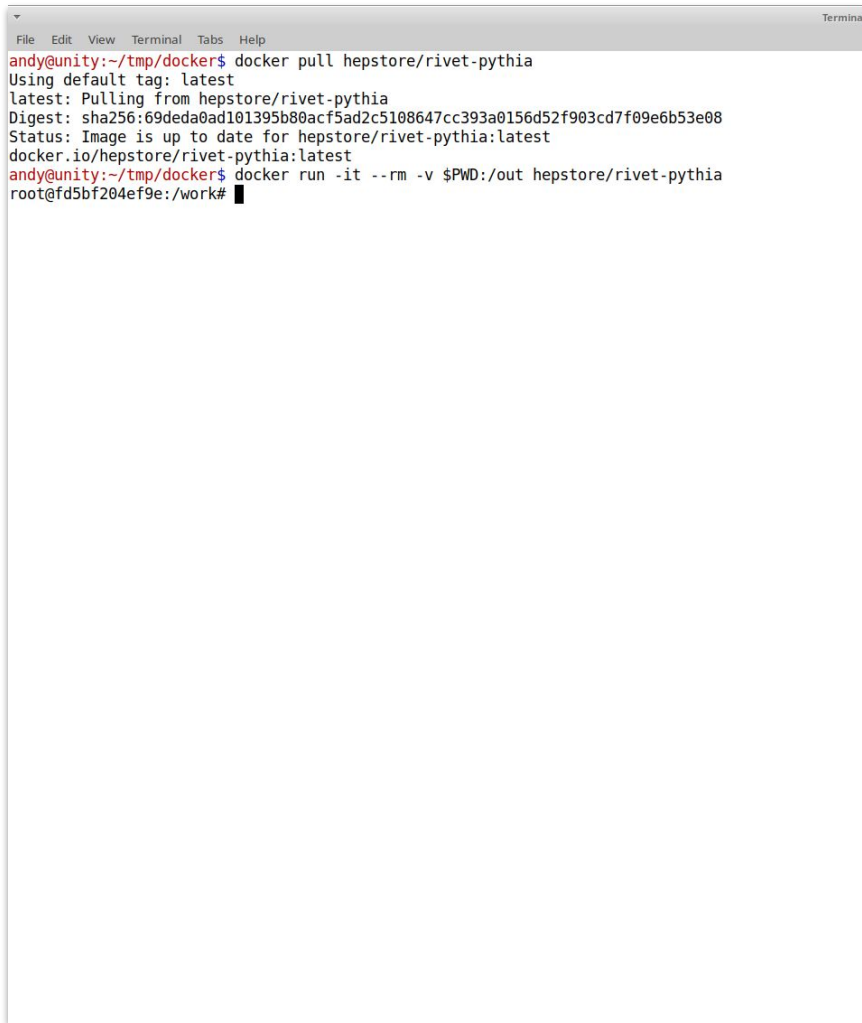
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```
File Edit View Terminal Tabs Help
andy@unity:~/tmp/docker$ docker pull hepstore/rivet-pythia
Using default tag: latest
latest: Pulling from hepstore/rivet-pythia
Digest: sha256:69deda0ad101395b80acf5ad2c5108647cc393a0156d52f903cd7f09e6b53e08
Status: Image is up to date for hepstore/rivet-pythia:latest
docker.io/hepstore/rivet-pythia:latest
andy@unity:~/tmp/docker$ docker run -it --rm -v $PWD:/out hepstore/rivet-pythia
root@fd5bf204ef9e:/work#
```

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the [R3 paper](#)

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```
File Edit View Terminal Tabs Help
root@d8c06acf8f66:/work# cp /usr/local/share/Pythia8/examples/main93.cmd py.cmd
root@d8c06acf8f66:/work# nano py.cmd
```

Getting & using Rivet

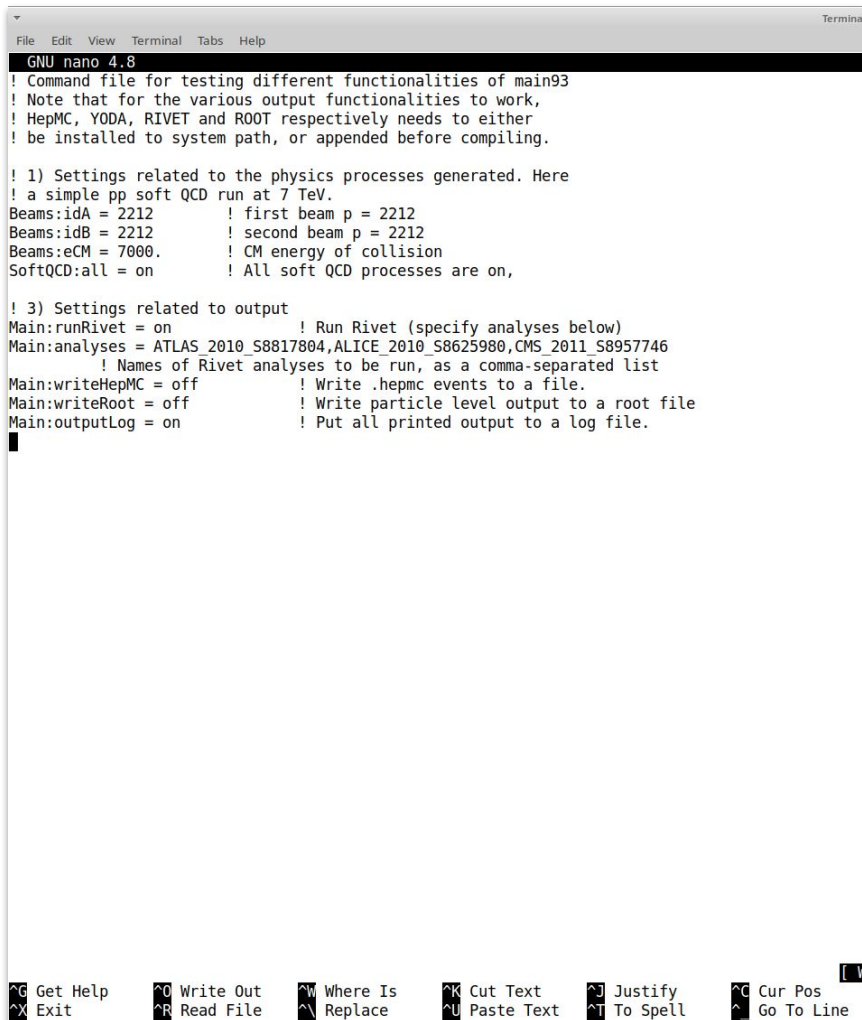
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```
GNU nano 4.8
! Command file for testing different functionalities of main93
! Note that for the various output functionalities to work,
! HepMC, YODA, RIVET and ROOT respectively needs to either
! be installed to system path, or appended before compiling.

! 1) Settings related to the physics processes generated. Here
! a simple pp soft QCD run at 7 TeV.
Beams:idA = 2212      ! first beam p = 2212
Beams:idB = 2212      ! second beam p = 2212
Beams:eCM = 7000.     ! CM energy of collision
SoftQCD:all = on      ! All soft QCD processes are on,

! 3) Settings related to output
Main:runRivet = on      ! Run Rivet (specify analyses below)
Main:analyses = ATLAS_2010_S8817804,ALICE_2010_S8625980,CMS_2011_S8957746
! Names of Rivet analyses to be run, as a comma-separated list
Main:writeHepMC = off  ! Write .hepmc events to a file.
Main:writeRoot = off   ! Write particle level output to a root file
Main:outputLog = on    ! Put all printed output to a log file.
█

⌘ Get Help  ⌘ Write Out  ⌘ Where Is  ⌘ Cut Text  ⌘ Justify  ⌘ Cur Pos
⌘ Exit      ⌘ Read File  ⌘ Replace   ⌘ Paste Text ⌘ To Spell  ⌘ Go To Line
```

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A terminal window with a grey title bar containing the text "Terminal". The terminal shows a series of shell commands and their outputs. The first command is `cp /usr/local/share/Pythia8/examples/main93.cmnd py.cmnd`, which is followed by the prompt `root@d8c06acf8f66:/work#`. The second command is `nano py.cmnd`, followed by the same prompt. The third command is `pythia8-main93 -c py.cmnd -n 10000`, followed by the same prompt. The cursor is at the end of the third command line.

```
File Edit View Terminal Tabs Help
root@d8c06acf8f66:/work# cp /usr/local/share/Pythia8/examples/main93.cmnd py.cmnd
root@d8c06acf8f66:/work# nano py.cmnd
root@d8c06acf8f66:/work# pythia8-main93 -c py.cmnd -n 10000
```


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root@d8c06acf8f66:/work# nano py.cmnd
root@d8c06acf8f66:/work# pythia8-main93 -c py.cmnd -n 10000
█
```

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root@d8c06acf8f66:/work# nano py.cmnd
root@d8c06acf8f66:/work# pythia8-main93 -c py.cmnd -n 10000

The MCnet usage guidelines apply to Rivet: see http://www.montecarlonet.org/GUIDELINES
Please acknowledge Rivet in results made using it, and cite https://arxiv.org/abs/1912.05451
root@d8c06acf8f66:/work# ls
Rivet.yoda  ex.cmnd  py.cmnd  pythia.log
root@d8c06acf8f66:/work# █
```

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root@d8c06acf8f66:/work# ls
Rivet.yoda  ex.cmnd  py.cmnd  pythia.log
root@d8c06acf8f66:/work# rivet-mkhtml Rivet.yoda
```

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Rivet.yoda ex.cmnd py.cmnd pythia.log
root@d8c06acf8f66:/work# rivet-mkhtml Rivet.yoda
Making 35 plots
Plotting ./rivet-plots/ALICE_2010_S8625980/Nevt_after_cuts.dat (35/35 remaining)
Plotting ./rivet-plots/ALICE_2010_S8625980/d03-x01-y01.dat (34/35 remaining)
Plotting ./rivet-plots/ALICE_2010_S8625980/d06-x01-y01.dat (33/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d01-x01-y01.dat (32/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d02-x01-y01.dat (31/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d03-x01-y01.dat (30/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d04-x01-y01.dat (29/35 remaining)
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Plotting ./rivet-plots/ATLAS_2010_S8817804/d06-x01-y01.dat (27/35 remaining)
█
```

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Rivet.yoda ex.cmnd py.cmnd pythia.log
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Making 35 plots
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Plotting ./rivet-plots/ATLAS_2010_S8817804/d07-x01-y01.dat (26/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d08-x01-y01.dat (25/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d09-x01-y01.dat (24/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d10-x01-y01.dat (23/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d11-x01-y01.dat (22/35 remaining)
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Plotting ./rivet-plots/ATLAS_2010_S8817804/d14-x01-y01.dat (19/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d15-x01-y01.dat (18/35 remaining)
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Plotting ./rivet-plots/ATLAS_2010_S8817804/d21-x01-y01.dat (12/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d22-x01-y01.dat (11/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d23-x01-y01.dat (10/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d24-x01-y01.dat (9/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d25-x01-y01.dat (8/35 remaining)
Plotting ./rivet-plots/ATLAS_2010_S8817804/d26-x01-y01.dat (7/35 remaining)
Plotting ./rivet-plots/CMS_2011_S8957746/d01-x01-y01.dat (6/35 remaining)
Plotting ./rivet-plots/CMS_2011_S8957746/d02-x01-y01.dat (5/35 remaining)
Plotting ./rivet-plots/CMS_2011_S8957746/d03-x01-y01.dat (4/35 remaining)
Plotting ./rivet-plots/CMS_2011_S8957746/d04-x01-y01.dat (3/35 remaining)
Plotting ./rivet-plots/CMS_2011_S8957746/d05-x01-y01.dat (2/35 remaining)
Plotting ./rivet-plots/CMS_2011_S8957746/d06-x01-y01.dat (1/35 remaining)
root@d8c06acf8f66:/work# █
```

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```
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root@d8c06acf8f66:/work# nano py.cmnd
root@d8c06acf8f66:/work# pythia8-main93 -c py.cmnd -n 10000

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root@d8c06acf8f66:/work# ls
Rivet.yoda ex.cmnd py.cmnd pythia.log
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Making 35 plots
Plotting ./rivet-plots/ALICE_2010_S8625980/Nevt_after_cuts.dat (35/35 remaining)
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root@d8c06acf8f66:/work# cp -r rivet-plots/ /out/
root@d8c06acf8f66:/work# █
```

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A terminal window titled "Terminal" with a menu bar (File, Edit, View, Terminal, Tabs, Help) and a title bar (root@d8c06acf8f66: /work). The terminal shows a user named "andy" at a shell prompt in a Docker container. The user enters "ls" and the output is "rivet-plots". The prompt then changes to "andy@unity:~/tmp/docker\$".

```
root@d8c06acf8f66: /work
andy@unity:~/tmp/docker$ ls
rivet-plots
andy@unity:~/tmp/docker$
```

Getting & using Rivet

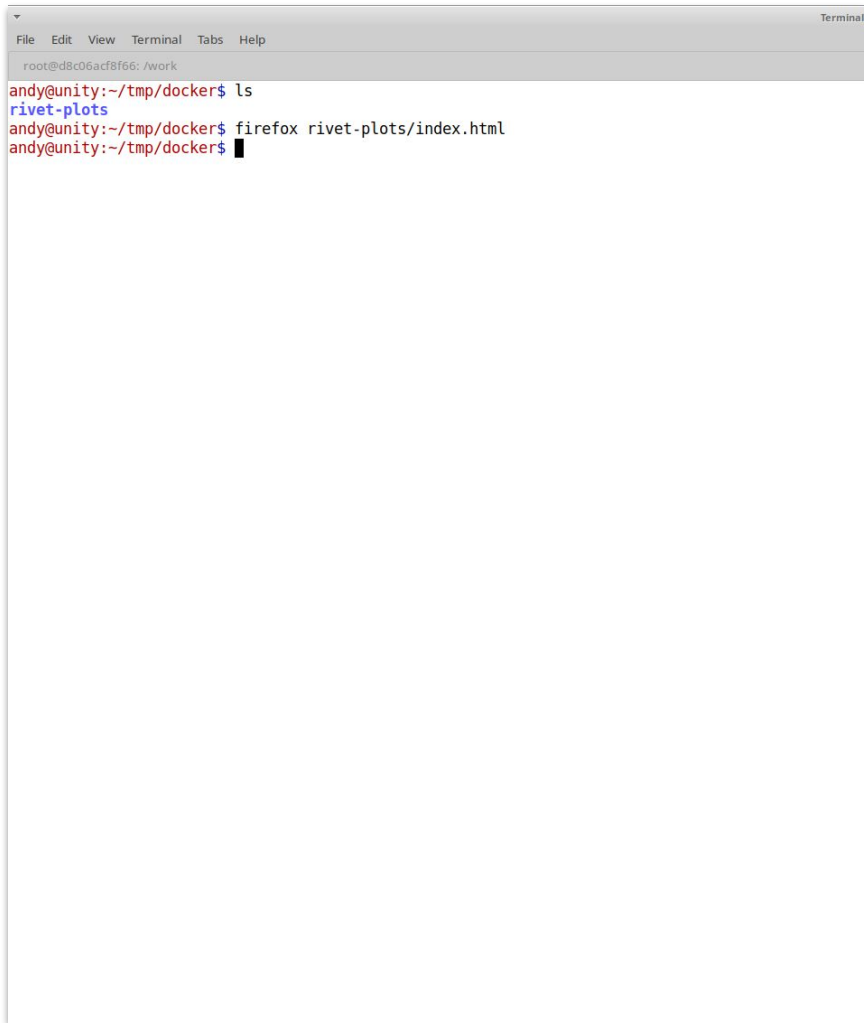
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A terminal window titled "Terminal" with a menu bar (File, Edit, View, Terminal, Tabs, Help) and a root directory path "root@d8c06acf8f66: /work". The terminal shows a sequence of commands and their outputs: "ls" returns "rivet-plots", and "firefox rivet-plots/index.html" opens a browser window.

```
root@d8c06acf8f66: /work
andy@unity:~/tmp/docker$ ls
rivet-plots
andy@unity:~/tmp/docker$ firefox rivet-plots/index.html
andy@unity:~/tmp/docker$
```


Getting & using Rivet

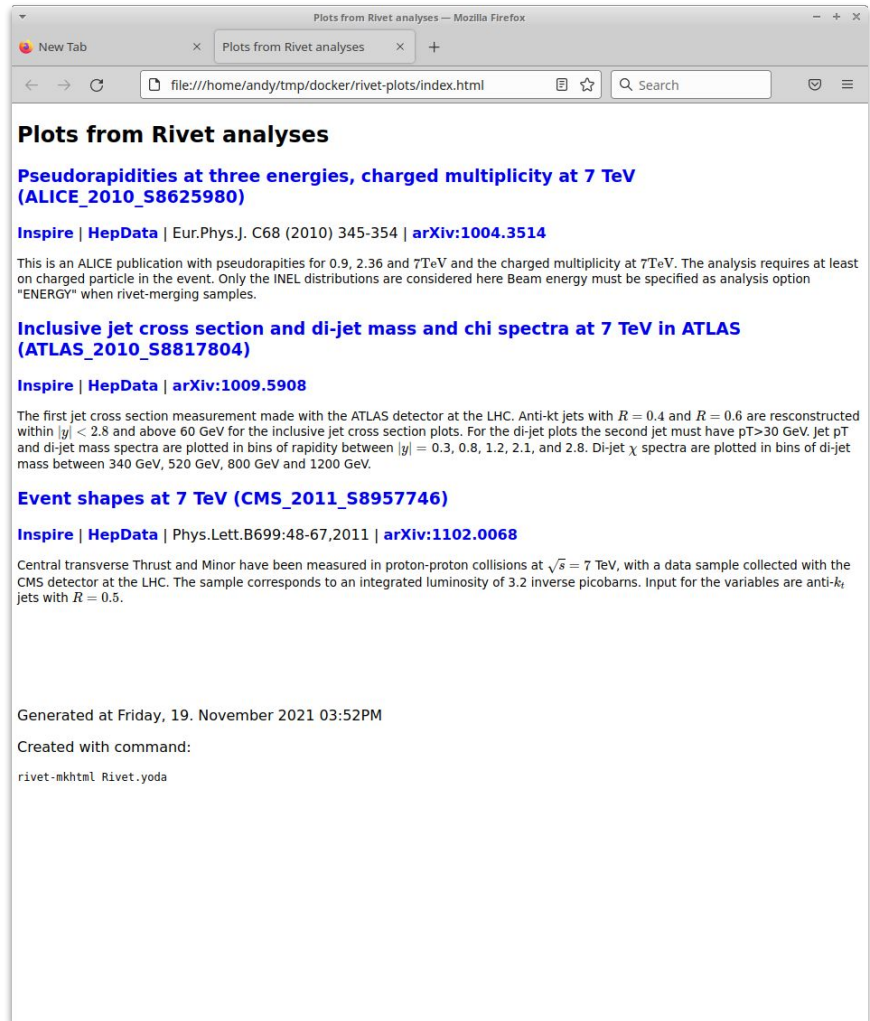
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The screenshot shows a Mozilla Firefox browser window with the address bar displaying `file:///home/andy/tmp/docker/rivet-plots/index.html`. The page content is titled "Plots from Rivet analyses" and lists three analysis entries:

- Pseudorapidities at three energies, charged multiplicity at 7 TeV (ALICE_2010_S8625980)**
Inspire | HepData | Eur.Phys.J. C68 (2010) 345-354 | arXiv:1004.3514
This is an ALICE publication with pseudorapidities for 0.9, 2.36 and 7TeV and the charged multiplicity at 7TeV. The analysis requires at least one charged particle in the event. Only the INEL distributions are considered here Beam energy must be specified as analysis option "ENERGY" when rivet-merging samples.
- Inclusive jet cross section and di-jet mass and chi spectra at 7 TeV in ATLAS (ATLAS_2010_S8817804)**
Inspire | HepData | arXiv:1009.5908
The first jet cross section measurement made with the ATLAS detector at the LHC. Anti-kt jets with $R = 0.4$ and $R = 0.6$ are reconstructed within $|y| < 2.8$ and above 60 GeV for the inclusive jet cross section plots. For the di-jet plots the second jet must have $pT > 30$ GeV. jet pT and di-jet mass spectra are plotted in bins of rapidity between $|y| = 0.3, 0.8, 1.2, 2.1, \text{ and } 2.8$. Di-jet χ spectra are plotted in bins of di-jet mass between 340 GeV, 520 GeV, 800 GeV and 1200 GeV.
- Event shapes at 7 TeV (CMS_2011_S8957746)**
Inspire | HepData | Phys.Lett.B699:48-67,2011 | arXiv:1102.0068
Central transverse Thrust and Minor have been measured in proton-proton collisions at $\sqrt{s} = 7$ TeV, with a data sample collected with the CMS detector at the LHC. The sample corresponds to an integrated luminosity of 3.2 inverse picobarns. Input for the variables are anti- k_r jets with $R = 0.5$.

Generated at Friday, 19. November 2021 03:52PM
Created with command:
rivet-mkhtml Rivet.yoda

Getting & using Rivet

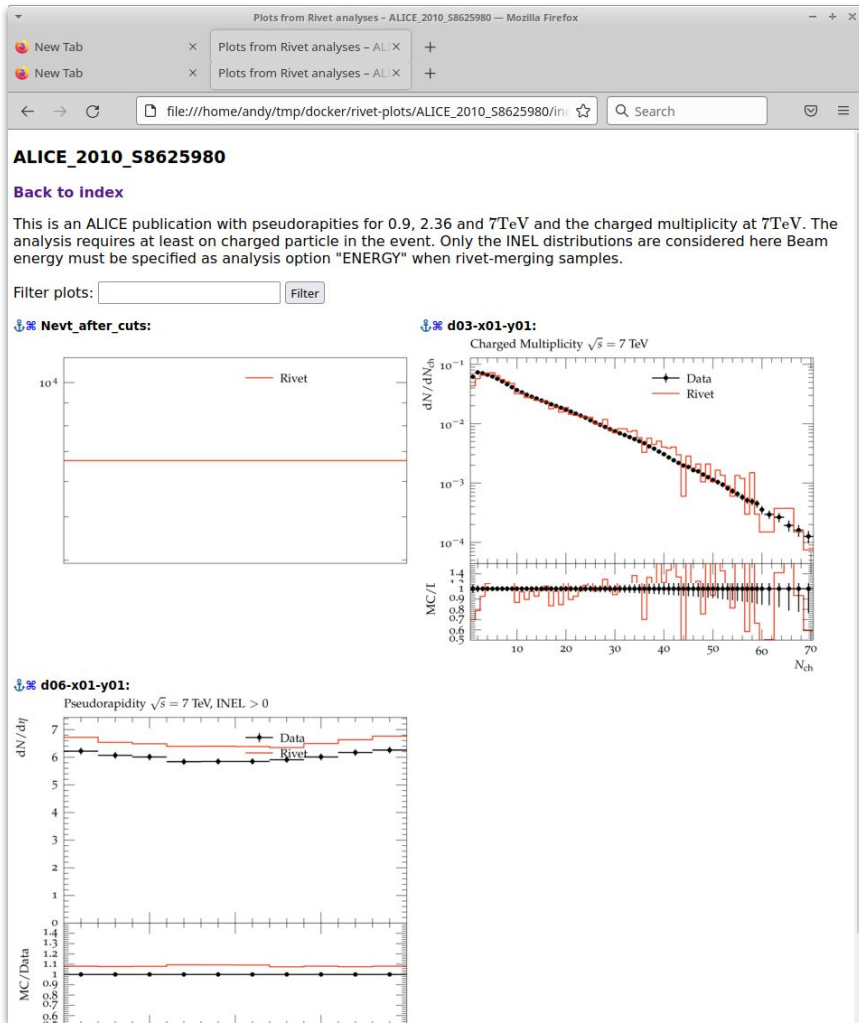
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Summary

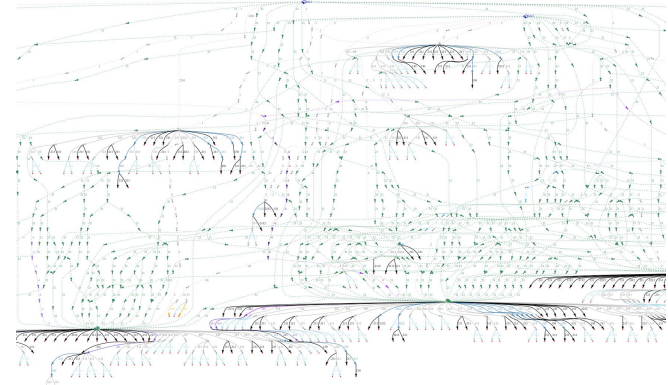
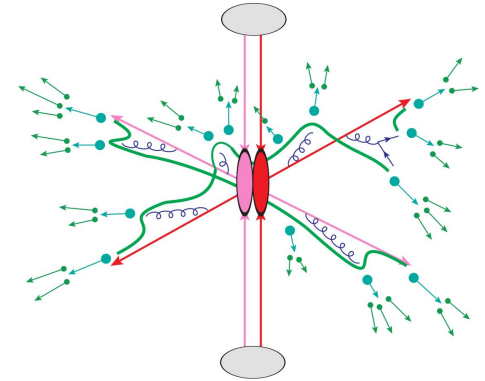
- ❖ Rivet arose from HERA experiment/MC author collaboration, in time for the LHC
- ❖ Experiment/pheno activities resulted, e.g.
 - MC(net) development, MC tuning, Higgs & BSM fits, ...
- ❖ **An accelerator for analysis impact:** many exp/theory studies using Rivet as their common language
- ❖ Development during MCnet3 took us from v1 + ideas to next-gen tool. **Collaboration** ⇒ **better ideas**
- ❖ Now entering another new era: precision machinery for LHC is in place ⇒ **need scaling & comprehensive uptake.** And looking *beyond LHC*, to HI, EIC, astroparticle, ...



Backup slides

MC generation

- ❖ **MC generation is where theory meets experiment**
 - The fundamental pp , pA , AA collision, *sans* detector
- ❖ **Components of an “exclusive” event-generator chain:**
 - QFT **matrix element** sampling at fixed-order in QCD
 - *Dressed* with approximate collinear splitting functions, iterated in factorised Markov-chain “**parton showers**”
 - FS parton evolution terminated at $Q \sim 1$ GeV: phenomenological **hadronisation** modelling
 - Mixed with **multiple partonic interaction** modelling
 - Finally particle **decays**, and other niceties
- ❖ **Modern HEP is hostage to shower MCs!**
 - The main mechanism for translating theory to experimental signatures, from QCD to BSM
 - Generally very complex modelling and output



From HZTool to Rivet

- ❖ The idea of preserving experimental analyses for MC validation was born out of HZTOOL
 - HERA (H1 and ZEUS) DIS and photoproduction
 - Probing low- x , semi-perturbative physics: DIS with $Q^2 \sim 4 \text{ GeV}^2$; jet $p_T \sim 5 \text{ GeV}$; diffraction
 - Many “state of the art” models only in MCs
 - Much confusion about comparing like-with-like between generators, experiments, and analyses
 - HZTool (Fortran) for cross-experiment comparisons of similar measurements modulo cut differences

❖ Direct line to Rivet, 10 years later: “HZ mark two”

- UK e-science funding; adopted by EU MCnet network



Aim: Study of future physics potentials at HERA in collider and fixed target modes, including high luminosity, polarized beams and nuclei.

[Proceedings of the Workshop](#)

[Old home page](#) and [workshop meetings](#)



Working Groups:

- Structure Functions
- Electroweak Physics
- Beyond the Standard Model
- Heavy Quark Production and Decay
- Jets and High p_T Phenomena
- Diffractive Hard Scattering
- Polarized Protons and Electrons
- Light and Heavy Nuclei in HERA
- HERA Upgrades and Impacts on Experiments



Organizing Committee:
Gunnar Ingelman, Uppsala/DESY (Chairman)
Albert De Roeck, DESY
Robert Klanner, DESY



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Advisory Committee:
W.Buchmüller, J.Feltesse, A.Levy,
H.Schröder, J.van den Brand, A.Wagner

If you are using mosaic, click [here](#).

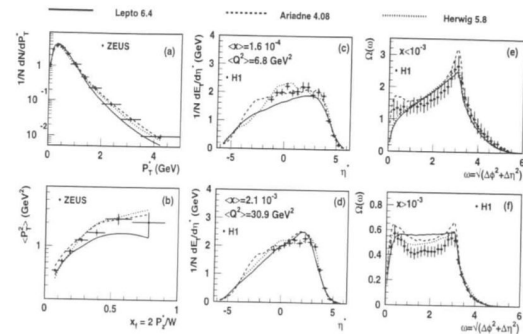
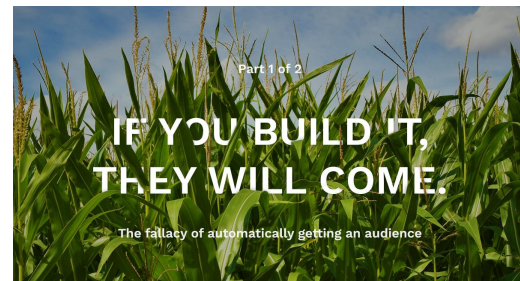
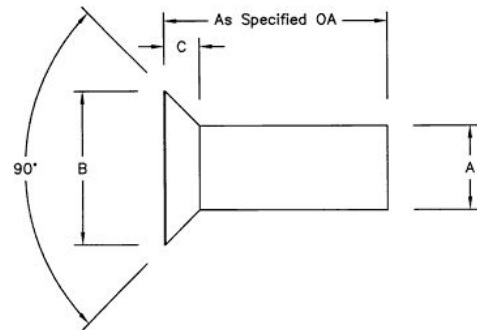


Figure 1: The transverse momenta dN/dp_T (a) and the ‘seagull’ plot $\langle P_T^2 \rangle \times x_F$ (b) of single particles in the positive hemisphere of the hadronic center of mass. The transverse energy flow $dE_T/d\eta$ in a low (c) and high (d) x and Q^2 bin. The transverse energy-energy correlations for $x > 10^{-3}$ (e) and $x < 10^{-3}$ (f).

Designing Rivet

- ❖ **Ease of use**
 - **Big emphasis on “more physics, less noise”!**
 - Minimal boilerplate analysis code, HepData sync
 - Event loop and histogramming basically familiar
 - **Tools to avoid having to touch the raw event graph**
- ❖ **Embeddable**
 - OO C++ library, Python wrapper, sane user scripts
 - Generator independence: communication via HepMC
 - Note HepMC3 HI-support efforts
 - Analysis routines factorised: loaded as “plugins”
- ❖ **Efficient**
 - **Avoid recomputations via “projection” caching system**
- ❖ **Physical**
 - **Measurements primarily from final-state particles only**



Event-generator tuning

Event generators all have dirty secrets. Usually non-perturbative ones... $O(30+)$ parameters

❖ **First systematic hadron collider “tunes” of PYTHIA6 by Rick Field for CDF ~ 2001**

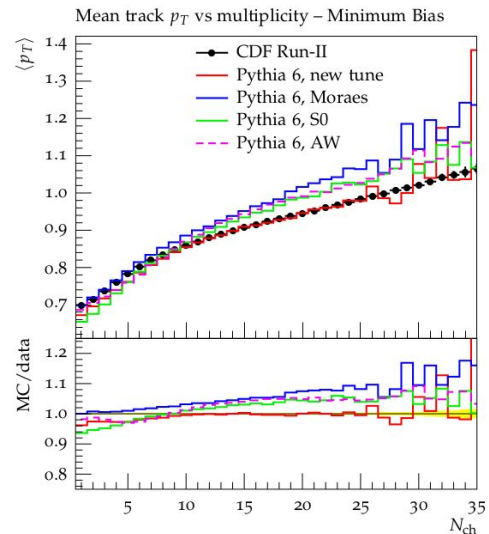
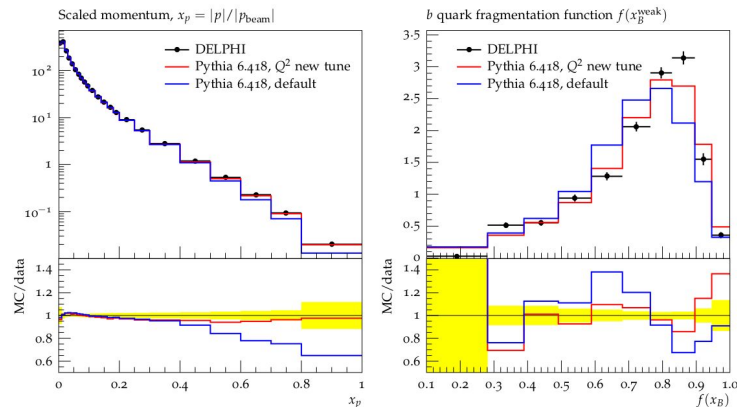
➤ Tune A, Tune D, Tune DW, etc. etc.

❖ **Limited datasets, variation by hand**

➤ Rivet and its analyses were a game-changer

➤ You only know a model is incapable when you’ve scanned its whole param space... and then the argument is over

❖ **The “Professor” tunes, 2008; and...**

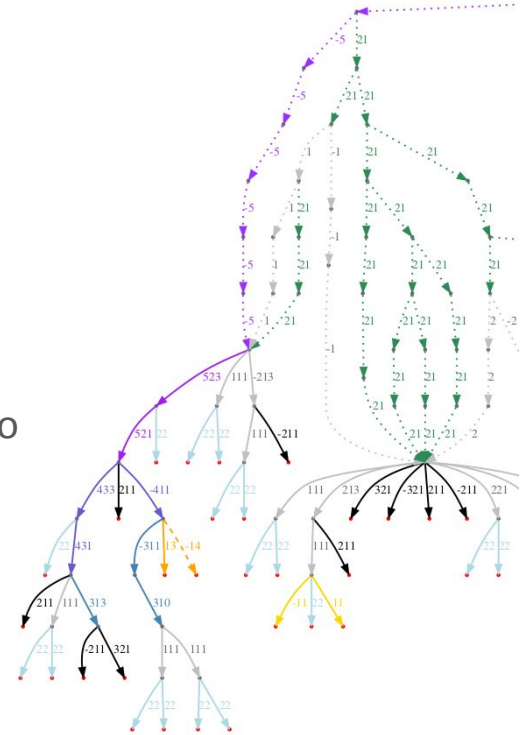


Physically safe analysis methods



Avoiding unstandardised event-graph features was pragmatic, but led to some genuine physical insights:

- ❖ refining the “fiducial” idea, defining *unfolding targets*
- ❖ **Hadronisation as a “decoherence barrier”**
use the natural dividing line between the quantum-interfering hard process & semi-classical decays: ~ no tempting partons!
- ❖ **Bringing truth tagging closer to reco**
first releases used *b*-ancestry of jet constituents to set HF labels: too inclusive! \Rightarrow *associate* the hard-fragmenting, weakly-decaying *B*
- ❖ **Promptness/directness tests**
don't identify a particle “from the hard process”; do it backward. Label as *indirect* via recursive checks for hadron parentage
- ❖ **Dressed leptons**
we now primarily *dress* truth leptons with their photon halo



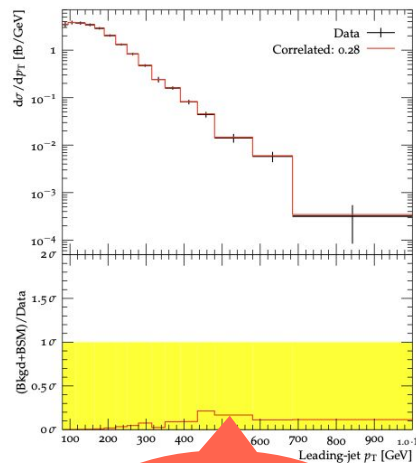
Contur



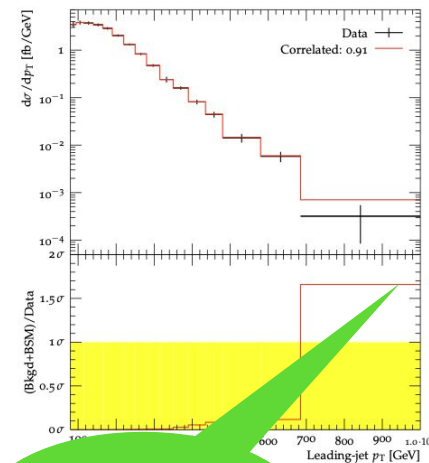
HT Louie Corpe

❖ Contur is “just” a wrapper on Rivet

- Ok, not just! You need to know which analyses are “safe”. Another reason for emphasis on final-states and *no cheating*
- In absence of unambiguous BSM, make zeroth-order assumption that data = SM
- Can be improved with high-precision SM theory predictions & uncertainties
- Signal-injection \Rightarrow care with e.g. ratios & profiles... cf. Rivet “perfect merging”
- Group analyses in stats-orthogonal “pools”. Use (expected) most-constraining element in the pool for setting limits — use correlations when possible to make “bigger” elements



Signal would have small effect wrt uncertainties, can't exclude it (28 % CL)



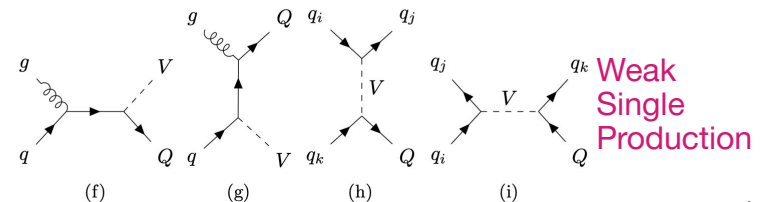
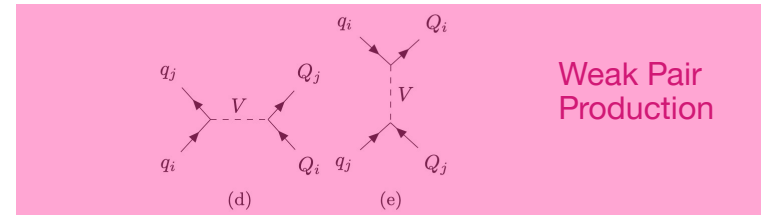
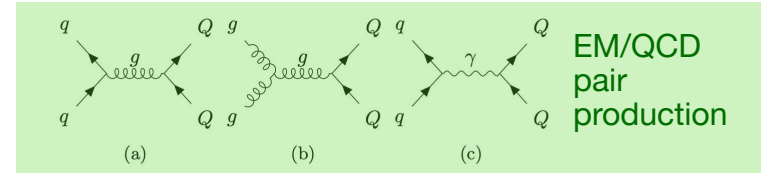
Signal would have large effects wrt uncertainties: can exclude at high CL

Contur BSM example

❖ Vector-like quarks [\[SciPost Phys. 9, 069 \(2020\)\]](#)

- Popular generic class of SM extensions, with new quark partners: $B^{-1/3}$, $T^{2/3}$, $X^{5/3}$, $Y^{4/3}$
- Couple to SM via usual quark EM & strong couplings, but
 - B, T : interact with W, Z or H via modified weak coupling
 - X, Y : interact **only with W** via modified weak coupling: $X \rightarrow Wt$, $Y \rightarrow Wb$ always
- LHC searches mostly for 3rd gen, strong pair-production only!
- 4 masses, 1 overall coupling κ , 3 generational couplings ζ , 3 branching ratios ξ
 - ⇒ rich collider phenomenology!

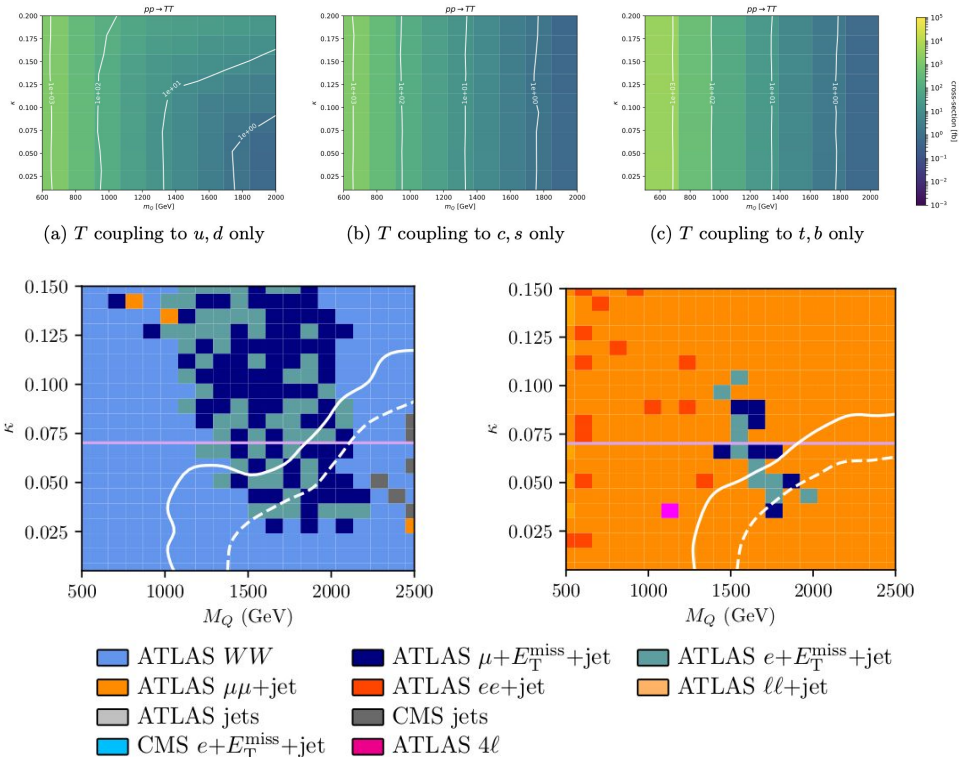
$$\begin{aligned} \mathcal{L} = & \kappa_B \left[\sqrt{\frac{\zeta_i \xi_W^B}{\Gamma_W^0}} \frac{g}{\sqrt{2}} [\bar{B}_{L/R} W_\mu^- \gamma^\mu u_{L/R}^i] + \sqrt{\frac{\zeta_i \xi_Z^B}{\Gamma_Z^0}} \frac{g}{2c_W} [\bar{B}_{L/R} Z_\mu \gamma^\mu d_{L/R}^i] - \sqrt{\frac{\zeta_i \xi_H^B}{\Gamma_H^0}} \frac{M_B}{v} [\bar{B}_{R/L} H d_{L/R}^i] \right] \\ & + \kappa_T \left[\sqrt{\frac{\zeta_i \xi_W^T}{\Gamma_W^0}} \frac{g}{\sqrt{2}} [\bar{T}_{L/R} W_\mu^+ \gamma^\mu d_{L/R}^i] + \sqrt{\frac{\zeta_i \xi_Z^T}{\Gamma_Z^0}} \frac{g}{2c_W} [\bar{T}_{L/R} Z_\mu \gamma^\mu u_{L/R}^i] - \sqrt{\frac{\zeta_i \xi_H^T}{\Gamma_H^0}} \frac{M_T}{v} [\bar{T}_{R/L} H u_{L/R}^i] \right] \\ & + \kappa_X \left[\sqrt{\frac{\zeta_i}{\Gamma_W^0}} \frac{g}{\sqrt{2}} [\bar{X}_{L/R} W_\mu^+ \gamma^\mu u_{L/R}^i] \right] + \kappa_Y \left[\sqrt{\frac{\zeta_i}{\Gamma_W^0}} \frac{g}{\sqrt{2}} [\bar{Y}_{L/R} W_\mu^- \gamma^\mu d_{L/R}^i] \right] + \text{h.c.}, \end{aligned}$$



VLQ pheno with Contur: 1st gen

- ❖ Even pair-production has κ -dependence via weak production initiated by valence quarks
- ❖ Weak Qq single-VLQ production can dominate over pair-prod!
- ❖ Different $W:Z:H$ BF's for T, B activate different analysis pools “automatically” due to Rivet coverage
- ❖ WW diboson mostly dominates, thanks to W and H decay channels
- ❖ “Injection” of ℓ +MET+jet events here from an unfolded VBF *control region*!

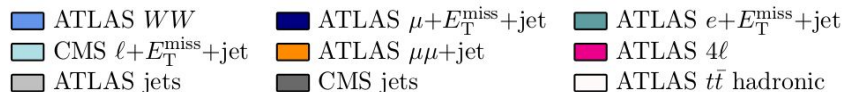
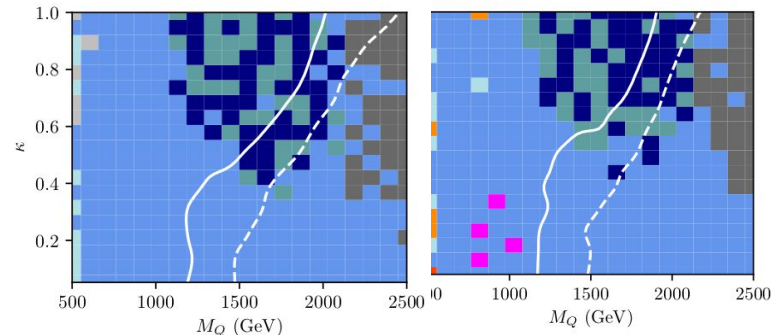
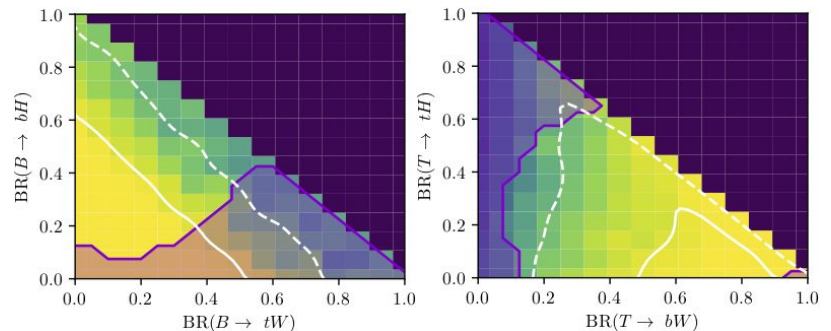
Pair-prod cross-sections



Exclusions complementary to non-collider limits

VLQ pheno with Contur: 3rd gen

- ❖ In pure T, B pair-production mode, diboson and ℓ +MET+jet “SM” analyses ~cover or complement direct searches wonderfully
- ❖ In general, for $W:Z:H = 0:1:0$, Tq and Xq production killed by tiny top-quark PDF: pairs at low- m_Q , Yq at high-mass. Decays always have a W (directly or via $T \rightarrow tZ$) \Rightarrow ℓ +MET pool always dominates
- ❖ Rivet+Contur “SM” routines give powerful sensitivity to VLQs, even far from the benchmark search modes

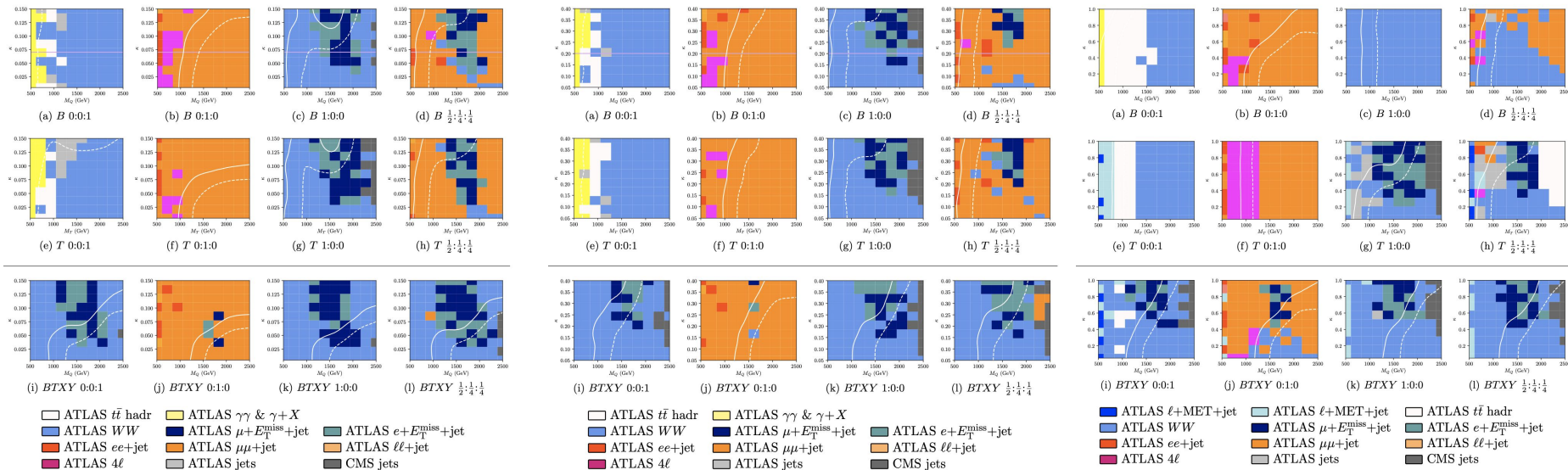


Generalising to 4 VLQs, still strong exclusions

More realistic models...

[singlets]

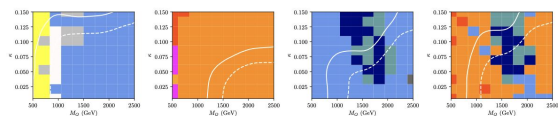
- ❖ Review requested a scan of realistic multiplets: 7 multiplets, each with 3 generational couplings, each with 4 W/H/Z-couplings, 300 points per scan, x 30,000 events!
- ❖ **~No problem! 1 month later...**



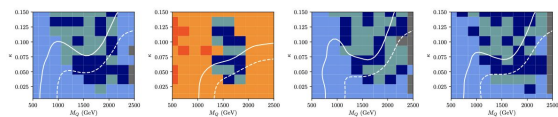
More realistic models...

[doublets]

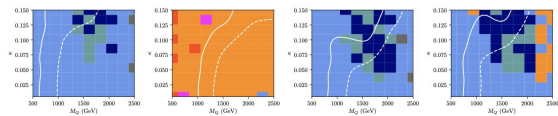
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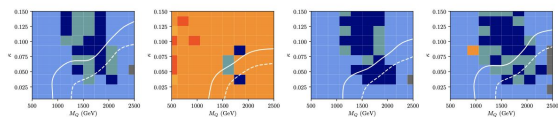
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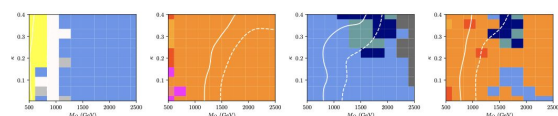
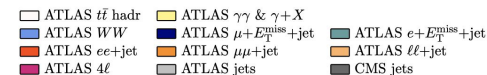
(e) *XT* 0:0:1 (f) *XT* 0:1:0 (g) *XT* 1:0:0 (h) *XT* $\frac{1}{2}:\frac{1}{2}:\frac{1}{4}$



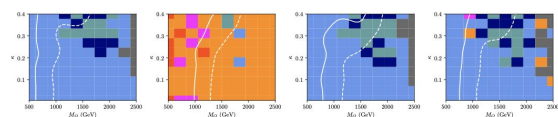
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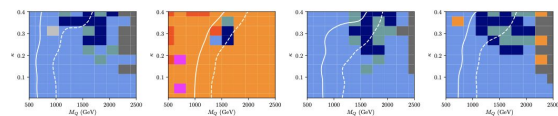
(m) *BTXY* 0:0:1 (n) *BTXY* 0:1:0 (o) *BTXY* 1:0:0 (p) *BTXY* $\frac{1}{2}:\frac{1}{2}:\frac{1}{4}$



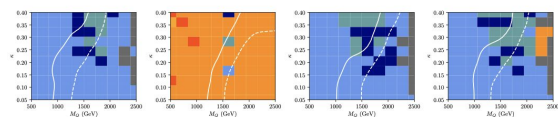
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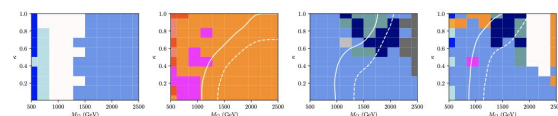
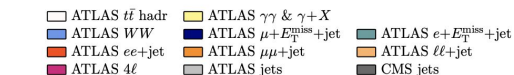
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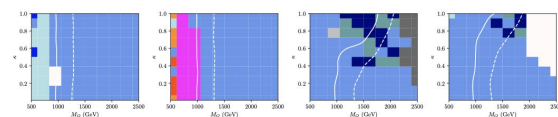
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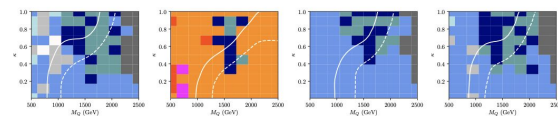
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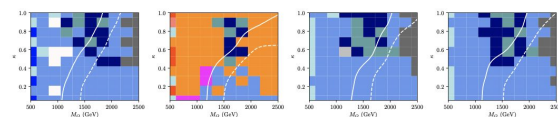
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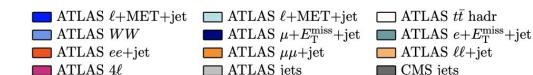
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(i) *BY* 0:0:1 (j) *BY* 0:1:0 (k) *BY* 1:0:0 (l) *BY* $\frac{1}{2}:\frac{1}{2}:\frac{1}{4}$



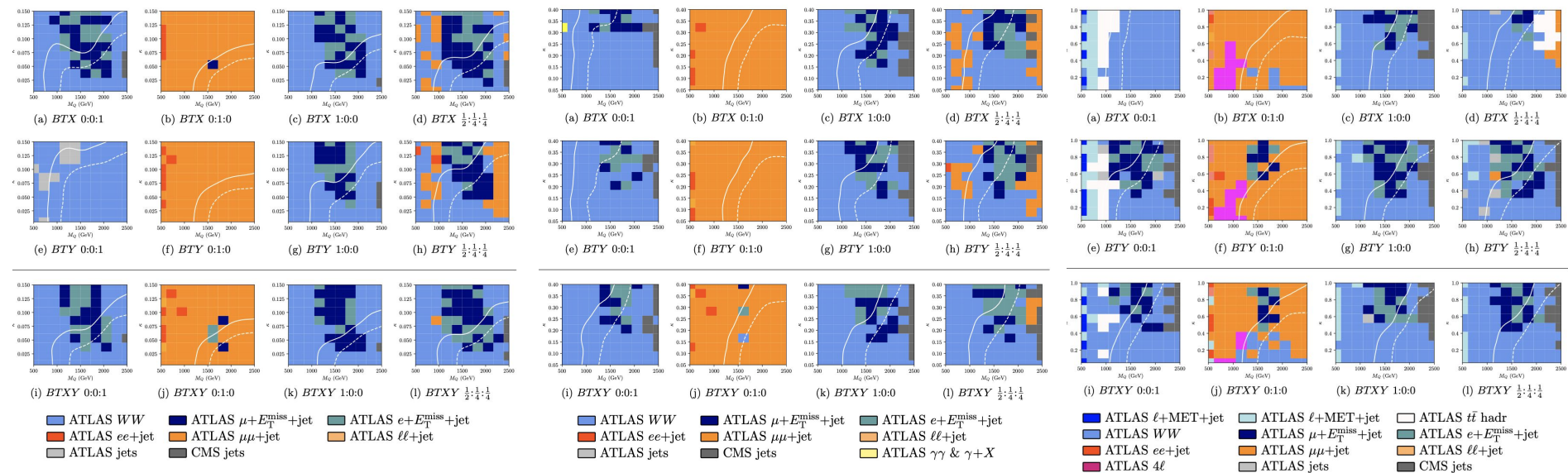
(m) *BTXY* 0:0:1 (n) *BTXY* 0:1:0 (o) *BTXY* 1:0:0 (p) *BTXY* $\frac{1}{2}:\frac{1}{2}:\frac{1}{4}$



More realistic models...

[triplets]

- Review requested a scan of realistic multiplets: 7 multiplets, each with 3 generational couplings, each with 4 W/H/Z-couplings, 300 points per scan, x 30,000 events!



Speed is good!

Harder, faster, stronger... moar BSM

- ❖ Now extending beyond 1D and 2D grids:
 - Rivet (and Herwig) as a function
 - Embed into adaptive scans
 - Higher param dimensionalities
 - Including beyond colliders, e.g. Gambit
- ❖ Rivet as a tool to probe new-observable sensitivity, e.g. in EFT models (TopFitter)
- ❖ Bootstrapping for victory: estimating statistical and systematic correlations (with SModelS, MadAnalysis5)

