The Future Interplay of Monte Carlo and experiment

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SLAC NATIONAL ACCELERATOR LABORATORY

Future Trends in Nuclear Physics Computing

Jefferson Lab (remotely), March 16, 2016

Outline

1. Monte Carlo Event Generators
2. Data / theory comparisons
3. Data / theory comparisons in LHC phenomonology
4. Making theory results available

Different reasons for Monte Carlo

Experimentalist: Estimate detector acceptance corrections.

Phenomenologist: Assess search strategies and detector development.

Theorist: Compare theory to data.

Common denominator:
Need detailed and accurate modelling of scattering events.

Event generators as theory repository

New discoveries can only be claimed if we compared data with our **"best"** theory knowledge before.

General Purpose Monte Carlo Event Generators (MCEGs) aim at being repositories for the most accurate theory knowledge.

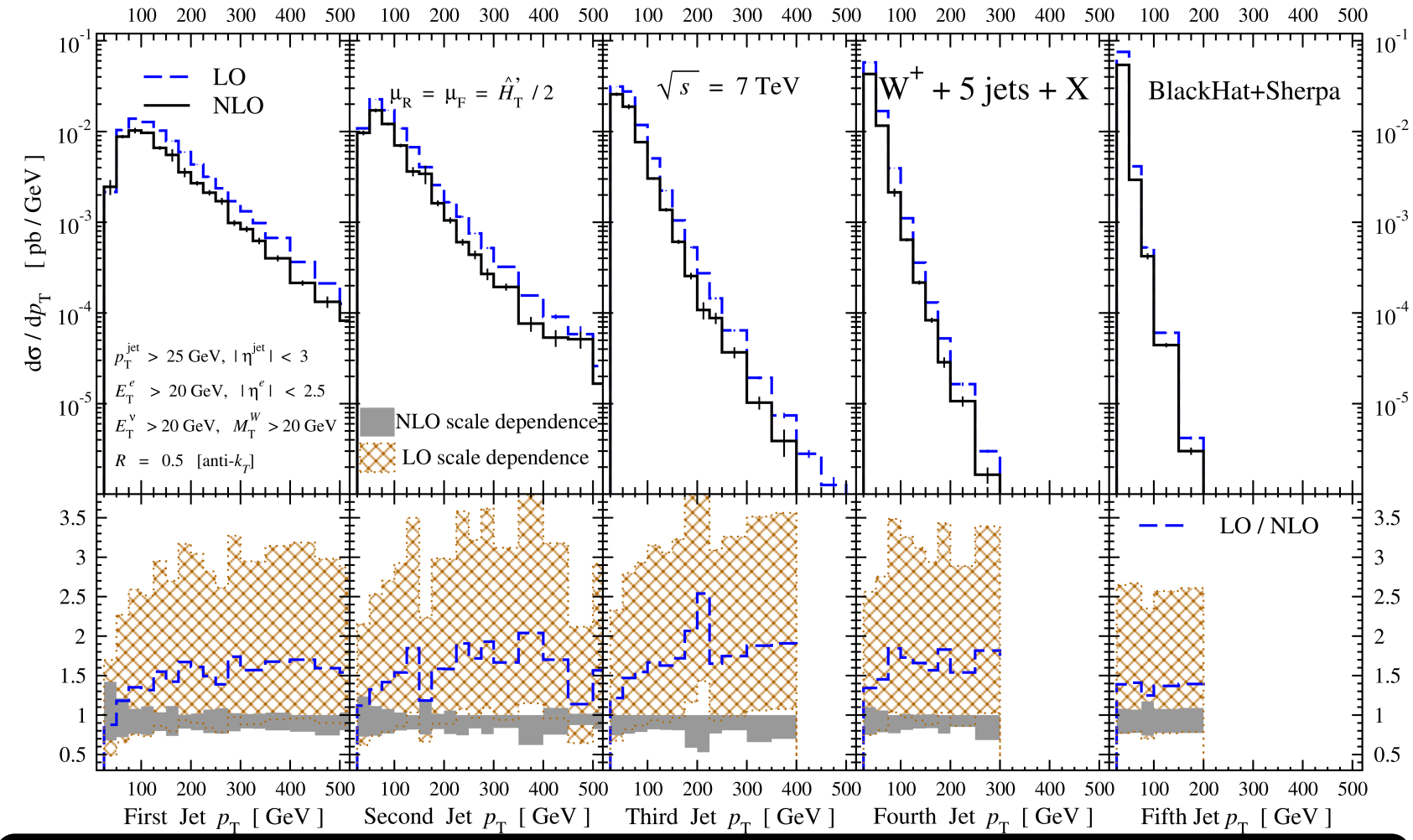
Common high-energy MCEGs are HERWIG, PYTHIA and SHERPA. They include knowledge of $\mathcal{O}$(40 research years), and need to be

Developed and improved
...or they stop being useful.

Maintained
...or they stop being useful.

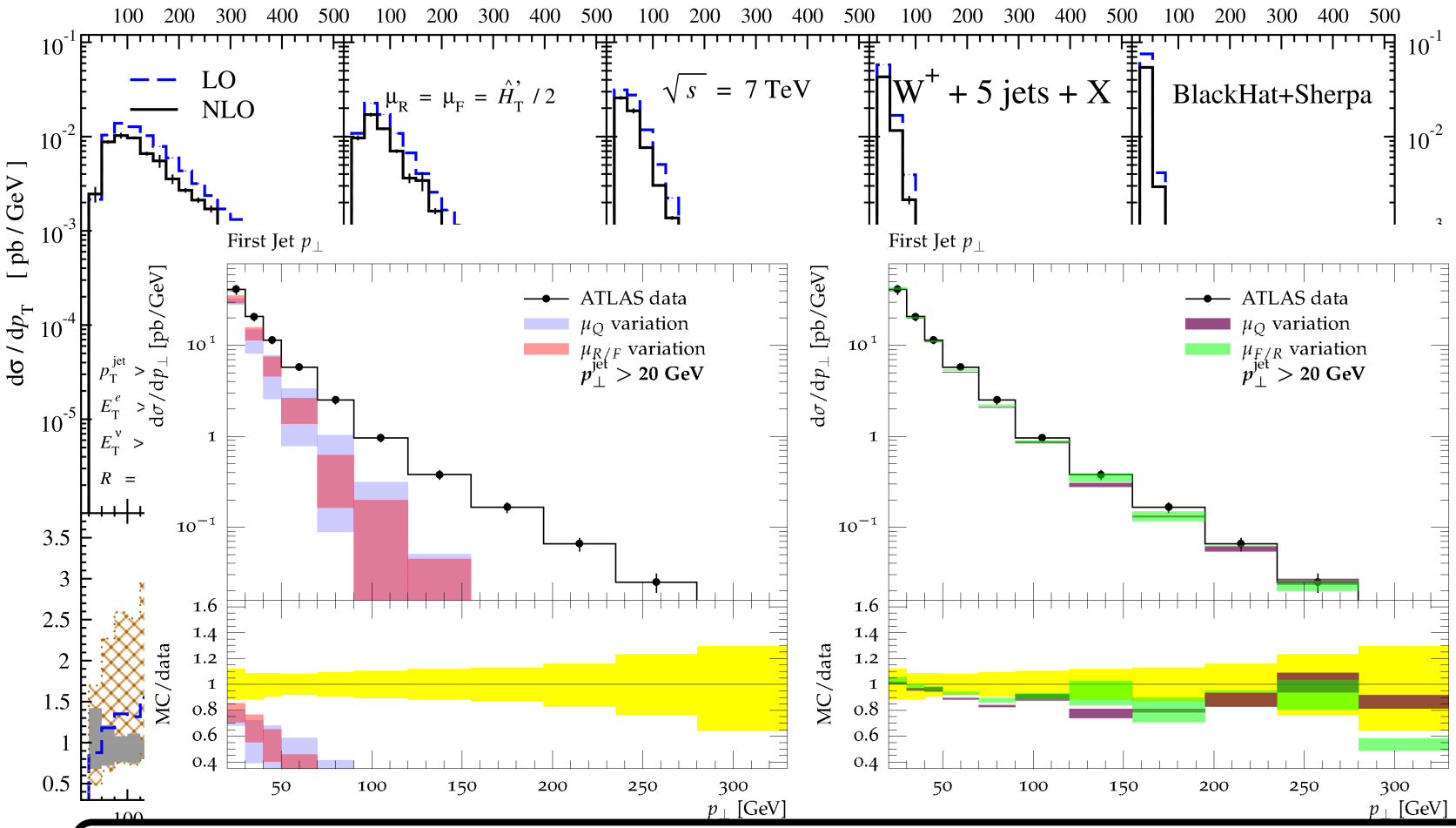
Modular and extendable design
...to enable the community can contribute.

Example: Include perturbative QCD frontier for LHC



F: (W + 5 jets) at next-to-leading order. Massive computational task (see Stefan Höche's talk).

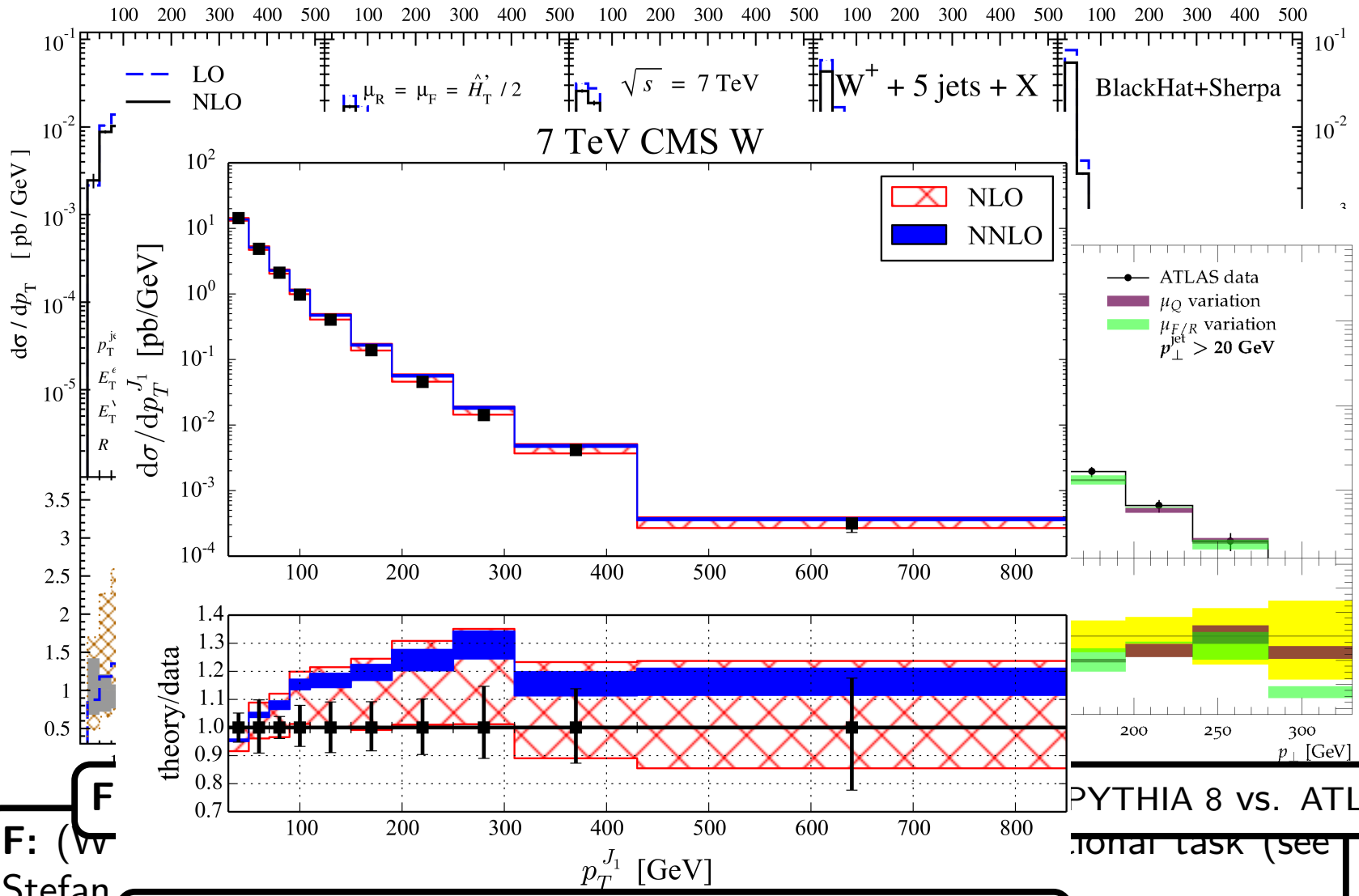
Example: Include perturbative QCD frontier for LHC



F: (W + 0 jet)@NLO + (W + 1 jet)@NLO combined in PYTHIA 8 vs. ATLAS.

F: (W + 5 jets) at next-to-leading order. Massive computational task (see Stefan Höche's talk).

Example: Include perturbative QCD frontier for LHC



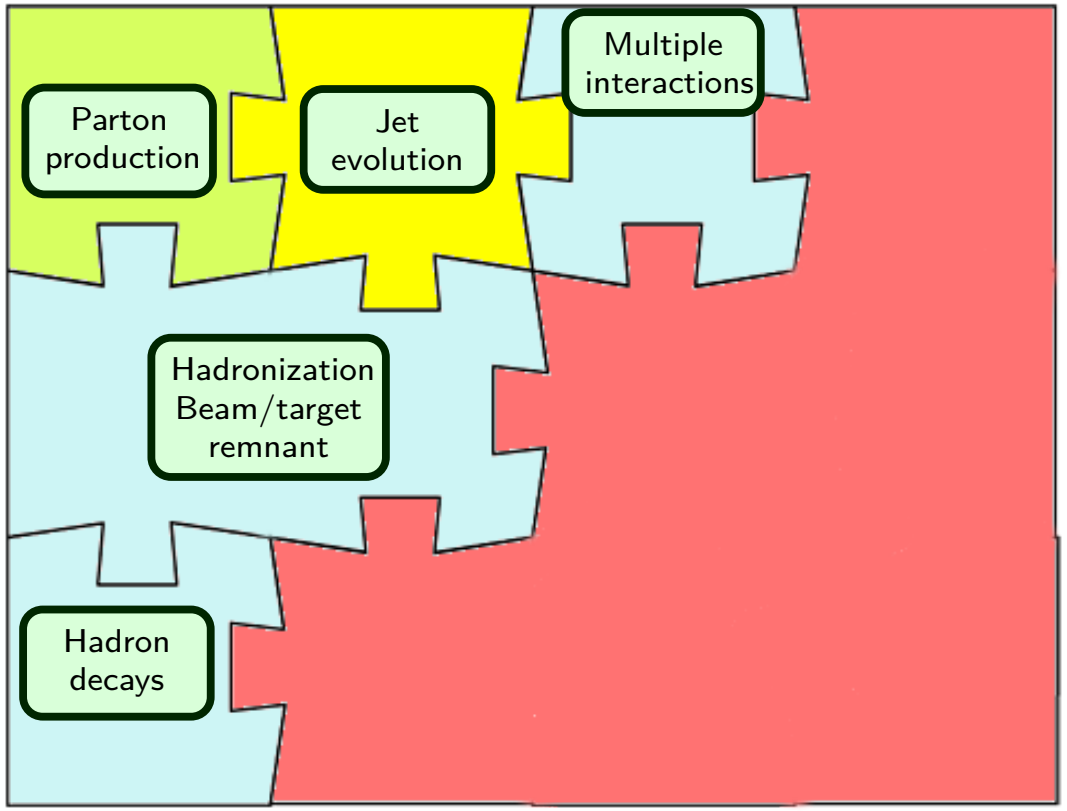
F: (W … PYTHIA 8 vs. ATLAS. … ional task (see Stefan …

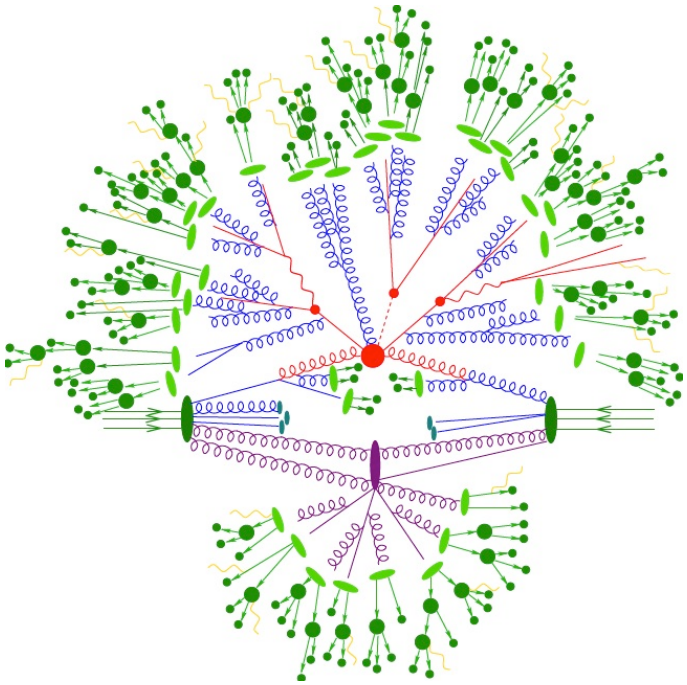
F: Hardest jet in W-production events in CMS. Massive computational task (see Stefan Höche's talk).

Pieces of the MC puzzle

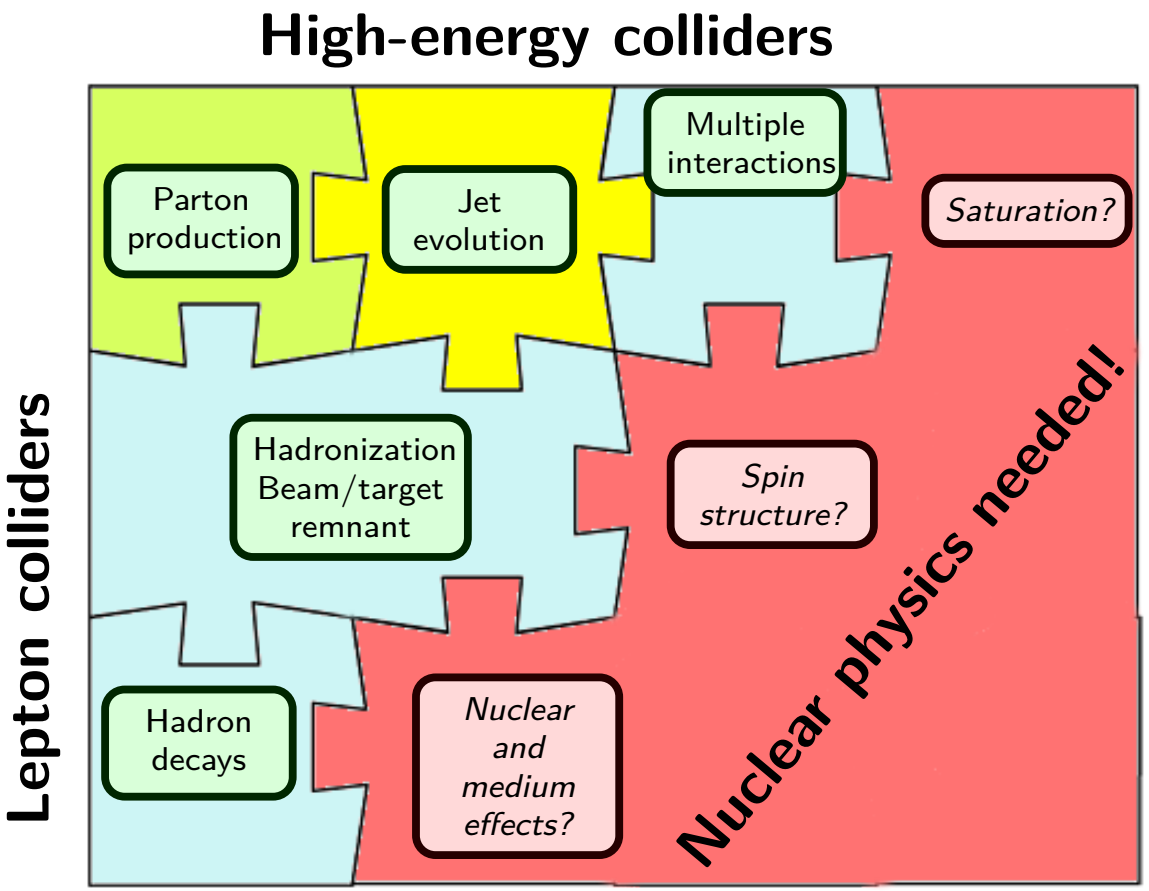
High-energy colliders

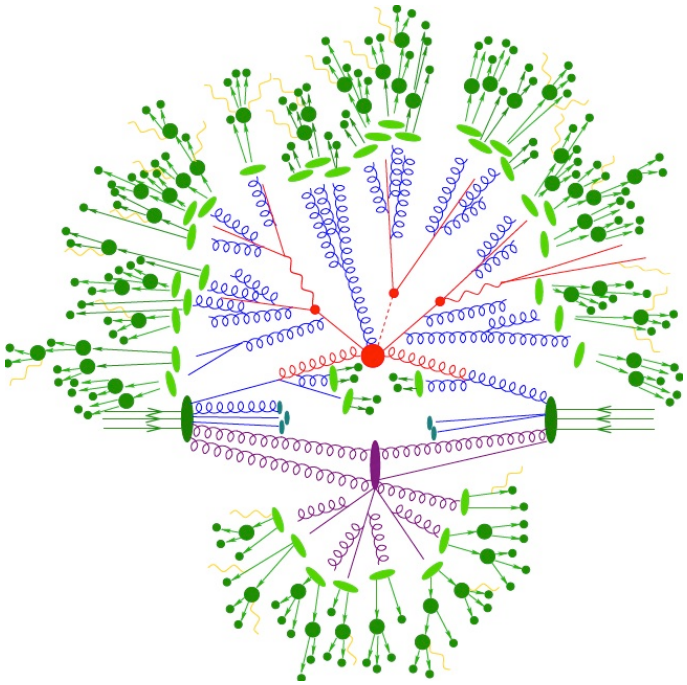
Lepton colliders





Pieces of the MC puzzle

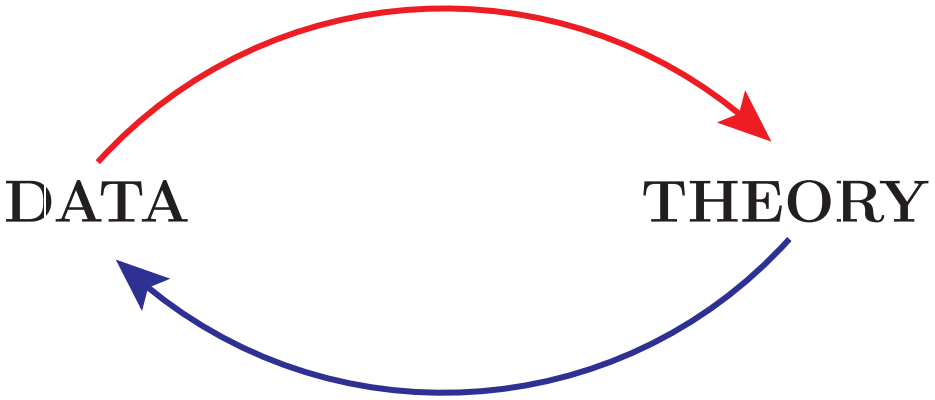




Feedback loop between data and theory

Realistic model? New phenomena?

Improvements necessary?



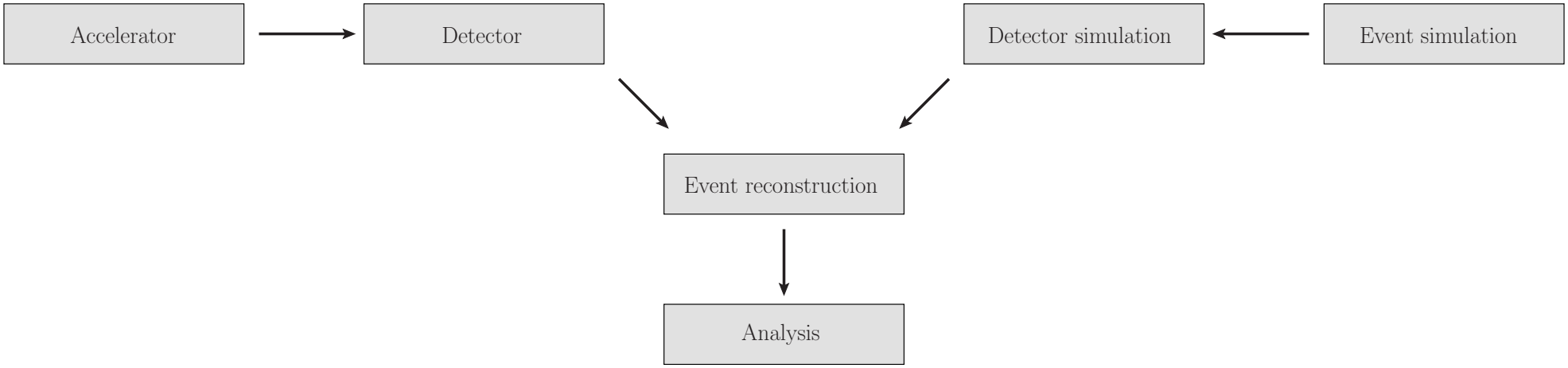
What are sensible measurements?

What are new predictions?

Crucially relies on ability to compare Monte Carlo and data!

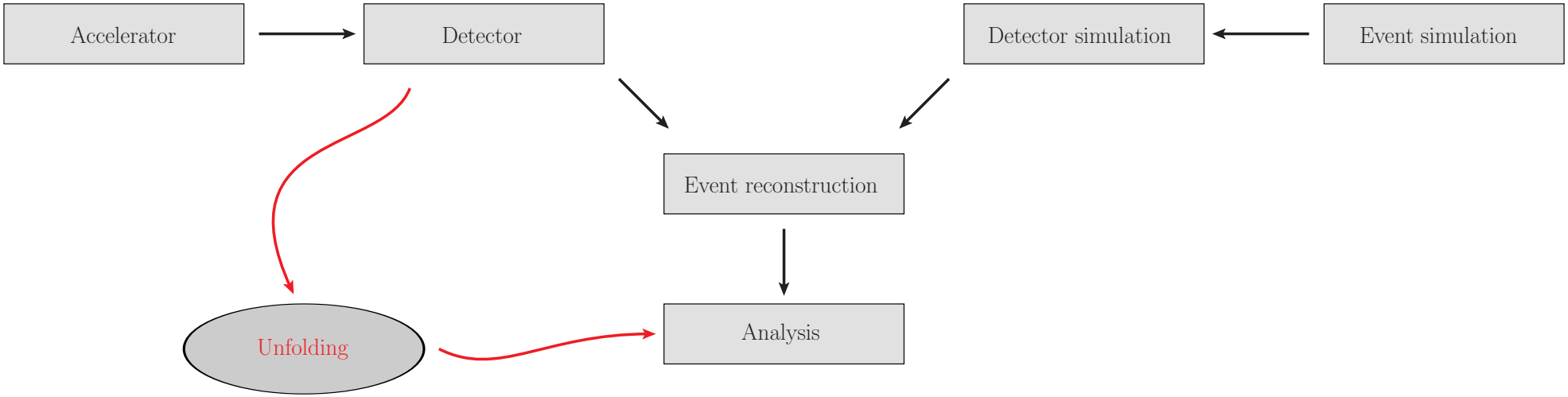
Data parametrizations may only enter MC if theory cannot provide a model. $\Rightarrow$ Monte Carlo tuning
Data must eventually lead to better theory.

Comparing MC and data



To compare theory and data, we need to simulate all effects entering the data.

Comparing MC and data



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This is never fully possible for an outsider.
Gold standard: Unfolded data $\Rightarrow$ Detector details irrelevant.

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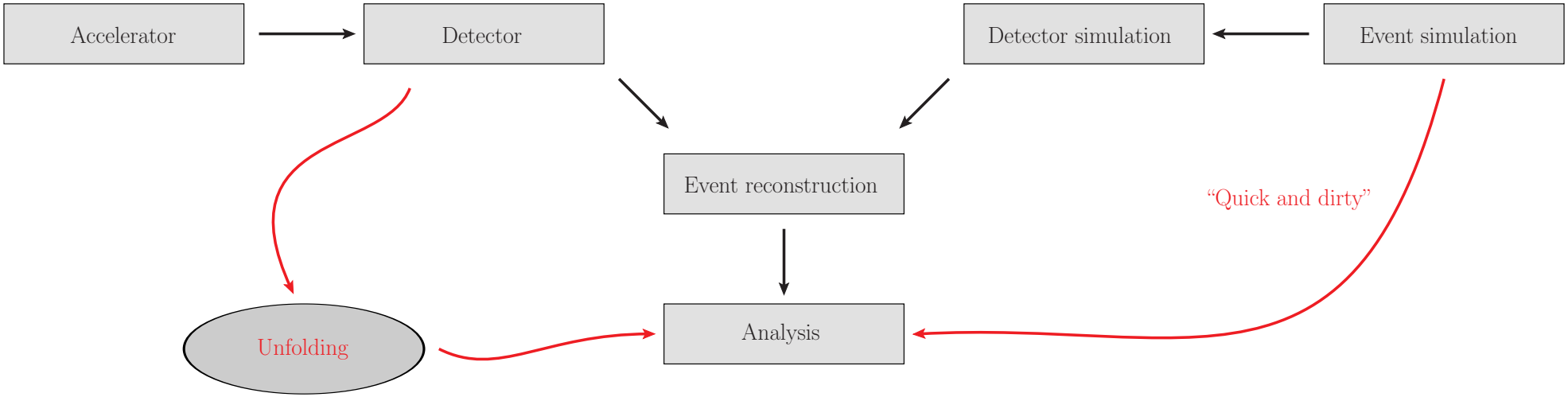

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What if simulation does not match data?
Need fast open-source analysis framework for quick progess.

Lessons from LHC

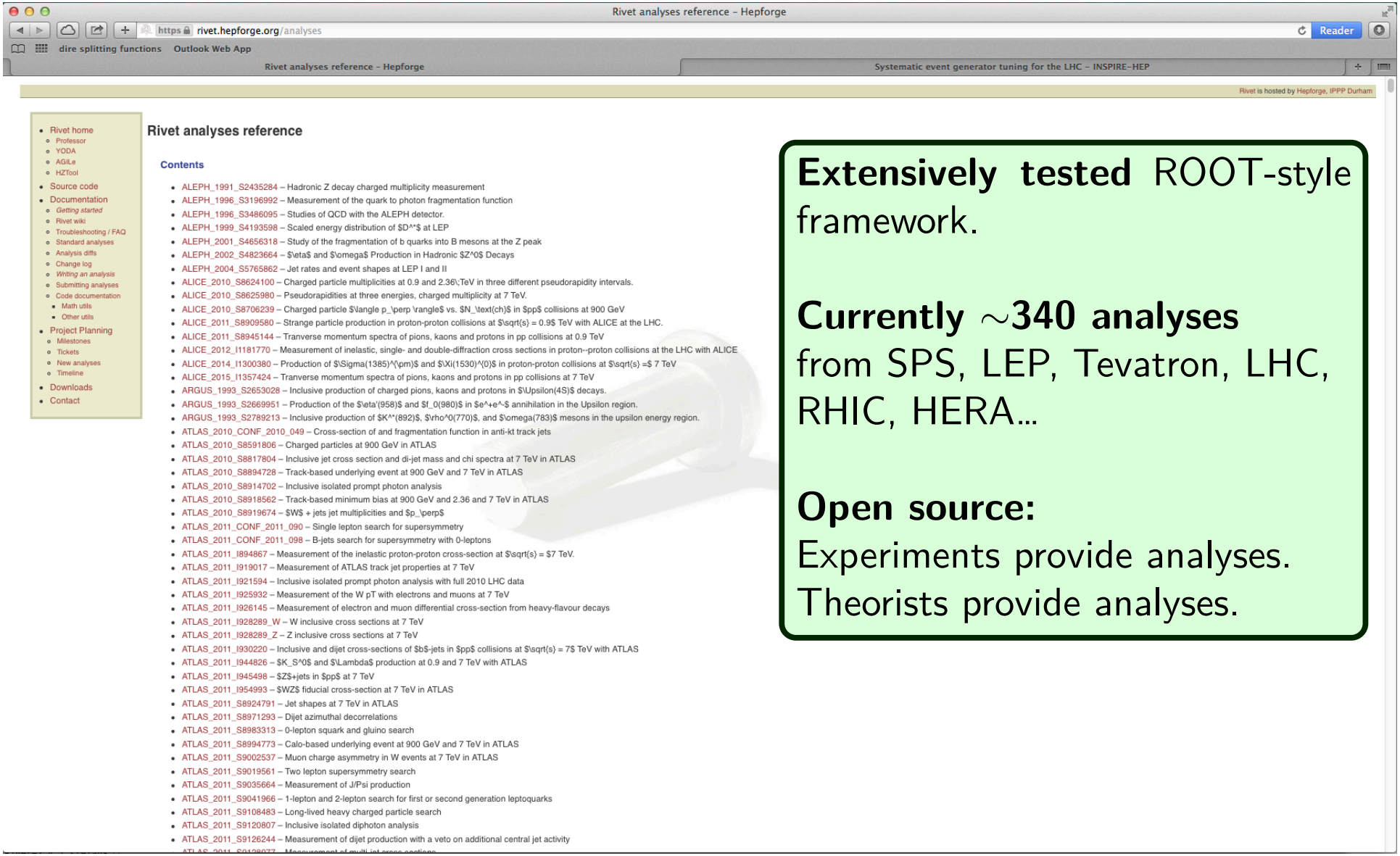
The progress of perturbative QCD initiated by the LHC relies on

- Unfolded data
- Standardized interfaces (HEPEVT, HepMC)
- Open-source analysis software used/developed by both experiment and Monte Carlo (RIVET, PROFESSOR)

$\Rightarrow$ Quick turnaround possible $\Rightarrow$ Fast progress

(Note: RIVET offers some "MC smearing" structures if unfolded data is definitely impossible)

The RIVET analysis repository

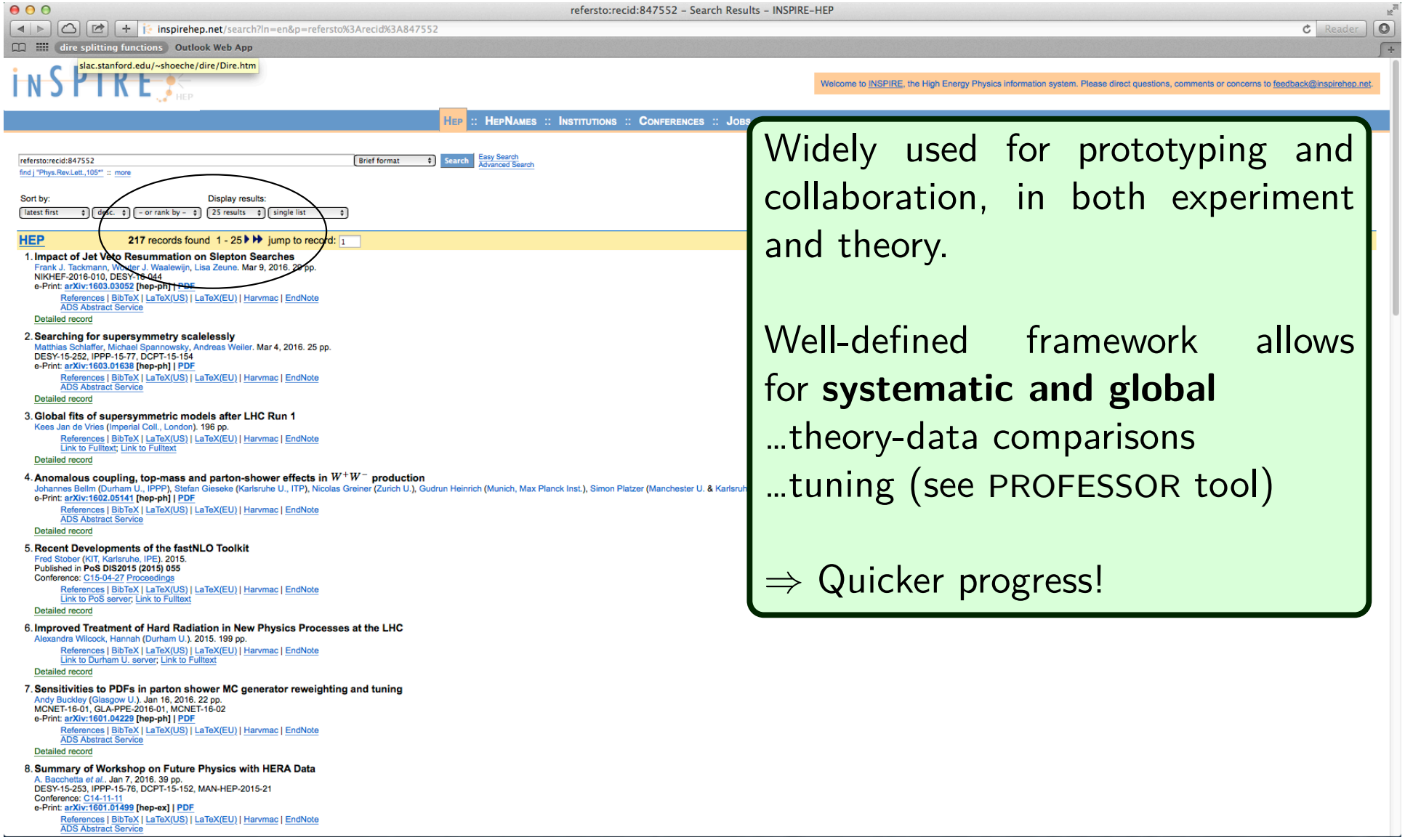


Extensively tested ROOT-style framework.

Currently ∼340 analyses from SPS, LEP, Tevatron, LHC, RHIC, HERA...

Open source:
Experiments provide analyses.
Theorists provide analyses.

The RIVET analysis repository



Widely used for prototyping and collaboration, in both experiment and theory.

Well-defined framework allows for **systematic and global**
…theory-data comparisons
…tuning (see PROFESSOR tool)

⇒ Quicker progress!

Conversation problems

Experimentalist: Something is wrong (in this plot).

Theorist: What version are you using? My version looks fine.

Experimentalist: Running version 0.VERY.OLD, and cannot run a newer version. What was wrong?

Theorist: A explains it. Thanks for reporting. Please update.

Experimentalist: Thanks.

Outcome:
Information gets lost, same question asked many years later.
Start from beginning.

Theory feedback through papers (or emails) is not enough.
$\Rightarrow$ **Make calculations and plots publicly accessible!**

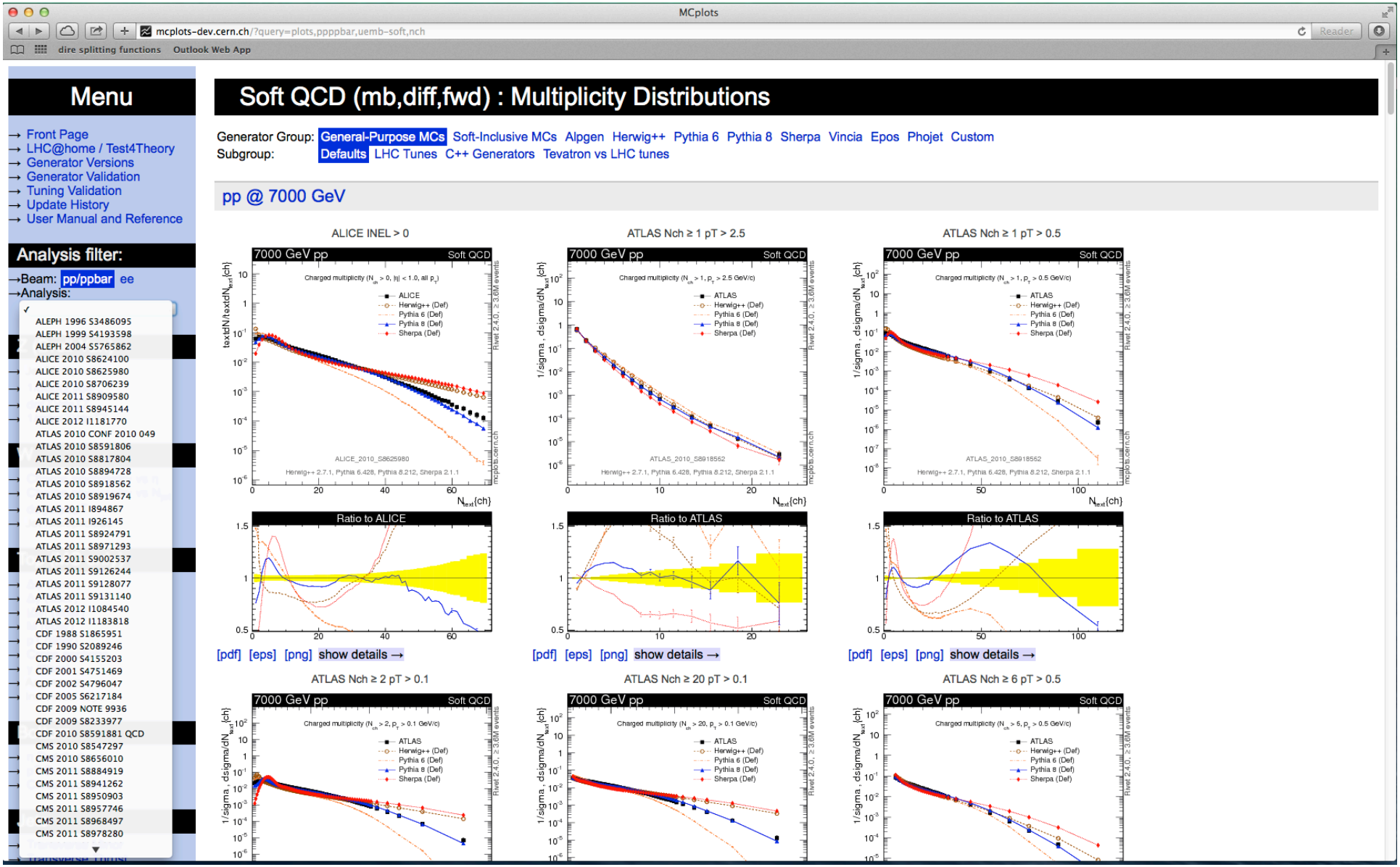
mcplots.cern.ch

Idea: Generate plot ASCII files, store in online data base.
Make plots available at (and generate on) web page.
Different views of plots to highlight changes over time.

Important as reference, but not time-critical.
$\Rightarrow$ Realization through volunteer computing.

Danger: Human intervention needed when new analysis or new generators are included. Needs to be up-to-date.

mcplots is powered by Rivet analysis repository



mcplots as an example plot generator

MCplots

mcplots.cern.ch/?query=frontpage

dire splitting functions Outlook Web App

Menu

- Front Page
- LHC@home / Test4Theory
- Generator Versions
- Generator Validation
- Tuning Validation
- Update History
- User Manual and Reference

Analysis filter:

→Beam: pp/ppbar ee
→Analysis:

Z (Drell-Yan)

- 1/σdσ(Z)/dφ*η
- dσ(Z)/dpTZ
- 1/σdσ(Z)/dpTZ

W

- Charge asymmetry vs η
- dσ(jet)/dpT
- Jet multiplicity

Top (MC only)

- Δφ (ttbar)
- Δy (ttbar)
- |Δy| (ttbar)
- M (ttbar)
- pT (ttbar)
- Cross sections
- y (ttbar)
- Asymmetry
- Individual tops

Jets

- Transverse Minor
- Transverse Thrust
- Di-jet χ
- Di-jet Δφ
- Di-jet mass
- HT
- Jet Fragmentation
- Differential Jet Shape
- Integral Jet Shape
- 3-jet mass
- dσ(jet)/dpT
- Jets + Veto
- Jet Multiplicities

Underlying Event

- AWAY
- TRNS
- TWRD
- Δφ Distribut

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Soft QCD

- <pT> vs No
- Forward en
- Forward en
- η Distributio
- Rapidity gap
- Rapidity Ga
- Multiplicity D
- pT Distributi
- Σ(ET)
- Σ(ET) vs No
- Σ(pT)
- Diffractive ξ
- Cross secti
- FB Correlations

mcplots.cern.ch

December 2015 - P. Skands, I. Charalimpidis, A. Karneyeu, D. Konstantinov, M. Mangano, L. Mijovic, S. Prestel

Reference: Eur Phys J C74 (2014) 1 (arXiv:1306.3436)

New! donate your unused CPU cycles to mcplots, via the Test4Theory project (based on LHC@home).

← Select beam, process, and observable

Navigate these pages by using the menu to the left. The default for each topic is a comparison of a small number of models to available data, but look for links at the top of each page for comparisons with more tunes/generators. Scroll down each page to see plots at other collider energies. To choose specific generator version(s), use the Generator Versions link towards the top of the menu (the default is to just display the most recent ones). More plots will be added, as new tunes become available, and as the available data increases.

Note: *For a description in layman's terms, and/or to find out how to donate your unused CPU cycles to help generate more statistics for mcplots see the Test4Theory project, the first volunteer cloud computing project to be based on Virtual Machines via the LHC@home platform.*

MCPLOTS

MCPLOTS is intended as a simple browsable repository of MC (Monte Carlo) plots comparing High Energy Physics event generators to a wide variety of available experimental data, for tuning and reference purposes. Apart from individual plots contained in papers and presentations, there has so far not been any central database where people can quickly see how tune X of version Y of generator Z looks on distribution D. The idea with mcplots is to provide such a repository, mainly based on the Rivet analysis tool.

On each page, selected by clicking in the menu on the left, you will see a number of plots at different collider energies, comparing a set of default generators/tunes to each other and to the data (if there is any). If data for several different fiducial cuts are available at the same energy, these will be arranged horizontally. At the top of the page, you can select other generator/tune groups. The default ("Main") is a comparison of the main generators. Each additional tab then gives access to illustrations of more specialized tunes/variations for each generator.

The millions of different possible combinations of beam energies, cuts, generators, versions, and tunes, means that a lot of attention has been paid to how to simplify the site, in particular how to organize the site visually, and how to minimize the number of user clicks/inputs required to get what you want. The current site is based on a prototype developed by P. Skands in the context of workshops in Les Houches and Perugia [LH08 , Ska10], but obviously it also draws heavily on the lessons and tools developed as part of the JetWeb project, in particular the Rivet analysis tool. The result is intended to look and feel much like any old-style browsable/clickable set of pages, with the more advanced technologies it is based on having been hidden 'under the hood', for the most part.

Ultimately, we aim to include a possibility for more interactive use of the site, with a special "USER" generator/tune group in which users can compose their own comparisons and even upload their own files for overplotting.

Missing an Interesting Plot / Tune / Generator?

Write to P. Skands (peter.skands.AT.cern.ch) if you are interested in adding more analyses, distributions, generators, tunes, etc to this site. We have endeavoured to make this as easy as possible.

- If your plot is based on Rivet , the procedure is almost automatic, with the user just having to furnish a few additional pieces of information.
- If you want to add a new generator, this requires a little bit more work.

While we are working on full documentation on how to do this, just write to us for information on how to get your favourite plot / tune / generator up on this site.

Problems with the Site?

Write to A. Karneyeu (anton.karneyeu.AT.cern.ch) if you are experiencing technical problems with this site, or to report problems with interpreting the contents of the site, such as menu names, insufficiently labeled cuts or plots, ranges, etc.

Support

The MCPlots site is being developed with participation by

- The CERN Theory Group

lo network
vices project
s Center (LPCC)
support development and integration of new features / new analyses / new tools on the site.
ands.AT.cern.ch) if you have a project to propose and would be interested in a short-term stay at CERN.

Like 4

mcplots as an example plot generator

mcplots to assess the quality of the theory

MCplots

mcplots.cern.ch/?query=valid%2C%2C%2C%2C%2C%2Cpythia8--default&vers%5B%5D=8.212&vers%5B%5D=8.201&vers%5B%5D=8.180&vers%5B%5D=8.160&vers%5B%5D=8.142

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Menu

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Generator / Tune

- → alpgenpythia6
- → epos
- → herwig++
- → herwig++powheg
- → phojet
- → pythia6
- → pythia8
  - → default
  - → default-CD
  - → default-DL
  - → default-MBR
  - → default-noCR
  - → default-noFsr
  - → default-noRap
  - → early
  - → hoeth
  - → jetset
  - → montull
  - → tune-1
  - → tune-2c
  - → tune-2m
  - → tune-4c
  - → tune-4cx
  - → tune-A14-CTEQL1
  - → tune-A14-MSTW2008LO
  - → tune-A14-NNPDF2.3LO
  - → tune-A2
  - → tune-A2m
  - → tune-AU2
  - → tune-AU2ct10
  - → tune-AU2lox
  - → tune-AU2loxx
  - → tune-AU2m
  - → tune-AZ
  - → tune-cmw
  - → tune-CUETP8S1
  - → tune-fischer1
  - → tune-fischer2
  - → tune-monash13
  - → tune-monashstar

Generator Validation

Note: this view is still in a development stage. Exercise care and common sense when interpreting results.

Use this view to look for changes between generator versions (technical validation). For each version, it can also be used as a condensed summary of the overall quality of the description of the various categories of data (physics validation).

Numbers in the tables correspond to chi2 values. To make them more physically meaningful, the MC predictions are assigned a flat 5% 'theory uncertainty', as a baseline sanity limit for the achievable theoretical accuracy with present-day MC models. A few clear cases of GIGO are excluded, but some problematic cases remain. Thus, e.g., if a calculation returns a too small cross section for a dimensionful quantity, the corresponding chi2 value will be large, even though the shape of the distribution may be well described. It could be argued how this should be treated, how much uncertainty should be allowed for each observable, whether it is reasonable to include observables that a given model is not supposed to describe, etc. These are questions that we do not believe can be meaningfully (or reliably) addressed by a fully automated site containing tens of thousands of model/observable combinations. In the end, the interpretation of the information we display is up to you, the user.

← *Select which generator / tune you want to see the validation view for, or go back to the normal mcplots view.*

Versions: ☑8.212 ☐8.210 ☐8.209 ☐8.205 ☑8.201 ☐8.186 ☐8.185 ☐8.183 ☑8.180 ☐8.176 ☐8.175 ☐8.170 ☐8.165 ☐8.163 ☐8.162 ☑8.160 ☐8.153 ☐8.150 ☐8.145 ☑8.142 ☐8.135 ☐8.130.p1 ☐8.108.p1

Display

Process Summary

(click on numbers to see individual observables)

$\langle\chi^2\rangle$ incl. 5% "theory uncertainty" on all points	min / max	8.212	best / worst	<Δ>	min / max	8.201	best / worst	<Δ>	min / max	8.180	best / worst	<Δ>	min / max	8.160	best / worst	<Δ>	min / max	8.142
ee → Z (hadronic)	0.00089 / 8.5	1.1	-0.57 / +0.27	0	0.00087 / 8.5	1.1	-6.7 / +3.5	-0.100	0.0011 / 13	1.2	-0.39 / +0.60	0	0.0020 / 13	1.2	-1.6 / +0.62	0	0.0028 / 13	1.2
pp/ppbar → Elastic	15 / 23	19	-0.42 / [illegible]	[illegible]	15 / [illegible]	[illegible]	-0.019 / [illegible]	[illegible]	15 / 23	19	-0.011 / 0	0	15 / 23	19	-0.099 / 0	0	15 / 23	19
pp/ppbar → Jets	0.000 / 85	2.[illegible]	[illegible]	[illegible]	[illegible] / [illegible]	[illegible]	[illegible] / [illegible]	[illegible]	0.00010 / 84	2.3	-3.6 / +3.1	0	0.00016 / 83	2.3	-3.6 / +13	0	0.00056 / 83	2.3
pp/ppbar → Total σ	2.0 / 2.0	2.[illegible]	[illegible]	[illegible]	[illegible] / [illegible]	[illegible]	[illegible] / [illegible]	[illegible]	2.0 / 2.0	2.0	-0.0000100 / -0.0000100	0	2.0 / 2.0	2.0	+0.0000100 / +0.0000100	0	2.0 / 2.0	2.0
pp/ppbar → Top (MC only)												0				0		
pp/ppbar → Underlying Event	0.07 / 22	1.8	-0.30 / +0.75	2.1	[illegible] / 22	[illegible]	-0.40 / +2.0	[illegible]	0.024 / 27	2.5	-4.1 / +2.5	+0.10	0.025 / 26	2.4	-17 / +4.3	-2.4	0.024 / 34	4.8
pp/ppbar → Soft QCD (mb,diff,fwd)	0.000061 / 6.0	6.0	-50 / -0.50	6.5	0.000061 / 6.5	6.5	-23 / +0.20	+0.20	0.000061 / 6.3	6.3	-6.6 / +0.20	+0.20	0.000061 / 6.1	6.1	-33 / -3.6	-3.6	0.000061 / 9.7	9.7

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mcplots to isolate issues with a few clicks

MCplots

mcplots.cern.ch/?query=validdetail,ppppbar,elastic,,,,pythia8--default--8.212--data

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  - → tune-fischer2
  - → tune-monash13
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Detail for Pythia 8 (Def) 8.212

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pp/ppbar → Elastic

Observable	Cut	Energy	χ^2
Cross sections	TOTEM Elastic	7000	23
	TOTEM Elastic	7000	n/a*
	TOTEM Elastic	7000	15

* not applicable: because number of bins of data ... f bins of theory histogram

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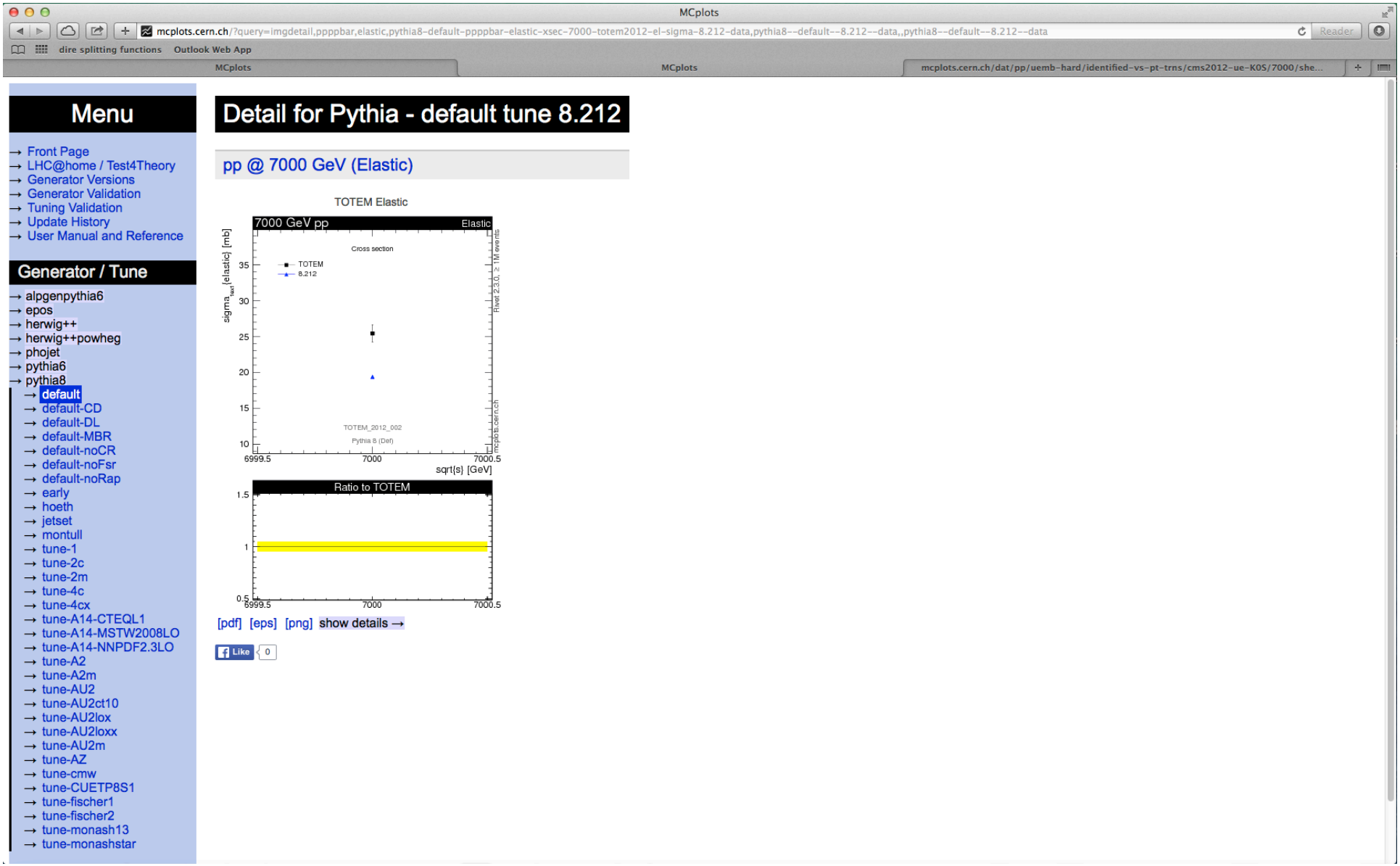
mcplots to isolate issues with a few clicks



mcplots was the first running project on LHC@home

Test4Theory | LHC@home

lhcathome.web.cern.ch/projects/test4theory

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LHC@home
Volunteer computing for the LHC

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Home / Projects / Test4Theory

Test4Theory

Welcome to Test4Theory (also known as "Virtual LHC@home" or "LHC@home 2.0" according to the evolutions of our technology!)

The Test4Theory project allows volunteers to run simulations of high energy particle collisions on their home computers. These simulations use theoretical models based on the Standard Model of particle physics, and are calculated using Monte Carlo methods. The theoretical models have adjustable parameters and the aim is that a given set of parameters (called a "tune") will fit the widest possible range of experimental results.

The Test4Theory results are therefore submitted to a database which contains a very wide set of experimental data from many accelerator experiments worldwide, including of course experiments at the Large Hadron Collider at CERN. The database and the theoretical fitting process is part of the project MCPLots, based in the Theory Unit at CERN.

Further information can be found on the links top right of this page.

Test4Theory

- High Energy Physics simulations
- Meet the Test4Theory team
- BOINC site

Test4Theory on the web

- T4T Leaderboard
- MC Production
- MC Plots

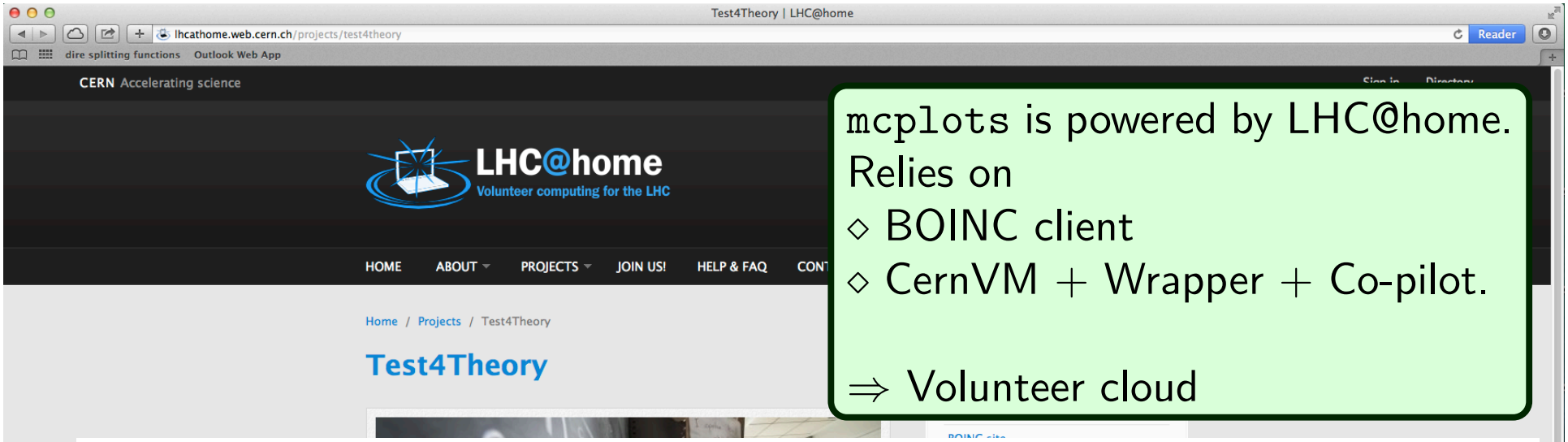
Want to participate?

Join Us

Articles on Test4Theory

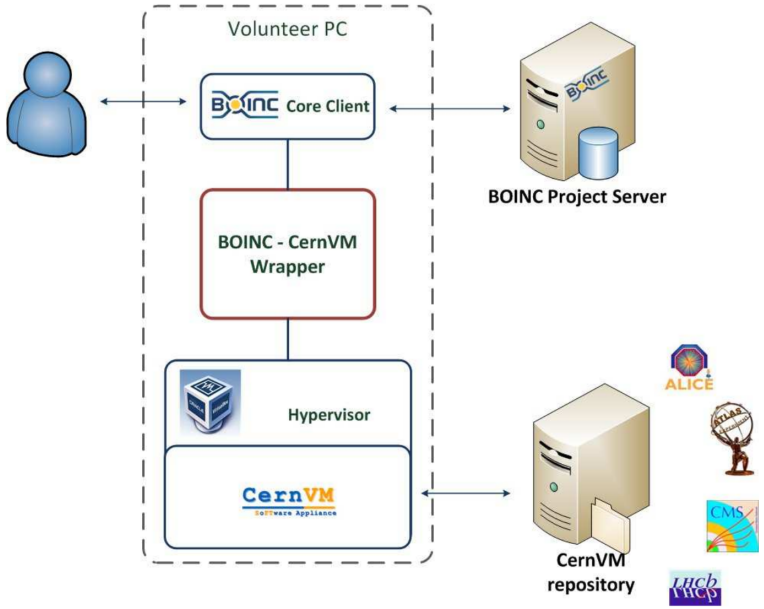
CERN 60 year computing challenge | *10 Dec 2014*
The virtual collider programs we run | *14 Nov 2014*

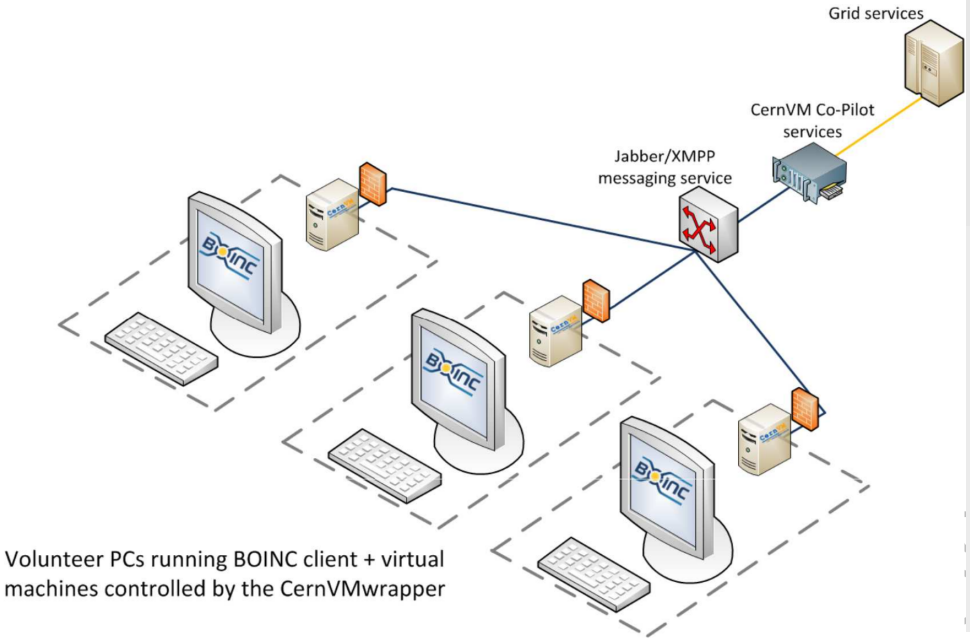
mcplots was the first running project on LHC@home



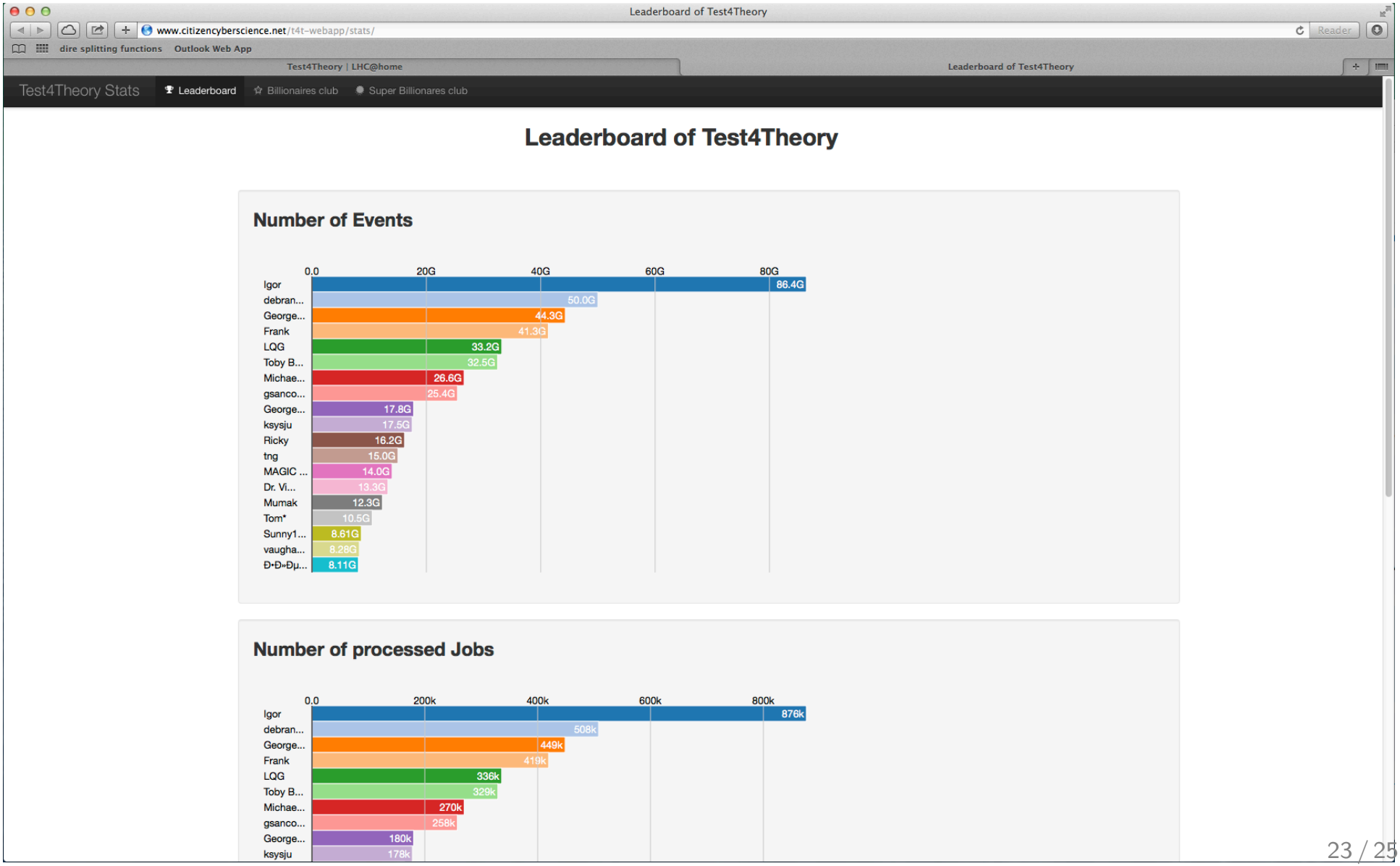
mcplots is powered by LHC@home.
Relies on
- ◇ BOINC client
- ◇ CernVM + Wrapper + Co-pilot.

⇒ Volunteer cloud





Volunteer computing = no deadline computing, but very important for long-lived database



Volunteer computing is excellent to engange public

Bigger Boson

lhcathome2.cern.ch/vLHCathome/forum_thread.php?id=1742

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tullio Send message Joined: 28 Nov 10 Posts: 1527 **MCPLOT stats** Jobs: 26.73k Events: 2.490552G BOINC stats Credit: 1,331,914 RAC: 650	Message 19756 - Posted: 17 Dec 2015, 18:56:32 UTC theregister.co.uk and the NYTimes carry news about a possible bigger boson (a graviton?) with a 750 GeV mass found in the data of both Atlas and CMS. Is it real? Tullio ID: *19756 · Rating: 0* · rate: / Reply Quote
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Summary

- Monte Carlo is implementation of theory.
  Needs to be seen and designed as knowledge vessel.
- Theory must be compared against data.
  Need standardized analysis tools to do that!
- Open-source analysis frameworks needed for quick turnaround.
- Theory needs to provide detailed feedback
  ...not only through papers
  ...through code and open access repositories.
  Volunteer clouds possible for such non-urgent HTC tasks.