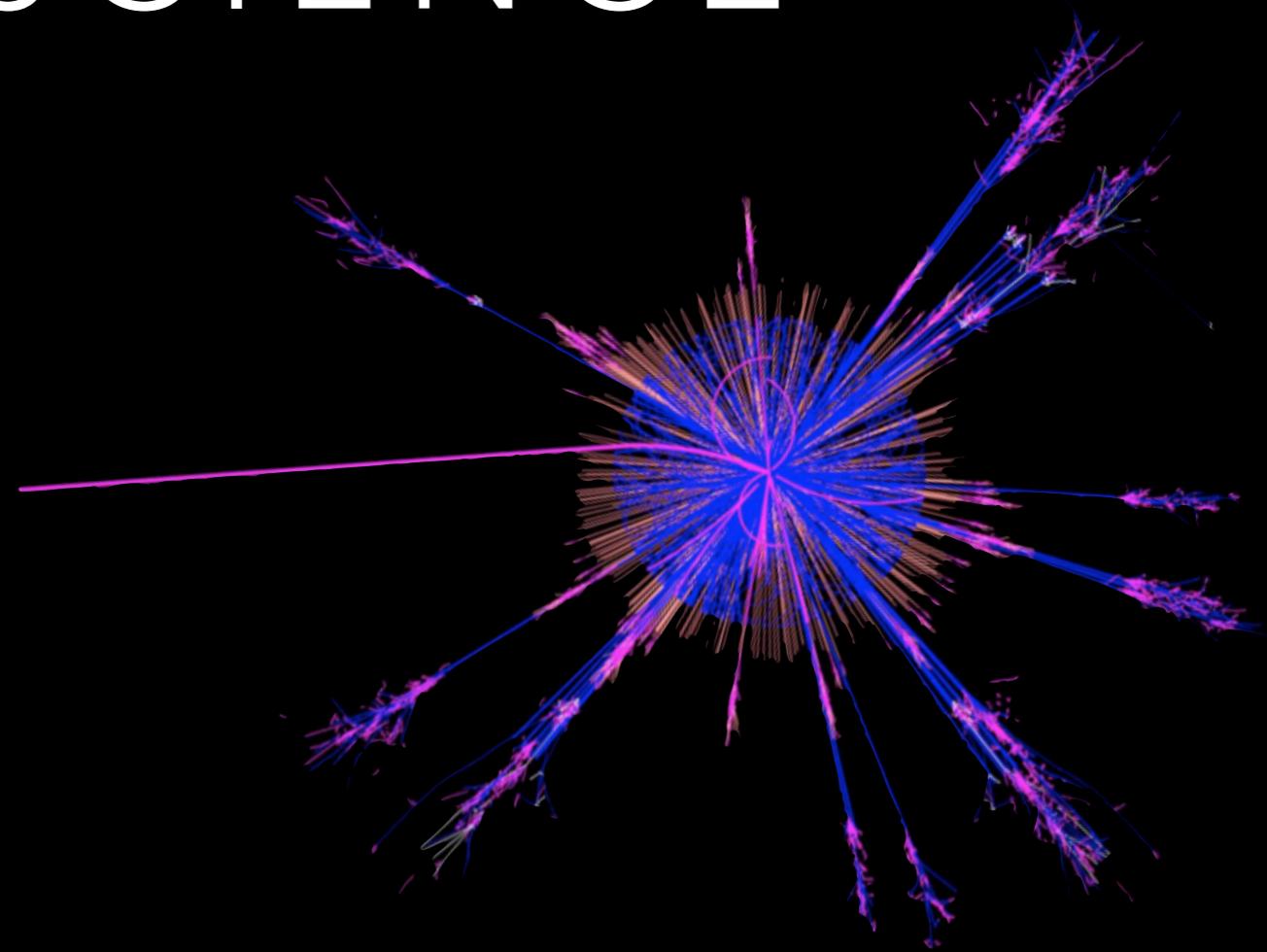




CYBERINFRASTRUCTURE FOR
HIGH-LEVEL SCIENCE
GOALS

@KyleCranmer
New York University
Department of Physics
Center for Data Science

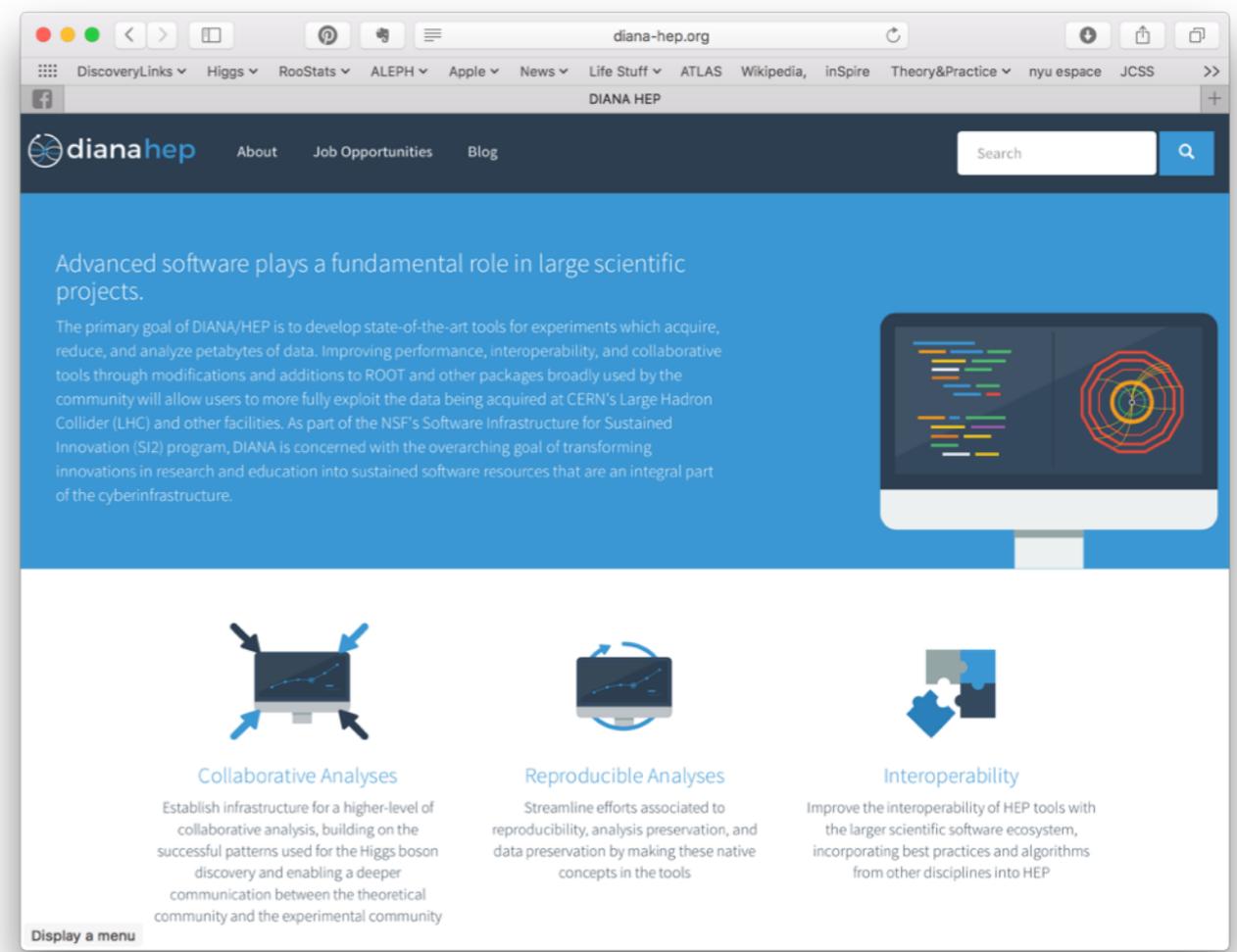
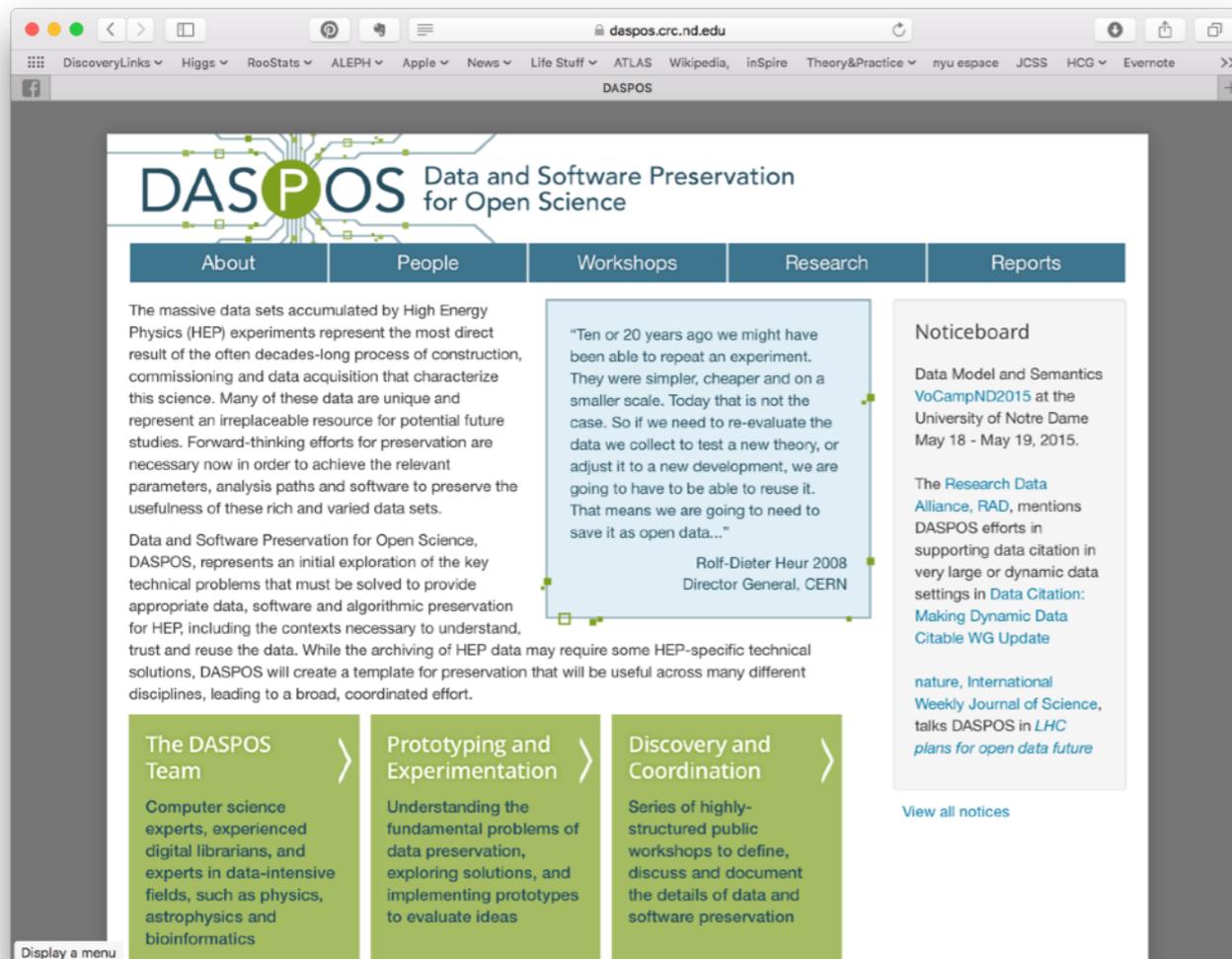


Infrastructure Components

DASPOS AND DIANA

DASPOS and DIANA are two large projects funded by the U.S. National Science Foundation focusing on issues around software and data for high energy physics.

We are working closely with CERN Analysis Preservation (CAP) portal, INSPIRE, and HEPData to build infrastructure for High Energy Physics



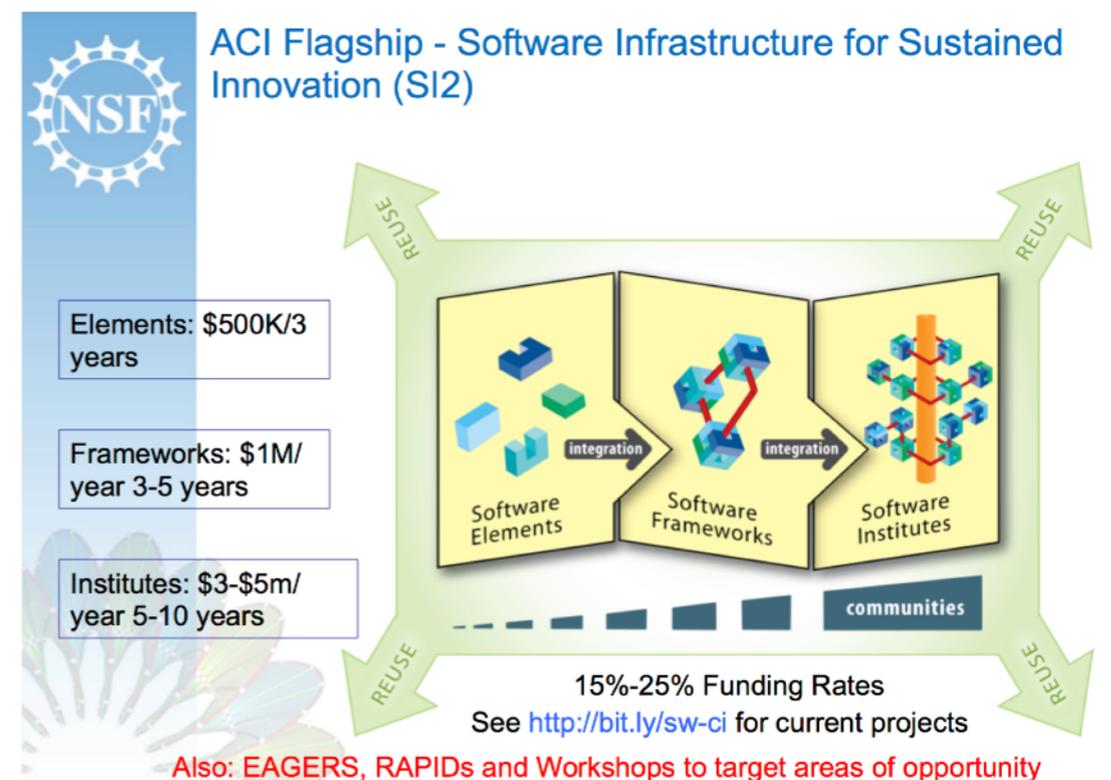
The SI2 program includes four classes of awards:

1. **Scientific Software Elements (SSE)**: SSE awards are Software Elements. They target small groups that will create and deploy robust software elements for which there is a demonstrated need that will advance one or more significant areas of science and engineering.

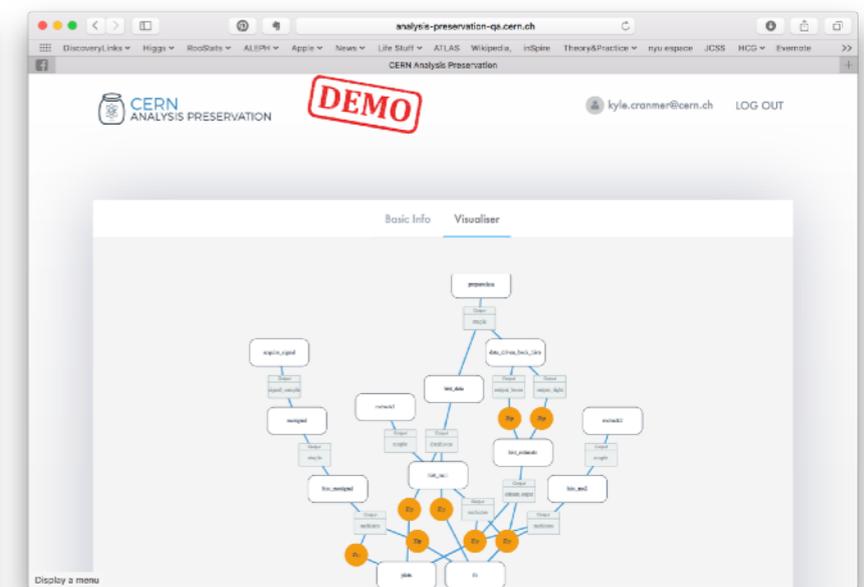
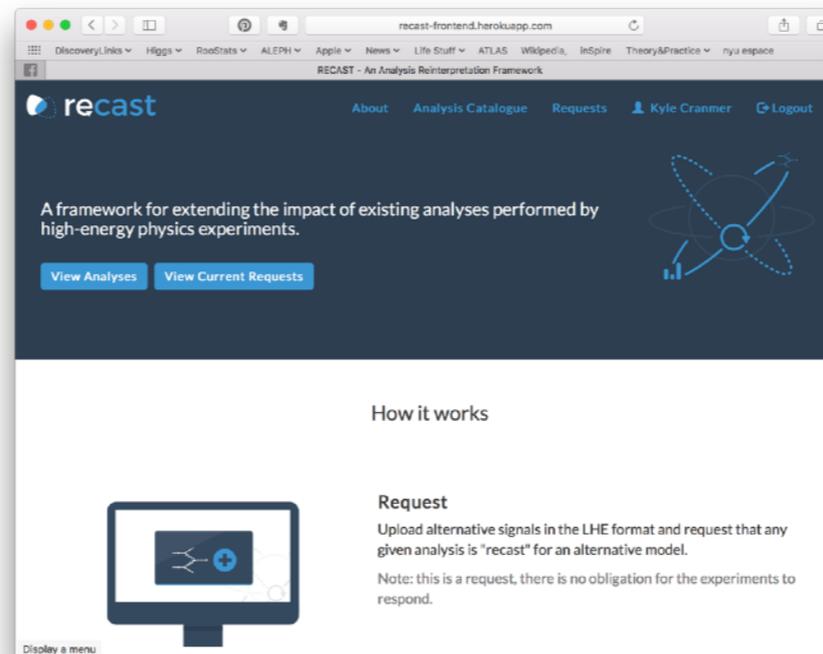
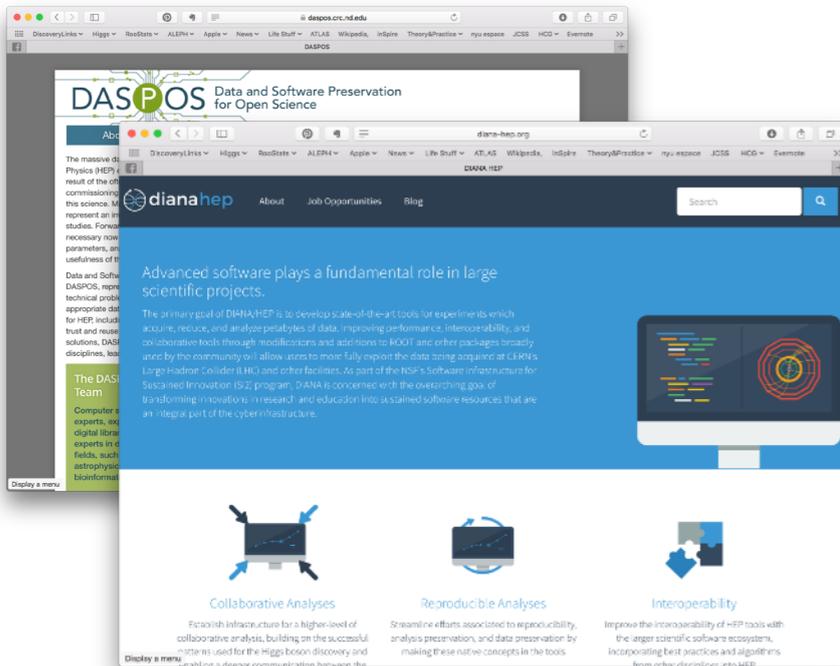
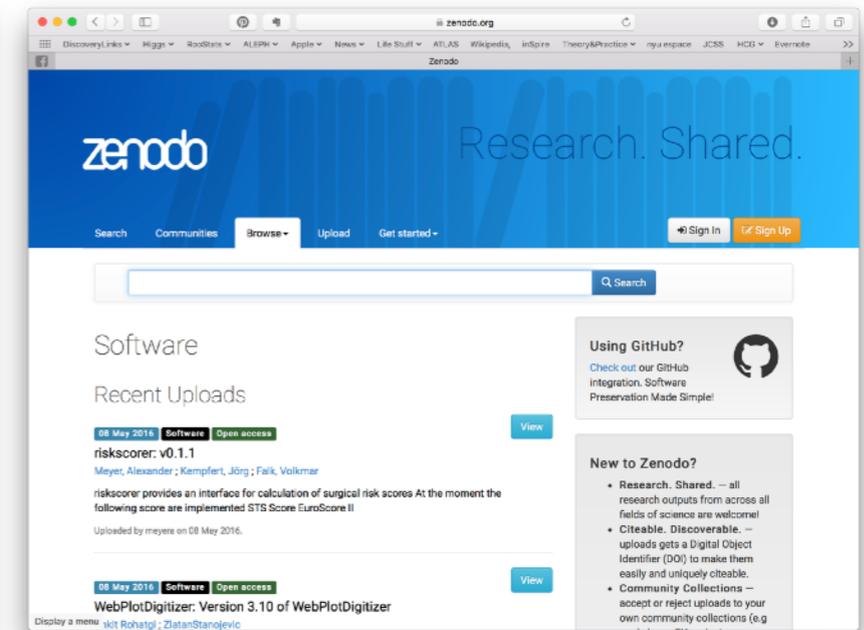
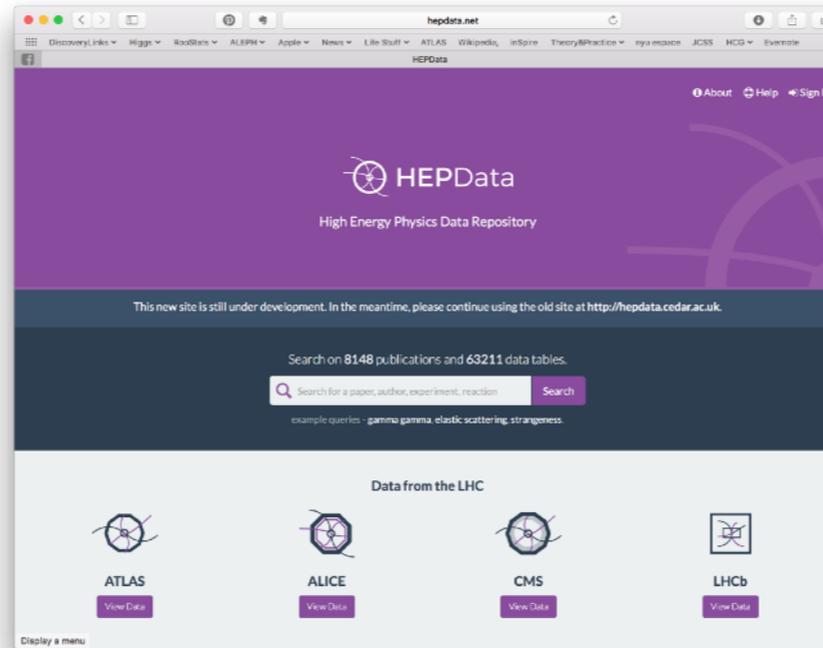
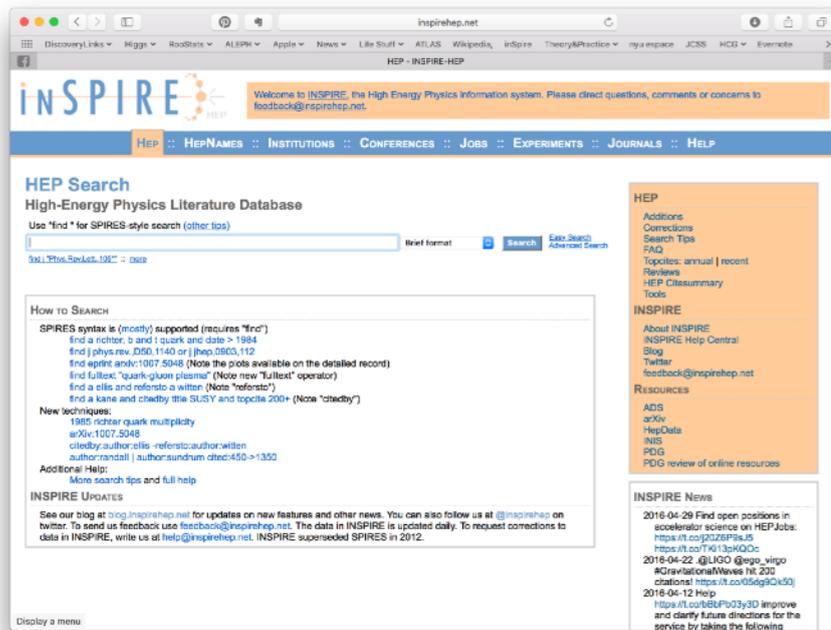
2. **Scientific Software Integration (SSI)**: SSI awards are Software Frameworks. They target larger, interdisciplinary teams organized around the development and application of common software infrastructure aimed at solving common research problems. SSI awards will result in sustainable community software frameworks serving a diverse community. ← DIANA is an SSI

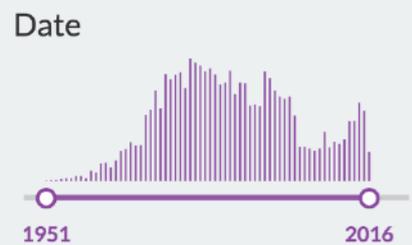
3. **Scientific Software Innovation Institutes (S2I2)**: S2I2 awards are Software Institutes. They focus on the establishment of long-term hubs of excellence in software infrastructure and technologies that will serve a research community of substantial size and disciplinary breadth. ← opens door to this

4. **Reuse**: In addition, SI2 provides support through a variety of mechanisms (including co-funding and supplements) to proposals from other programs that include, as an explicit outcome, reuse of software. Proposals that integrate with previously developed software, either by reference or inclusion, are encouraged. Proposals developing new software with an explicitly open design for reuse may also be considered. The purpose of the Reuse class is to stimulate connections within the broader software ecosystem. The class of reuse awards is currently being developed.



INFRASTRUCTURE FOR DATA AND ANALYSIS PRESERVATION





- Collaboration**
- ATLAS 246
 - CDF 205
 - ZEUS 167
 - CMS 162
 - H1 142
- [Next 5](#) [Show All](#)

- Phrases**
- Exclusive 4187
 - Cross Section 3843
 - Integrated Cross Section 3843
 - Inclusive 3833
 - Single Differential Cross Section 2773
- [Next 5](#) [Show All](#)

- Reactions**
- pp -> pp 314

Production of $K^*(892)^0$ and $\phi(1020)$ in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Adam, Jaroslav ; Adamova, Dagmar ; Aggarwal, Madan Mohan ; *et al.* [The ALICE collaboration.](#)

No Journal Information, 2016.

[Inspire Record 1418181](#)
[DOI 10.17182/hepdata.72807](#)

The production of $K^*(892)^0$ and $\phi(1020)$ mesons has been measured in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. K^{*0} and ϕ are reconstructed via their decay into charged hadrons with the ALICE detector in the rapidity range $-0.5 < y < 0$. The transverse momentum spectra, measured as a function of the multiplicity, have p_T range from 0 to 15 GeV/c for K^{*0} and from 0.3 to 21 GeV/c for ϕ . Integrated yields, mean transverse momenta and particle...

30 data tables

- Table 1** Average charged particle pseudo-rapidity density, $\langle dN_{ch}/d\eta_{lab} \rangle$, measured at mid-rapidity in visible cross section event classes and average number of colliding nucleons, $\langle N_{coll} \rangle$. Multiplicity classes are defined using the VOA estimator; values for $\langle dN_{ch}/d\eta_{lab} \rangle$ are corrected for vertexing and trigger efficiency. Since statistical uncertainties are negligible, only total systematic uncertainties are reported.
 - Table 2** p_T -differential yield of $(K^{*0} + \overline{K}^{*0})/2$ in p-Pb collisions with centre-of-mass energy/nucleon=5.02 TeV (NSD). Additional systematic error: +- 3.1% (normalization).
 - Table 3** p_T -differential yield of $(K^{*0} + \overline{K}^{*0})/2$ in p-Pb collisions with centre-of-mass energy/nucleon=5.02 TeV (0-20% multiplicity class).
- [More...](#)

INVESTIGATION OF INCLUSIVE PROCESSES $\pi^- A \rightarrow \pi^- X$ AND $\pi^- A \rightarrow p$ (backwards) X AT 40-GeV/c

Abrosimov, A.T. ; Albini, E. ; Antipov, V.V. ; *et al.*

Conference Paper, 2016.

[Inspire Record 209961](#)
[DOI 10.17182/hepdata.39782](#)

None

3 data tables

- Table 1 No description provided.

Interactive Plotting Library

momentum for...

Table 9

Data from Auxiliary Material
10.17182/hepdata.72205.v1/t9
Extrapolated charged-particle multiplicity distributions in proton-proton collisions at a centre-of-mass energy of 13000 GeV for events with the number of...

Table 10

Data from Auxiliary Material
10.17182/hepdata.72205.v1/t10
Extrapolated average transverse momentum in proton-proton collisions at a centre-of-mass energy of 13000 GeV as a function of the number...

Table 11

Data from F 5A
10.17182/hepdata.72205.v1/t11
Charged-particle multiplicities in proton-proton collisions at a centre-of-mass energy of 13000 GeV as a function of pseudorapidity for events with...

Table 12

Data from F 5B

Table 10

Extrapolated average transverse momentum in proton-proton collisions at a centre-of-mass energy of 13000 GeV as a function of the number of charged particles in the event for events with the number of charged particles ≥ 1 having transverse momentum > 500 MeV and absolute(pseudorapidity) < 2.5 .

[10.17182/hepdata.72205.v1/t10](http://dx.doi.org/10.17182/hepdata.72205.v1/t10)

observables

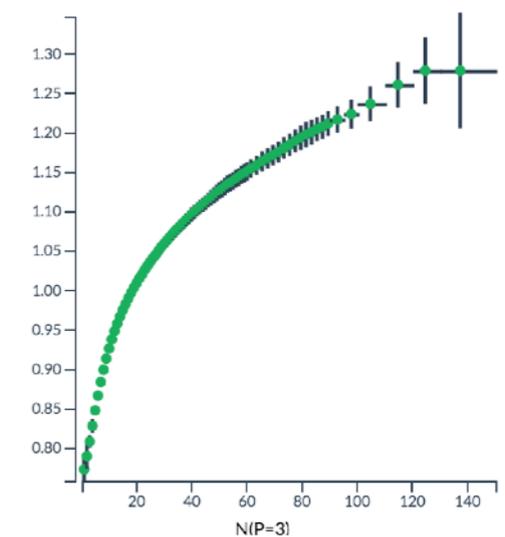
phrases

reactions

Showing 50 of 81 values

ETARAP(P=3)	-2.5-2.5
Extrapolated to include strange baryons	
N(P=3)	≥ 1
PT(P=3)	> 500 MEV
RE	P P --> CHARGED X
SQRTS(S)	13000.0 GeV
N(P=3)	MEAN(NAME=PT(P=3)) [GEV]
0.50 - 1.50	0.7737 ± 0.0008 stat ± 0.0155 sys
1.50 - 2.50	0.7904 ± 0.0007 stat ± 0.0158 sys
2.50 - 3.50	0.809 ± 0.001 stat ± 0.008 sys
3.50 - 4.50	0.8289 ± 0.0006 stat ± 0.0084 sys

Visualize


 Sum errors Log Scale (X) Log Scale (Y)

Abstract (data abstract)

CERN-LHC. Measurements of charged particle distributions in proton-proton collisions at a centre-of-mass energy of 13 TeV. A data sample of nearly 9 million events recorded by the ATLAS detector during a special LHC fill with low beam currents, and thus giving a low expected mean number of interactions, is used. The charged-particle multiplicity, its dependence on transverse momentum and pseudorapidity and the dependence of the mean transverse momentum on the charged-particle multiplicity are presented. The measurements are performed with charged particles with transverse momentum greater than 500 MeV and absolute pseudorapidity less than 2.5, in events with at least one charged particle satisfying these kinematic requirements

Open Data & Preservation



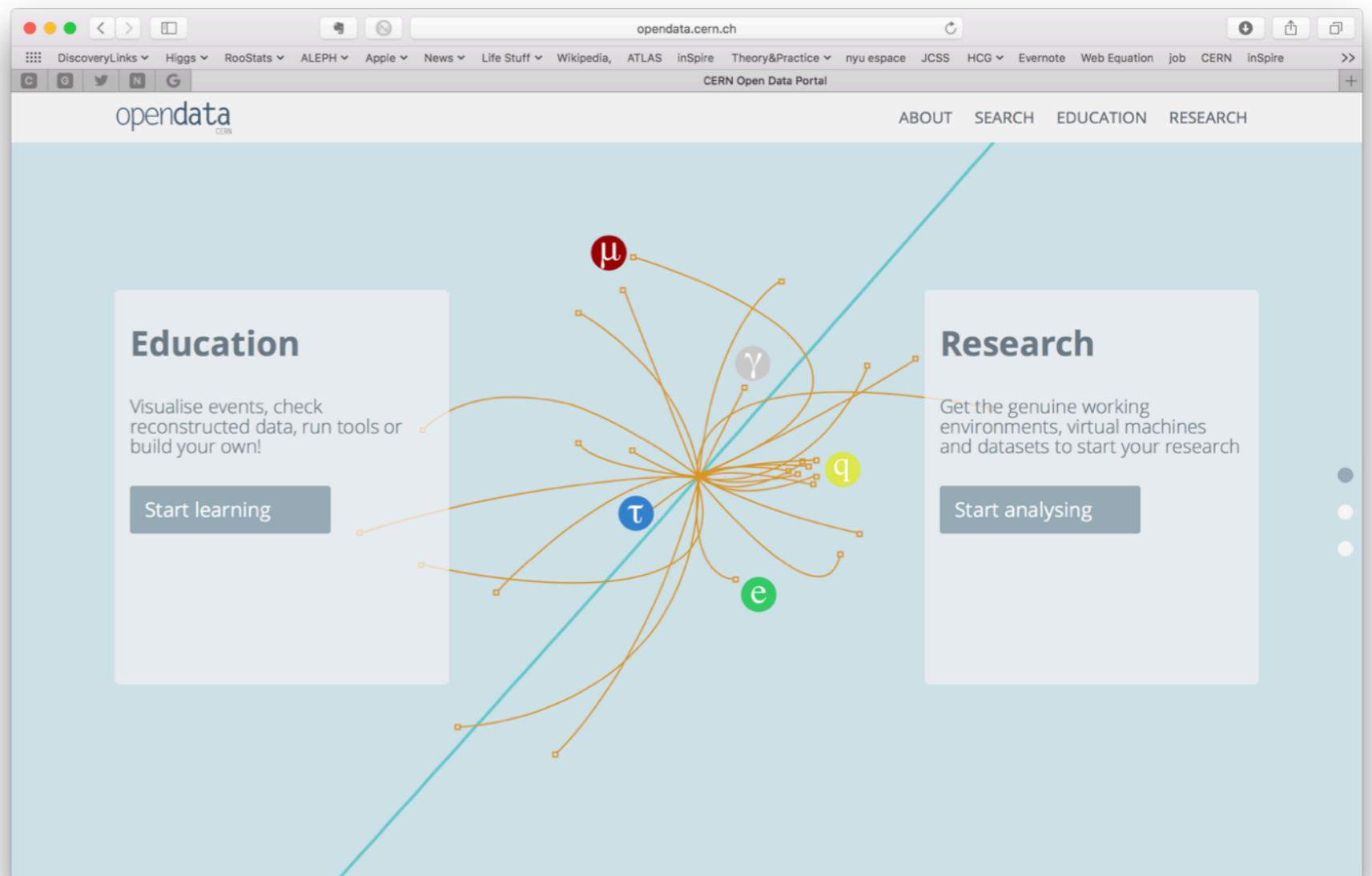
Data Preservation in High Energy Physics

Collaboration for Data Preservation and Long Term Analysis in High Energy Physics

- Partners
- Accelerators
- Meetings
- ICFA Stud

Preservation Model	Use case
1. Provide additional documentation	Publication-related information search
2. Preserve the data in a simplified format	Outreach, simple training analyses
3. Preserve the analysis level software and data format	Full scientific analysis based on existing reconstruction
4. Preserve the reconstruction and simulation software and basic level data	Full potential of the experimental data

Table 3: Various preservation models, listed in order of increasing complexity.



Jet Substructure Studies with CMS Open Data

Aashish Tripathy^{1,*} Wei Xue^{1,†} Andrew Larkoski^{2,‡} Simone Marzani^{3,§} and Jesse Thaler^{1,¶}

¹*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

²*Physics Department, Reed College, Portland, OR 97202, USA*

³*University at Buffalo, The State University of New York, Buffalo, NY 14260-1500, USA*

We use public data from the CMS experiment to study the 2-prong substructure of jets. The CMS Open Data is based on 31.8 pb^{-1} of 7 TeV proton-proton collisions recorded at the Large Hadron Collider in 2010, yielding a sample of 768,687 events containing a high-quality central jet with transverse momentum larger than 85 GeV. Using CMS's particle flow reconstruction algorithm to obtain jet constituents, we extract the 2-prong substructure of the leading jet using soft drop declustering. We find good agreement between results obtained from the CMS Open Data and those obtained from parton shower generators, and we also compare to analytic jet substructure calculations performed to modified leading-logarithmic accuracy. Although the 2010 CMS Open Data does not include simulated data to help estimate systematic uncertainties, we use track-only observables to validate these substructure studies.

From a physics perspective, our experience with the CMS Open Data was fantastic. With PFCs, one can essentially perform the same kinds of four-vector-based analyses on real data as one would perform on collisions from parton shower generators. Using open data has the potential to accelerate scientific progress (pun intended) by allowing scientists outside of the official detector collaborations to pursue innovative analysis techniques. We hope that our jet substructure studies have demonstrated both the value in releasing public data and the enthusiasm of potential external users. We encourage other members of the particle physics community to take advantage of this unique data set.

From a technical perspective, though, we encountered a number of challenges. Some of these challenges were simply a result of our unfamiliarity with the CMSSW framework and the steep learning curve faced when trying to properly parse the AOD file format. Some of these challenges are faced every day by LHC experimentalists, and it is perhaps unreasonable to expect external users to have an easier time than collaboration members. Some of these challenges (particularly the issue of detector-simulated samples) have been partially addressed by the 2011A CMS Open Data release [215]. That said, we suspect that some issues were not anticipated by the CMS Open Data project, and we worry that they have deterred other analysis teams who might have otherwise found interesting uses for open data. Therefore, we think it is useful to highlight the primary challenges we faced, followed by specific recommendations for how potentially to address them.

A. Challenges

Here are the main issues that we faced in performing the analyses in this paper.

- *Slow development cycle.* As CMSSW novices, we often needed to perform run-time debugging to figure out how specific functions worked. There were two elements of the CMSSW workflow that introduced a considerable lag between starting a job and getting debugging feedback. The first is that, when using the XROOTD interface, one has to face the constant overhead (and inconstant network performance) of retrieving data remotely. The second is that, as a standard part of every CMS analysis, one has to load configuration files into memory. Loading `FrontierConditions_GlobalTag.cff` (which is necessary to get proper trigger prescale values) takes around 10 minutes at the start of a run. For most users, this delay alone would be too high of a barrier for using the CMS Open Data. By downloading the AOD files directly and building our own MOD file format, we were able to speed up the

development cycle through a lightweight analysis framework. Still, creating the MODPRODUCER in the first place required a fair amount of trial, error, and frustration.

- *Scattered documentation.* Though the CMS Open Data uses an old version of CMSSW (v4.2 compared to the latest v9.0), there is still plenty of relevant documentation available online. The main challenge is that it is scattered in multiple places, including online TWIKI pages, masterclass lectures, thesis presentations, and GITHUB repositories. Eventually, with help from CMS insiders, we were able to figure out which information was relevant to a particular question, but we would have benefitted from more centralized documentation that highlighted the most important features of the CMS Open Data. Centralized documentation would undoubtedly help CMS collaboration members as well, as would making more TWIKI pages accessible outside of the CERN authentication wall.
- *Lack of validation examples.* When working with public data, one would like to validate that one is doing a sensible analysis by trying to match published results. While example files were provided, none of them (to our knowledge) involved the complications present in a real analysis, such as appropriate trigger selection, jet quality criteria, and jet energy corrections. Initially, we had hoped to reproduce the jet p_T spectrum measured by CMS on 2010 data [263], but that turned out to be surprisingly difficult, since very low p_T jet triggers are not contained in the Jet Primary Dataset, and we were not confident in our ability to merge information from the MinimumBias Primary Dataset. (In addition, the published CMS result is based on inclusive jet p_T spectra, while we restricted our analysis to the hardest jet in an event to simplify trigger assignment.) Ideally, one should be able to perform event-by-event validation with the CMS Open Data, especially if there are important calibration steps that could be missed.¹³
- *Information overload.* The AOD files contains an incredible wealth of information, such that the majority of official CMS analyses can use the AOD format directly without requiring RAW or RECO information. While ideal for archival purposes, it is an overload of information for external users, especially because some information is effectively duplicated. The main reason we introduced the MOD

¹³ In the one case where we thought it would be the most straightforward to cross check results, namely the luminosity study in Fig. 2, it was frustrating to later learn that the AOD files contained insufficient information.

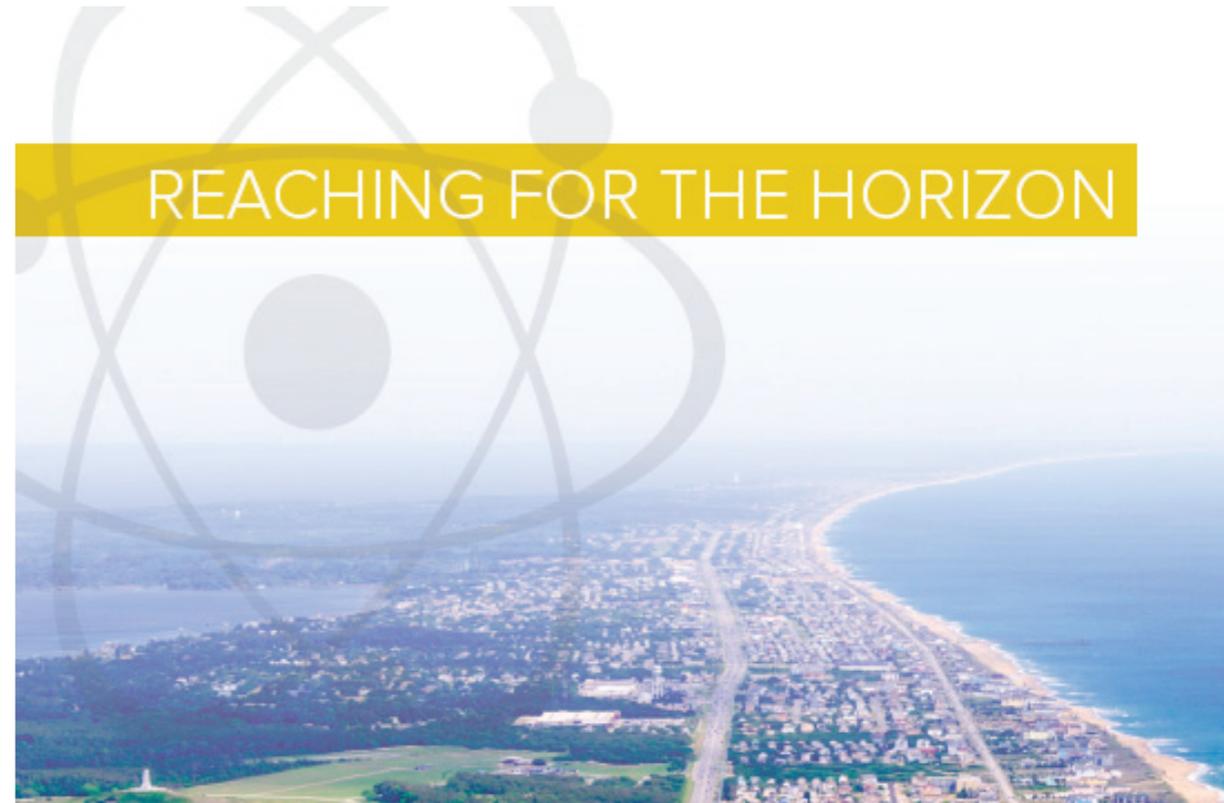
Excerpts from Symposium

NUCLEAR PHYSICS IN A DECADE

DONALD GEESAMAN
Argonne National Laboratory

Future Trends in Nuclear Physics Computing
May 2, 2017

REACHING FOR THE HORIZON



The Site of the Wright Brothers' First Airplane Flight



The 2015
LONG RANGE PLAN
for **NUCLEAR SCIENCE**

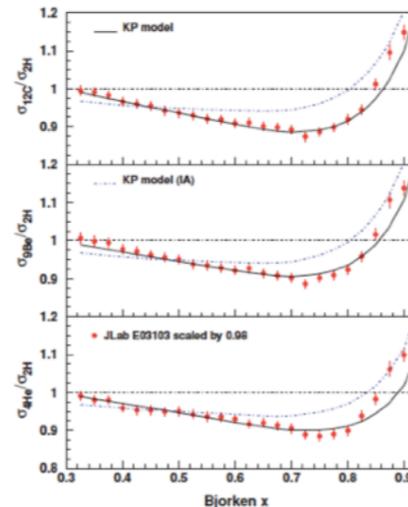


IN MOST CASES, IT WILL BE JOINT PROGRESS BETWEEN THEORY AND EXPERIMENT THAT MOVES US FORWARD, NOT IN ONE SIDE ALONE

Does the structure of the proton and the forces between nucleons change in nuclear matter (beyond n-body force effects)?

This has been an active subject since the dawn of the EMC effect. The problem is we have just had “toy” models that fit systematics for one observable but gave us little insight into others.

In ten years I expect lattice QCD calculations of nuclei to be able to properly ask this question and tell us what measurements will confirm it. I think we will have the measurements in hand.



SUMMARY

- It will be joint progress and theory and experiment that moves us forward, not in one side alone
- Continued rapid progress in Nuclear Physics Computing is imperative.
 - Challenge in handling the raw data
 - Challenge in analyzing the data
 - Challenge in simulating real detectors
- Theory challenge in calculating the physics right
 - Nuclear structure
 - Hadron structure
 - Astrophysical environments

GLOBAL COLLABORATION

All of this is in the context of more globalization of the research effort.

There will be an emphasis on

- Common Tools
- Common Structures
- Remote collaboration

but on diverse architectures and with diverse short range goals.



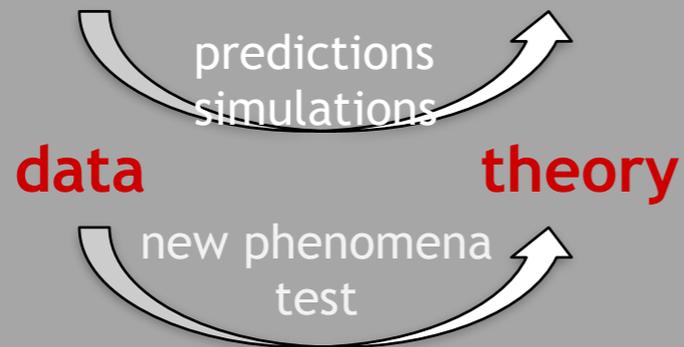
Synergies of Computing and the Next Generation of Nuclear Physics Experiments

Rolf Ent (Jefferson Lab)

With acknowledgement to Amber Boehnlein, Markus Diefenthaler and Graham Heyes for their help

Interplay of data and theory

Feedback loop between data and theory



Comparison to:

- analytical calculations
- Monte Carlo (MC) simulations
- Lattice-QCD calculations

Data-theory comparison: relies on

- open access to data-theory tools
- standardization of data-theory tools
- comparison tools for quick turnaround

MC event generator:

- faithful representation of QCD dynamics
- based on QCD factorization and evolution equations

Usage by experimentalists:

- detector corrections
- analysis prototyping
- comparing to theory

Usage by theoreticians:

- easy off-the-shelf state-of-the-art tool that looks like data
- validate against and investigate theoretical improvements

Analysis environments

Developments of analysis environments:

- new projects starting (JLab 12 GeV) and on the horizon (EIC)
- likely explosion of data even at the small nuclear experiments
- think about the **next generation(s) of analysis environments** that will **maximize** the **science output**

LHC experiments: tremendous success in achieving their analysis goals and producing results in timely manners

Lesson learned at LHC experiments:

- as the complexity and size of the experiments grew
- the complexity of analysis environment grew
- time dealing with the analysis infrastructure grew

Anecdote from LHC

a typical LHC student or post-doc spends up to 50 % of his/her time dealing with computing issues

Targeting the theory/experiment interface

Level-1. Published results

All scientific output is published in journals, and preliminary results are made available in Conference Notes. All are openly available, without restriction on use by external parties beyond copyright law and the standard conditions agreed by CERN.

Data associated with journal publications are also made available: tables and data from plots (e.g. cross section values, likelihood profiles, selection efficiencies, cross section limits, ...) are stored in appropriate repositories such as [HEPDATA\[2\]](#). ATLAS also strives to make additional material related to the paper available that allows a reinterpretation of the data in the context of new theoretical models. For example, an extended encapsulation of the analysis is often provided for measurements in the framework of RIVET [3]. For searches information on signal acceptances is also made available to allow reinterpretation of these searches in the context of models developed by theorists after the publication. ATLAS is also exploring how to provide the capability for reinterpretation of searches in the future via a service such as RECAST [4]. RECAST allows theorists to evaluate the sensitivity of a published analysis to a new model they have developed by submitting their model to ATLAS.



U.S. Particle Physics: Building for Discovery

U.S. Particle Physics Strategy

Education and Outreach Site

Five intertwined Science Drivers provide compelling lines of inquiry that show great promise for discovery.



Use the Higgs boson as a new tool for discovery.



Pursue the physics associated with neutrino mass.



Identify the new physics of dark matter.

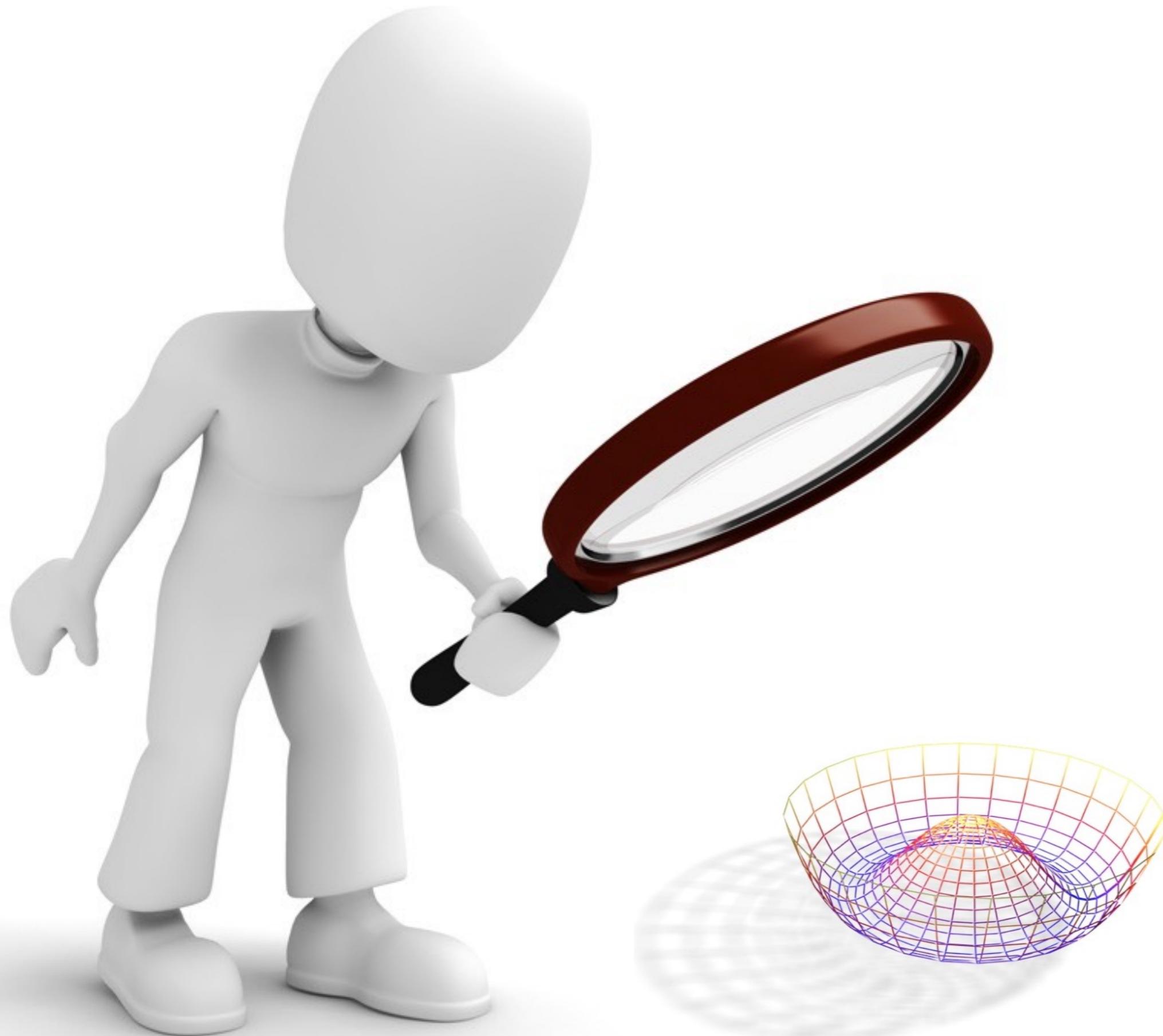


Understand cosmic acceleration: dark energy and inflation.

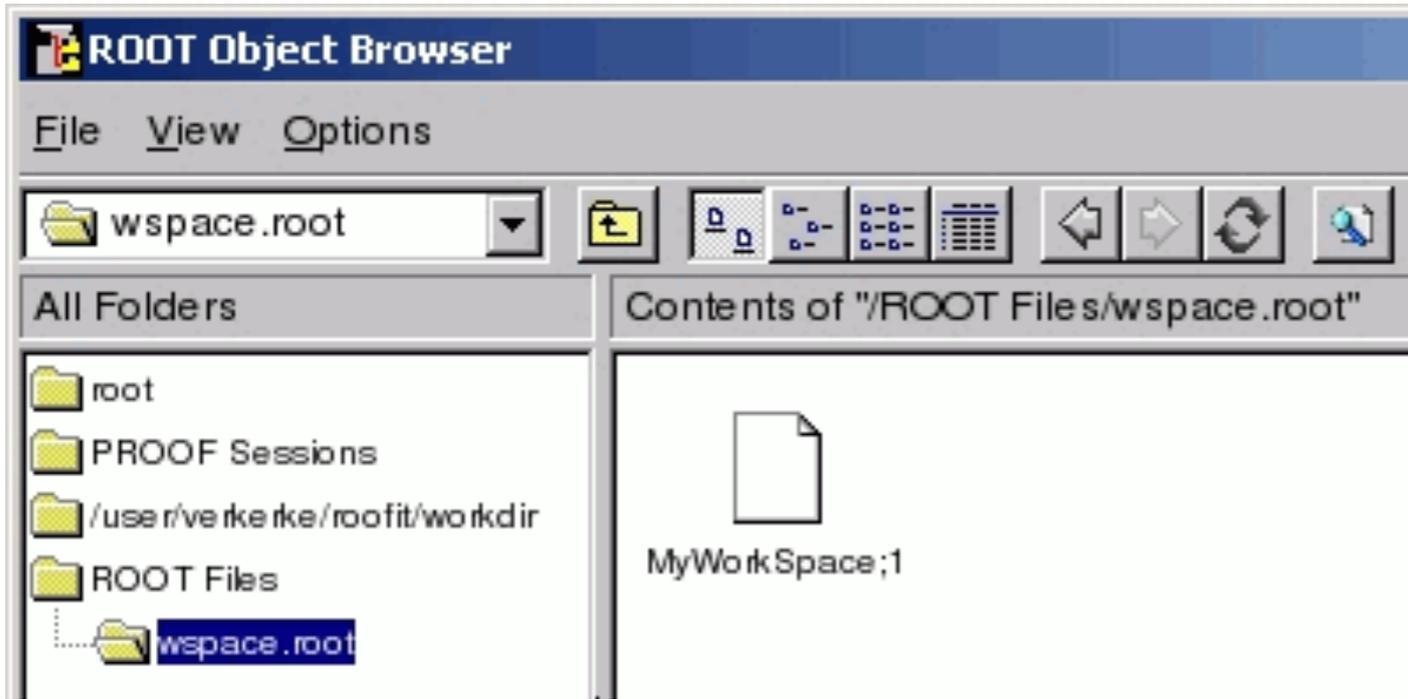


Explore the unknown: new particles, interactions, and physical principles.

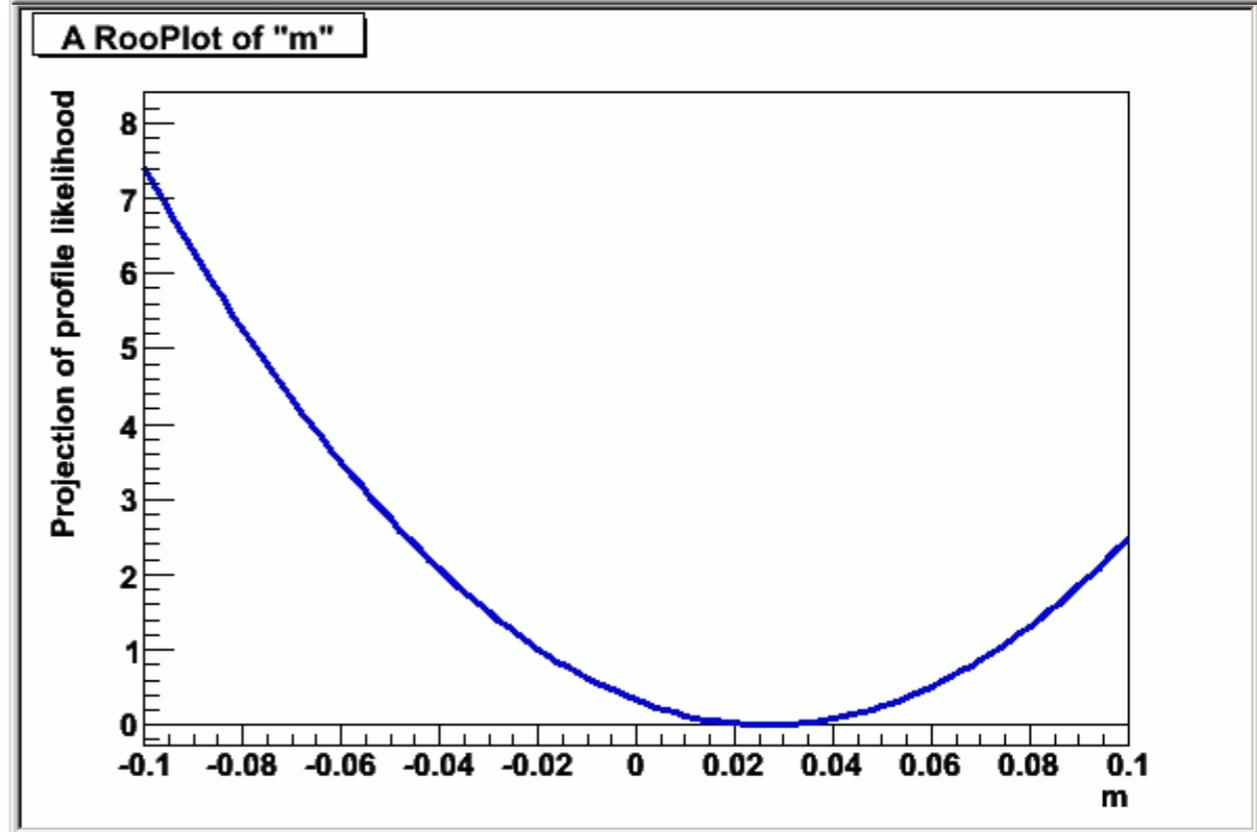
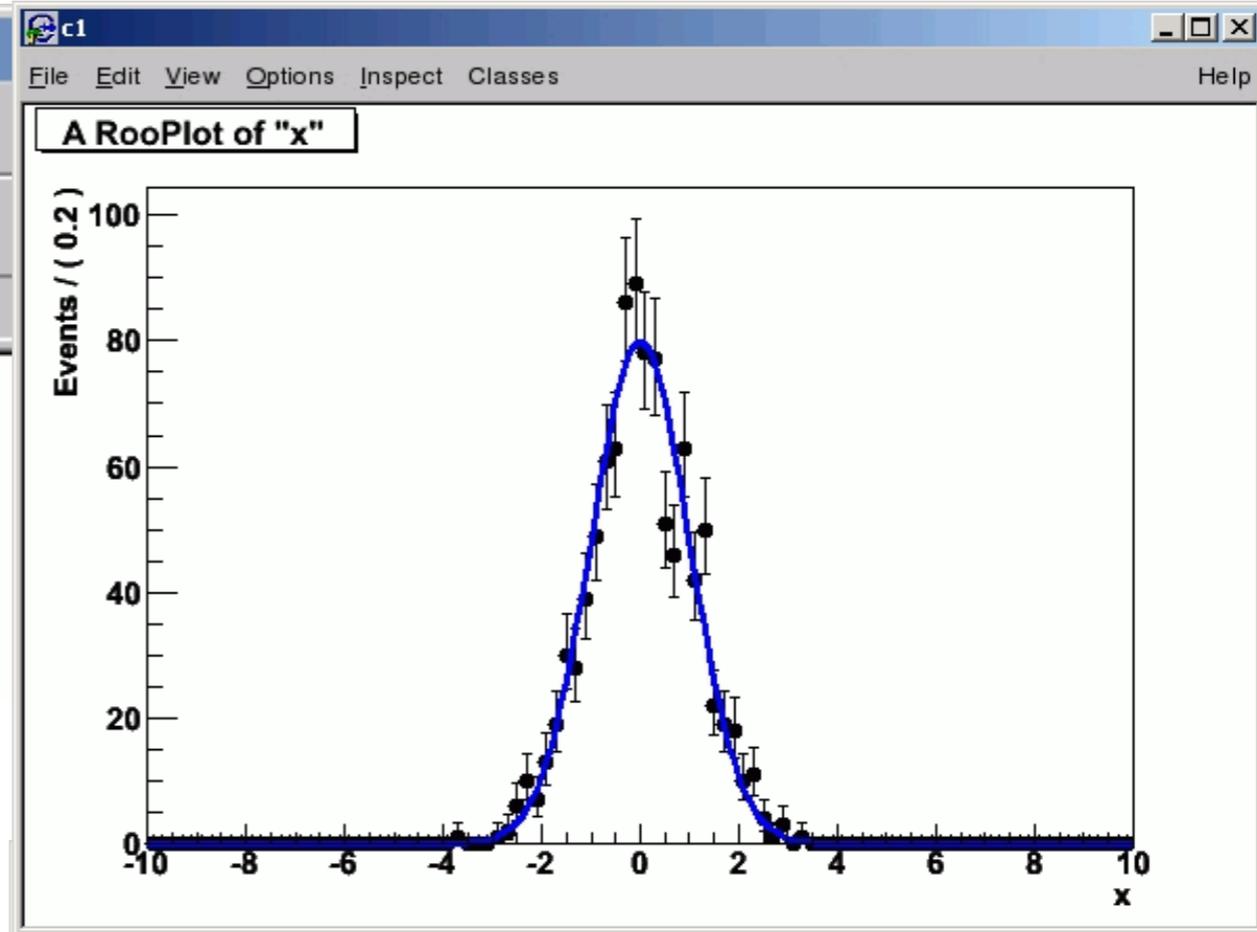




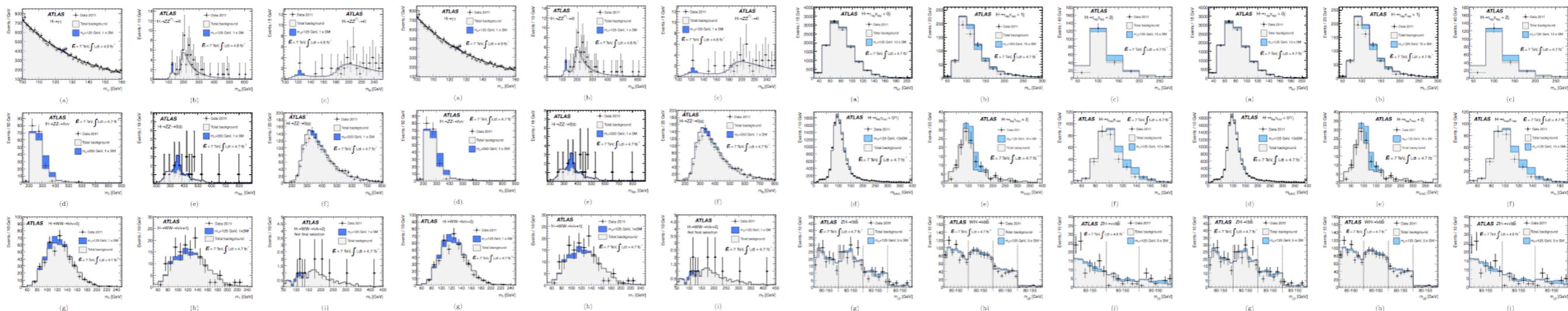
DIGITAL PUBLISHING STATISTICAL MODELS



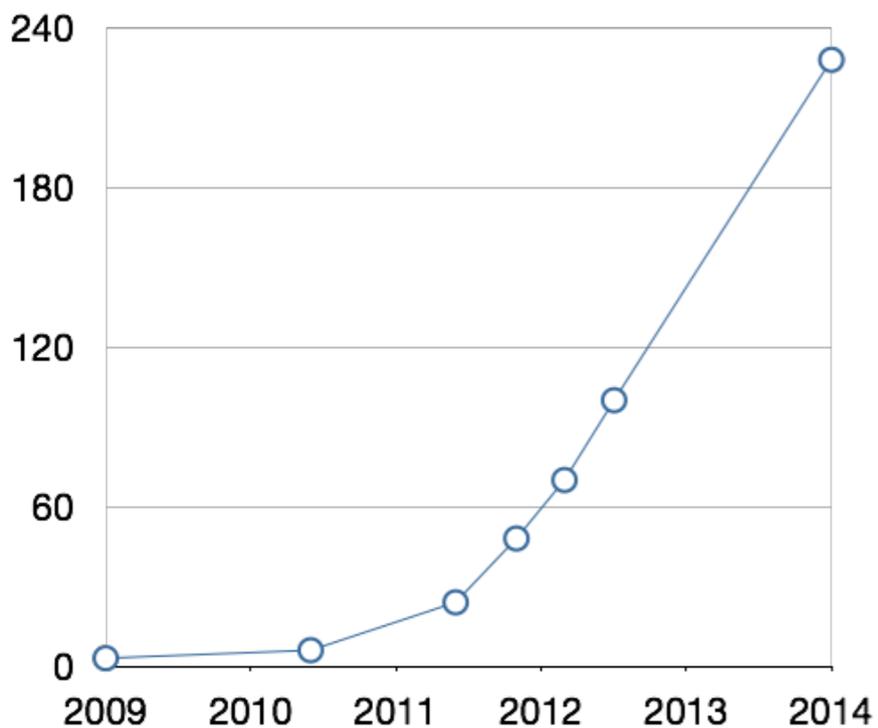
RooFit workspaces & HistFactory



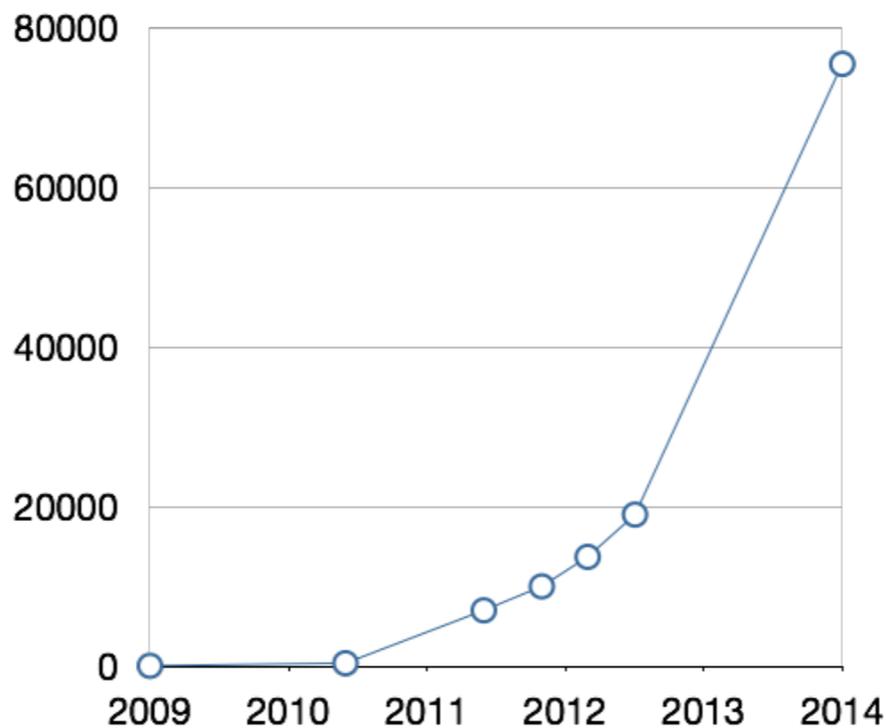
COLLABORATIVE STATISTICAL MODELING



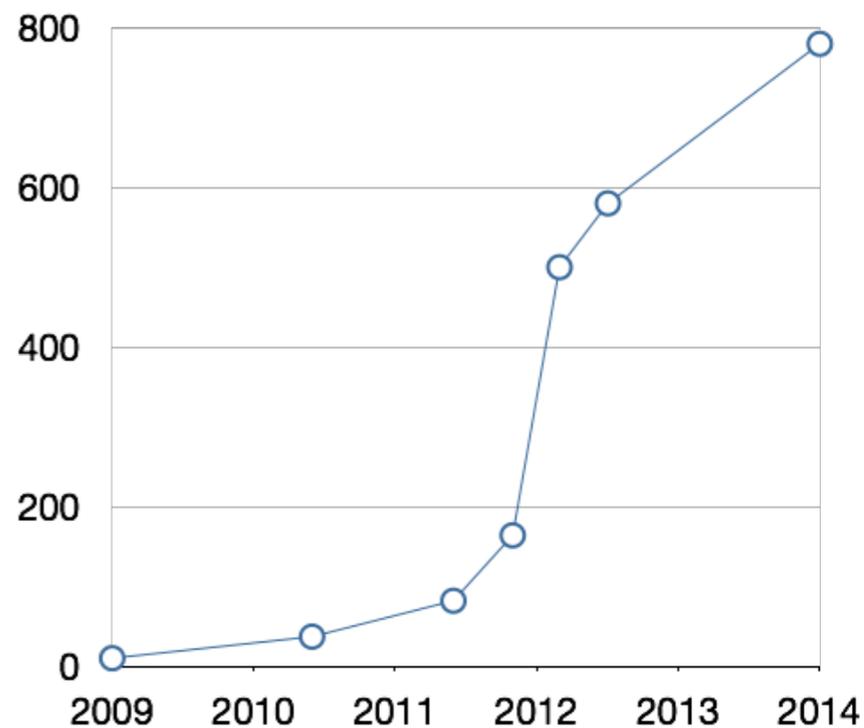
Number of Datasets Combined



Number of Model Components

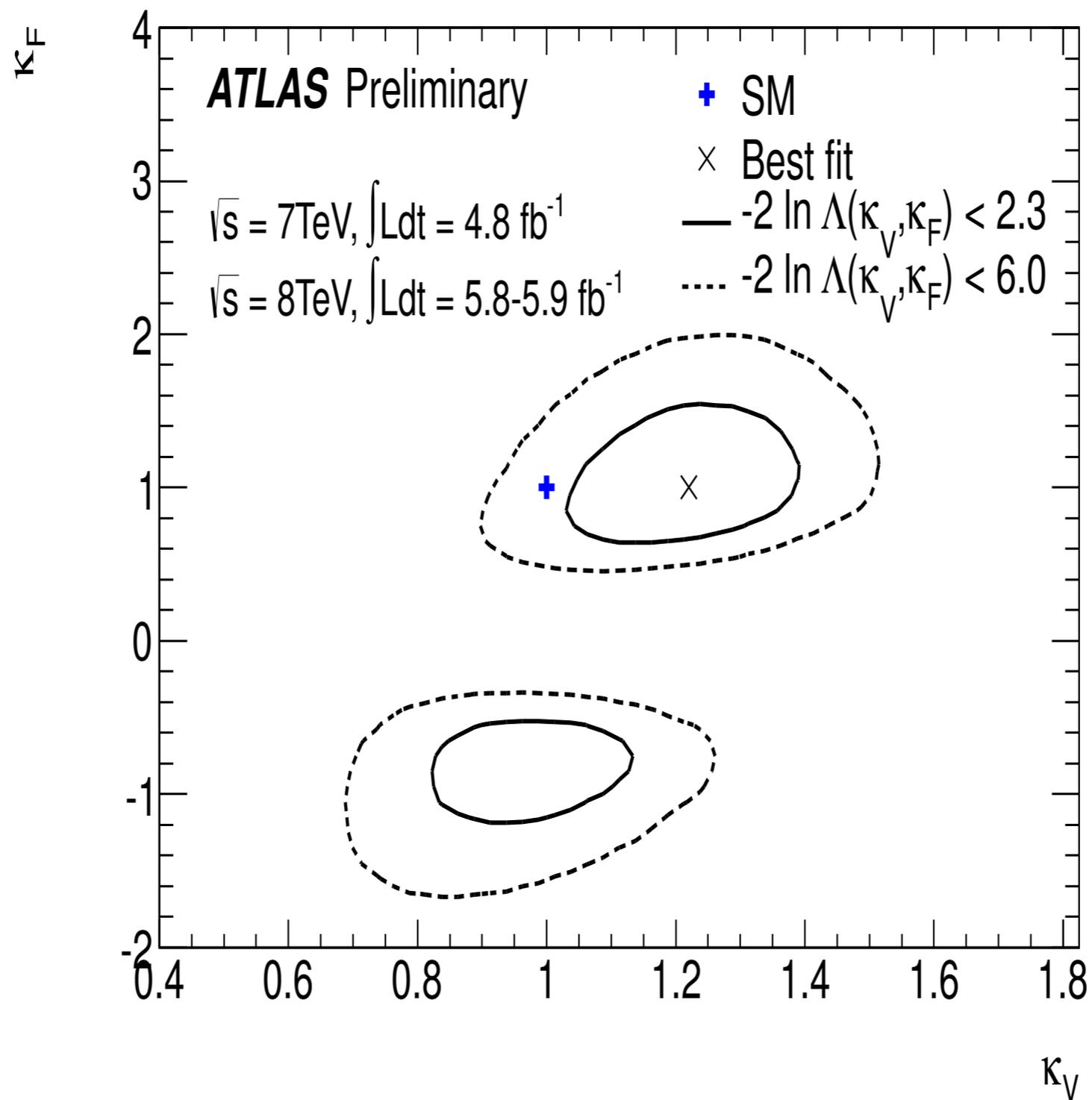


Number of Parameters in Likelihood



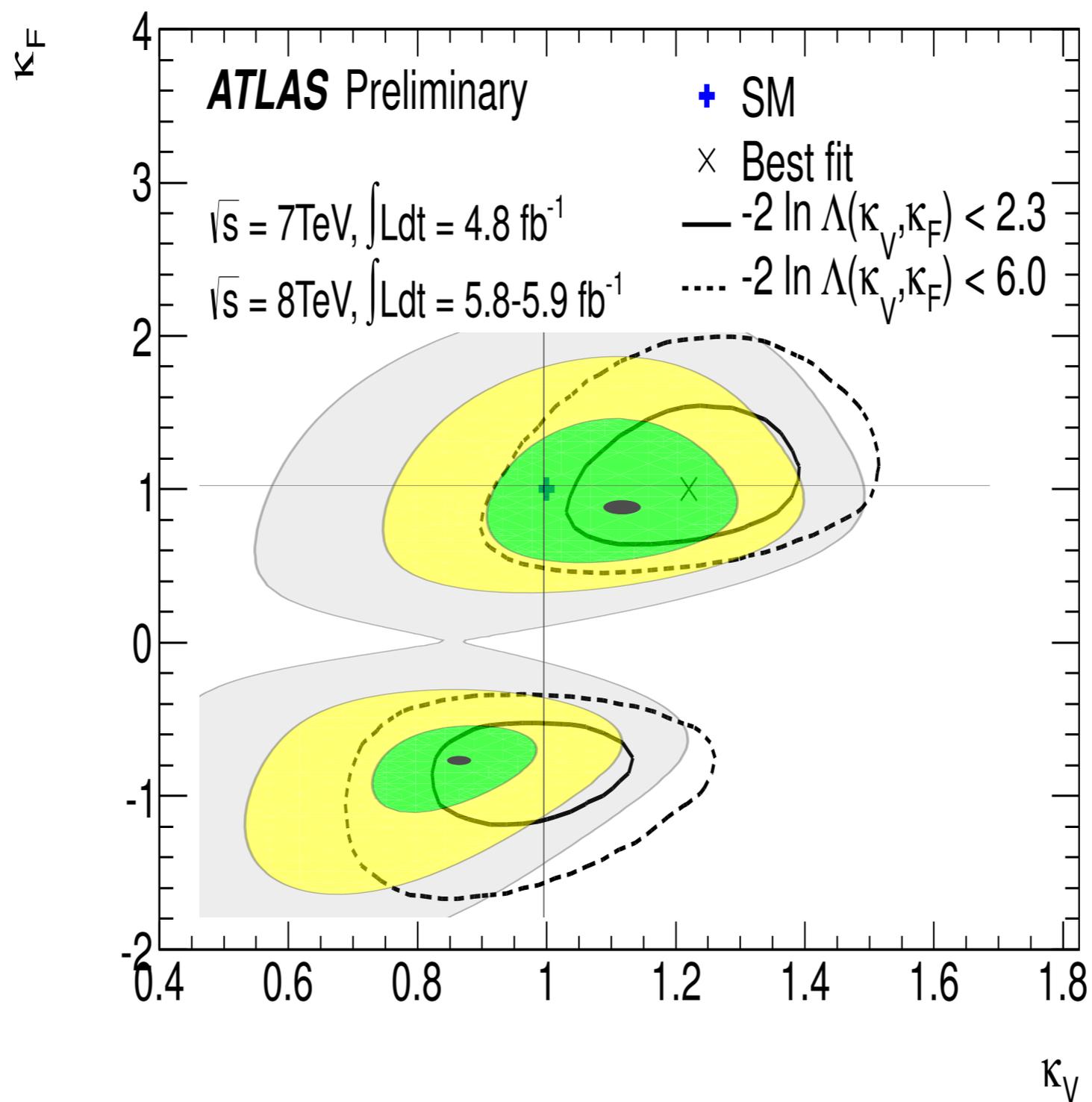
REPRODUCIBILITY PROBLEM

Not possible for others to reproduce results from paper.



REPRODUCIBILITY PROBLEM

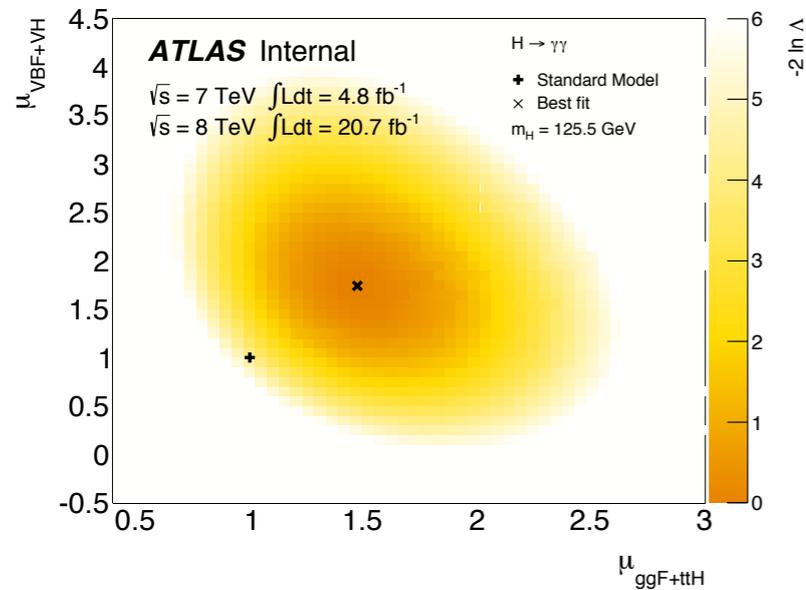
Not possible for others to reproduce results from paper.



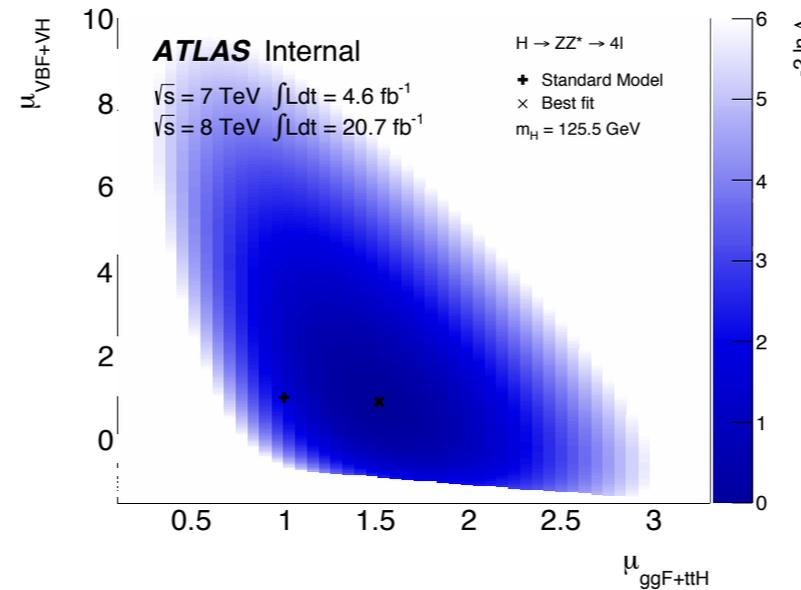
WHAT INFO AND HOW TO RETRIEVE IT

Through collaboration with theoretical community, we were able to identify a targeted form of data sharing that balanced generality &

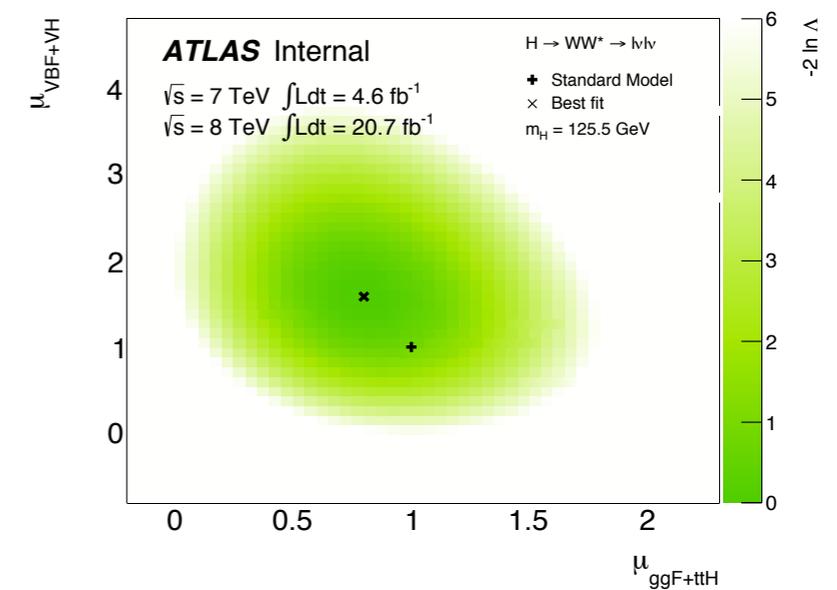
<http://doi.org/10.7484/INSPIREHEP.DATA.A78C.HK44>



<http://doi.org/10.7484/INSPIREHEP.DATA.RF5P.6M3K>



<http://doi.org/10.7484/INSPIREHEP.DATA.26B4.TY5F>



These data are directly linked to the paper in INSPIRE and have been cited:



Welcome to [INSPIRE](http://inspirehep.net), the High Energy Physics information system. Please direct questions, comments or corrections to feedback@inspirehep.net.

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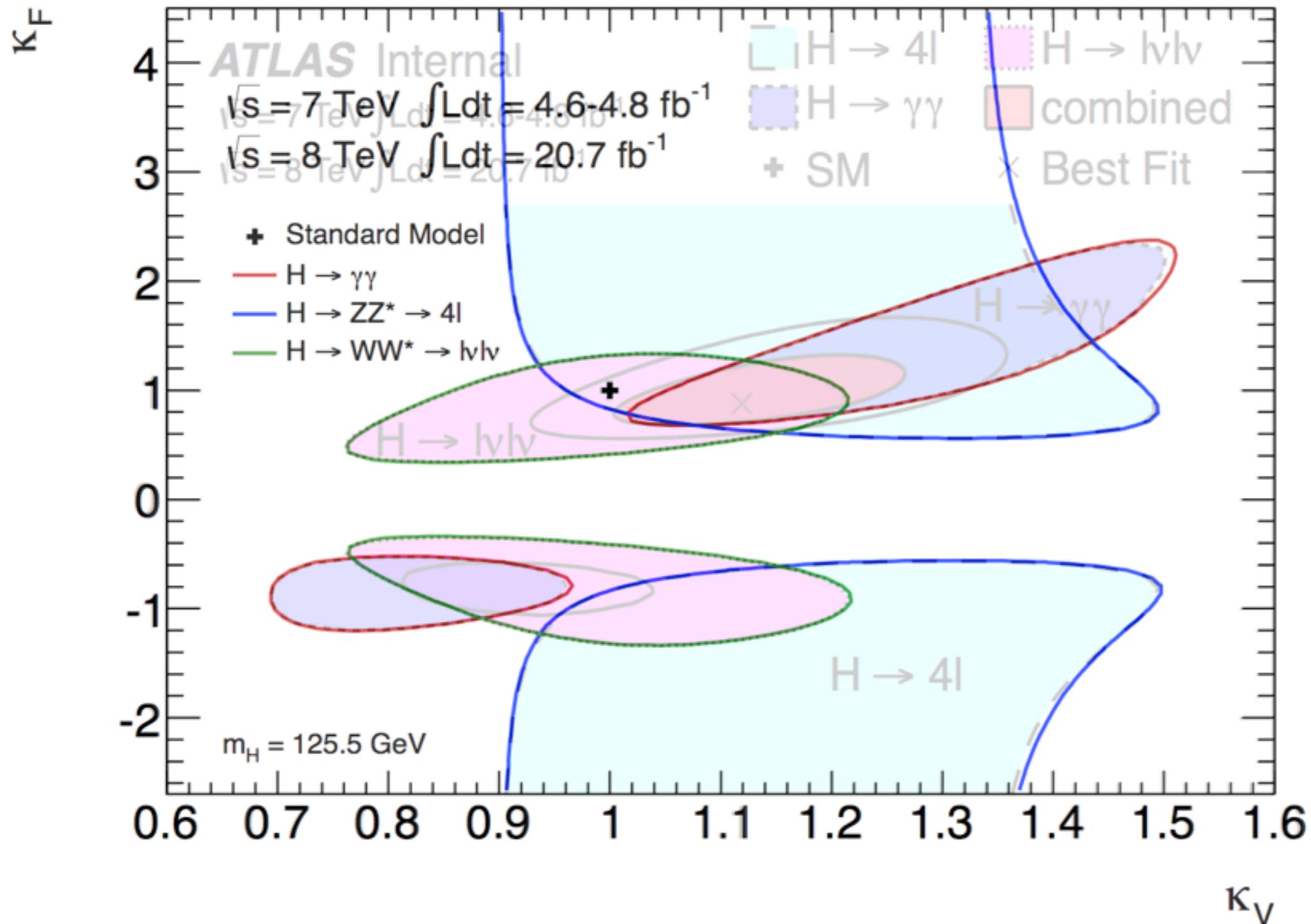
Data from Figure 7 from: Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

ATLAS Collaboration (Aad, Georges (Freiburg U.) [...]) [Show all 2923 authors](#)

Cite as: ATLAS Collaboration (2013) HepData, <http://doi.org/10.7484/INSPIREHEP.DATA.A78C.HK44>

LIKELIHOODS ON HEPDATA

Reproducing derived results from original paper!



Reinterpretation & Reusability



FOLDING VS. UNFOLDING

Rivet
Unfolding

Accuracy meets precision MC event simulation in a decade

Stefan Höche

SLAC National Accelerator Laboratory

Future Trends in Nuclear Physics Computing

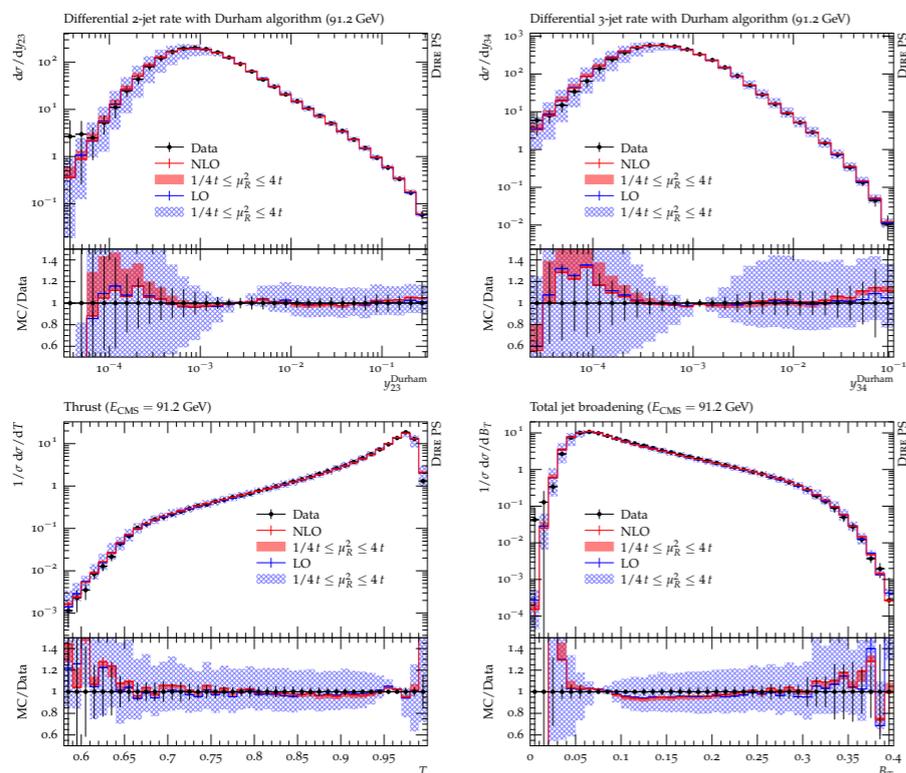
Jefferson Lab, 05/02/2017



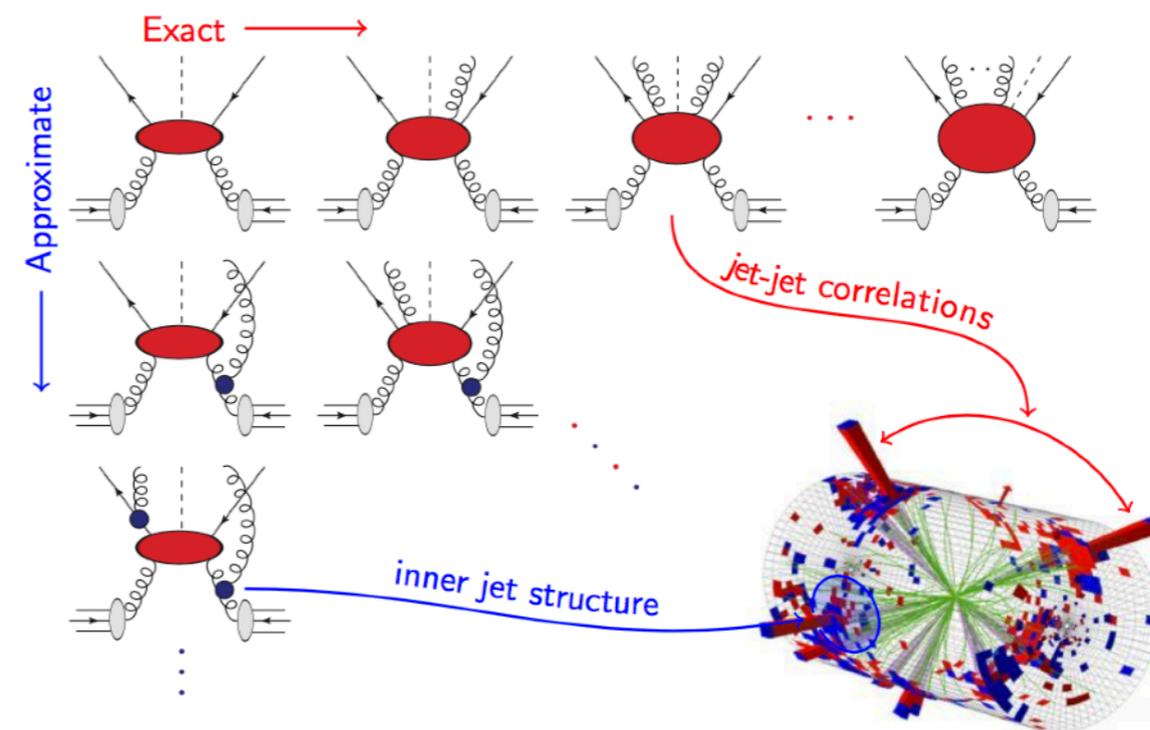
Recast
Folding

First phenomenological predictions

[Krauss, Prestel, SH] arXiv:1705.tonight



Parton-shower matching & merging





U.S. Particle Physics: Building for Discovery

U.S. Particle Physics Strategy

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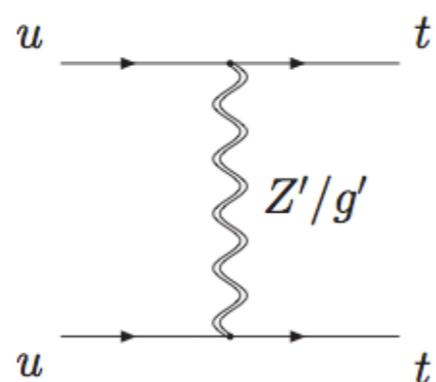
Understand cosmic acceleration: dark energy and inflation.



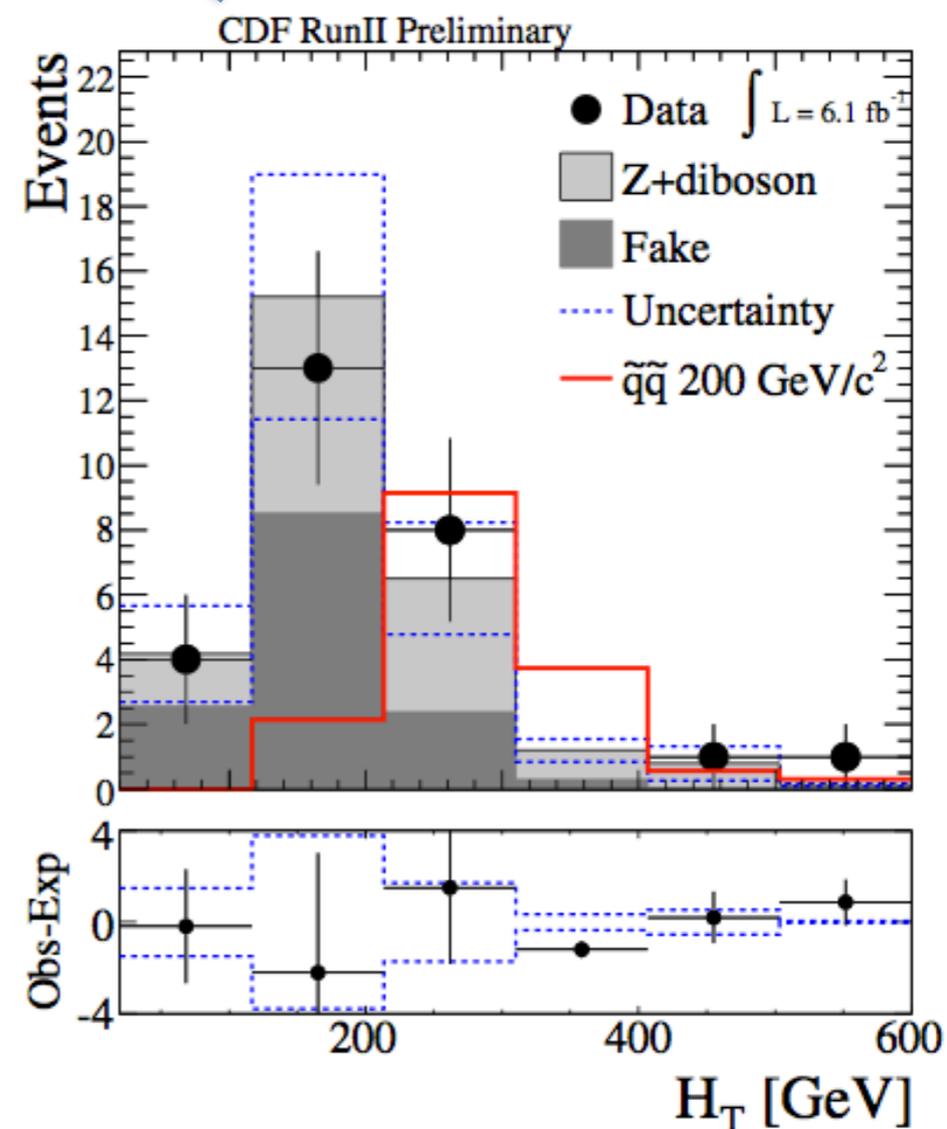
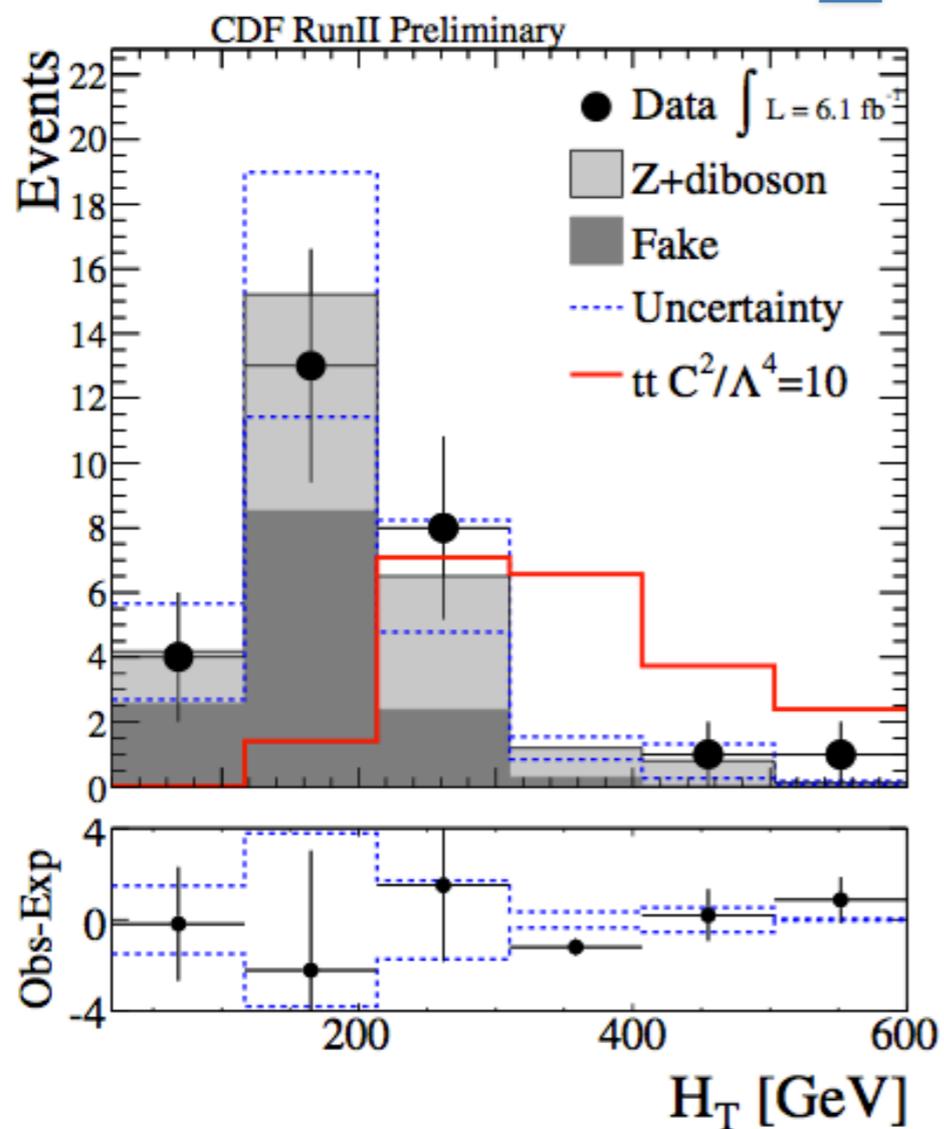
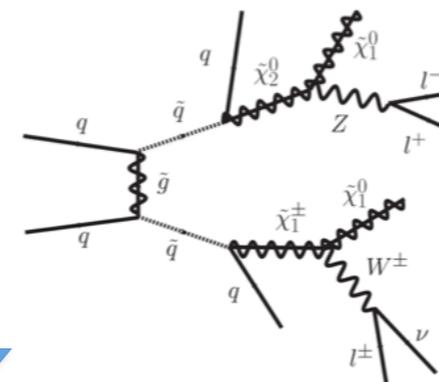
Explore the unknown: new particles, interactions, and physical principles.



RECASTING / REINTERPRETATION



recasting





It's the difference between if you had airplanes where you threw away an airplane after every flight, versus you could reuse them multiple times.

— Elon Musk



ATLAS analysis

ATLAS analyses

checking
one theory

It's the difference between if you had ~~airplanes~~ where you threw away an ~~airplane~~ after ~~every~~ flight, versus you could reuse them multiple times.

— Elon Musk

DEMAND

>50 requests from theorists within ~2 months

RECAST [beta] [Feedback](#) [Login](#) [Register](#)

[Home](#) [Analyses Catalog](#) [Requests](#) [About](#) [Developers](#) [News](#) [Help](#)

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About this site

RECAST is a framework for extending the impact of existing analyses performed by high-energy physics experiments.

1. Anyone can add *analyses* to the Analysis Catalog
2. Anyone can upload alternative signals in the LHE format and *request* that any given analysis is "recast" for their alternative model (Note: this is a request, there is no obligation for the experiments to respond.)
3. Anyone can *subscribe* to an analysis to be informed of activity associated with the analysis
4. Experimentalists can accept the request, process these alternative signals with the full simulation, reconstruction, and analysis selection. If they are authorized by their collaboration, then they can respond with an authoritative *result* for the selection efficiency and cross-section limits for the alternative signal. Note, anyone can provide a non-authoritative result, for instance one based on fast simulation.

Latest Requests

Request	Analysis	Model	Status
1603.0045	Search for massive supersymmetric particles decaying to many jets using the ATLAS detector in pp collisions at $\sqrt{s} = 8$ TeV	asdafa	Incomplete
1505.0044	Search for massive supersymmetric particles decaying to many jets using the ATLAS detector in pp collisions at $\sqrt{s} = 8$ TeV	stealth supersymmetry	Incomplete
1408.0043	Search for direct third-generation squark pair production in final states with missing transverse momentum and two b-jets in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector	3-body decay of sbottom into b-quark and two invisible final states	Active
1408.0042	Search for direct top-squark pair production in final states with two leptons in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector	3-body decay of stop into top and two invisible final states	Active
1408.0041	Search for direct pair production of the top squark in all-hadronic final states in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector	3-body decay of stop into top and two invisible final states	Active
	Search for direct third-generation squark pair	3-body decay of	

PHENO RECASTING SOFTWARE

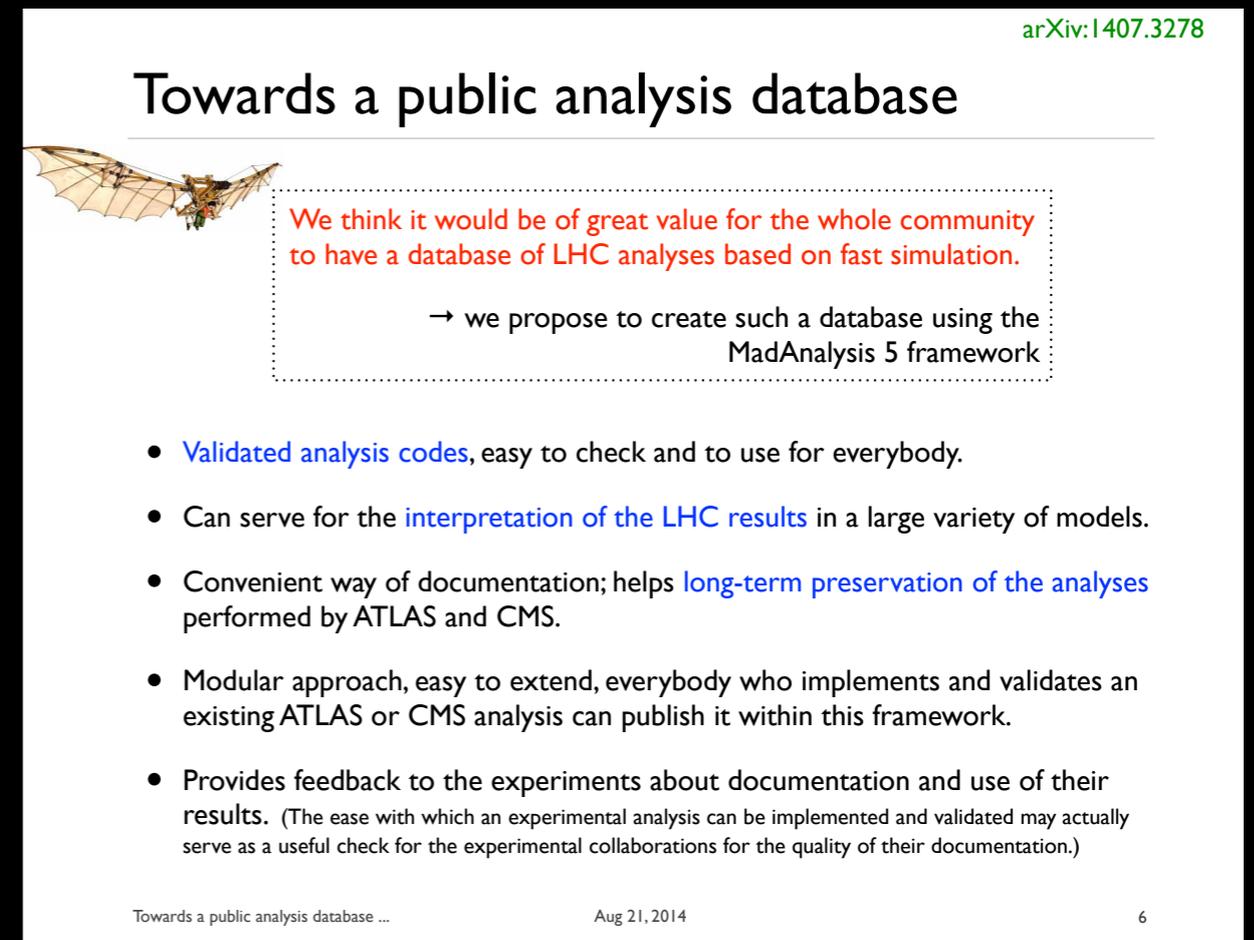
- Several tools being developed by phenomenologists to address the need for an organized approach to recasting (but using unofficial and/or approximate methods).

Sabine Kraml

arXiv:1407.3278

- ATOM
- FastLim
- MadAnalysis
- Gambit
- SModelS
- XQCAT
- CheckMate
- unofficial contributions to Rivet

- As I'll show, it is possible to interface RECAST infrastructure with these unofficial pheno recasting tools.



Towards a public analysis database

We think it would be of great value for the whole community to have a database of LHC analyses based on fast simulation.

→ we propose to create such a database using the MadAnalysis 5 framework

- Validated analysis codes, easy to check and to use for everybody.
- Can serve for the interpretation of the LHC results in a large variety of models.
- Convenient way of documentation; helps long-term preservation of the analyses performed by ATLAS and CMS.
- Modular approach, easy to extend, everybody who implements and validates an existing ATLAS or CMS analysis can publish it within this framework.
- Provides feedback to the experiments about documentation and use of their results. (The ease with which an experimental analysis can be implemented and validated may actually serve as a useful check for the experimental collaborations for the quality of their documentation.)

Towards a public analysis database ... Aug 21, 2014 6

Forum on the Interpretation of the LHC Results for BSM studies

The quest for new physics beyond the Standard Model is arguably the driving topic for Run 2 of the LHC. Indeed, the LHC collaborations are pursuing searches for new physics in a vast variety of channels. While the collaborations typically provide themselves interpretations of their results, for instance in terms of simplified models, **the full understanding of the implications of these searches requires the interpretation of the experimental results in the context of all kinds of theoretical models.** This is a very active field, with close theory-experiment interaction and with several public tools being developed.

With this forum, we want to provide a platform for continued discussion of topics related to the BSM (re)interpretation of LHC data, including the development of the necessary **public [RecastingTools](#)** and related infrastructure.

If you have questions or want to contribute, contact Sabine Kraml, sabine.kraml@gmail.com, or any of the topical contacts given below.

Meetings

Meetings of this forum

- [2nd workshop](#), 12-14 Dec 2016 at CERN
 - [Agenda](#) | [introduction](#) | [final discussion](#) | [WorkshopSummaryNotes](#)
- **Kick-off workshop: (Re)interpreting the results of new physics searches at the LHC**, 15-17 June 2016 at CERN
 - [Agenda](#) | [general discussion](#) | [KickoffSummaryNotes](#)

Other workshops, potentially interesting for our forum

- The [Les Houches PhysTev2017 workshop](#) will have a strong activity on interpreting LHC results; the BSM session in LH is taking place 14-23 June 2017.
- 2nd [LHC Long-Lived Particle workshop](#), CERN, 24-26 April 2017, "to address the status and future of beyond-the-Standard Model LLP searches at the ATLAS, CMS, and LHCb experiments, as well as auxiliary LHC detectors and projects".
- 6th edition of the workshop "[Implications of LHCb measurements and future prospects](#)", CERN, 12-14 October 2016. NB participation is restricted to the members of the LHCb Collaboration, and of interested theorists.

Mailing list

- CERN e-group: info-LHC-interpretation@cern.ch
- To subscribe, go to <https://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=info-lhc-interpretation>

A FLEXIBLE WORKFLOW MODEL

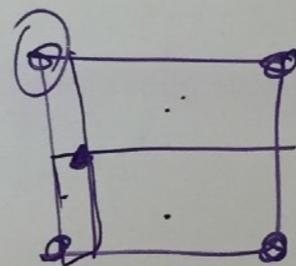
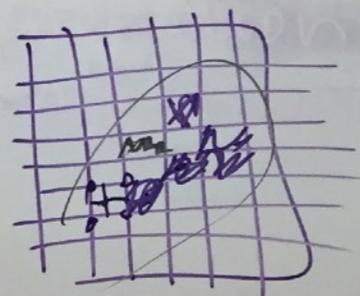
- 1) read/export json
- 2) interactive shell

$y_{min} \quad x_{max}$
 $x_1 \dots x_n$
 $\Delta x_1 \dots \Delta x_n$
 $N_1 \dots N_n$

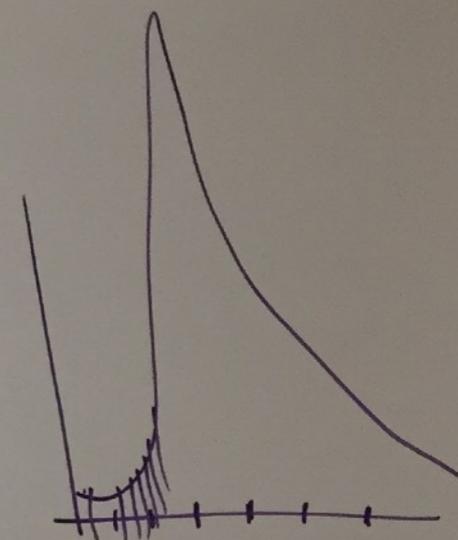
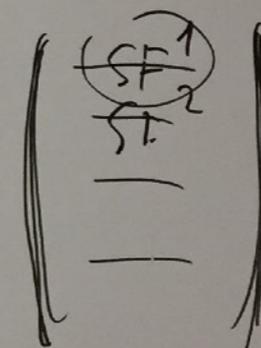
C - command
 L - line
 I - interface

- 3) projection $(3 \times 3 \times 3) \rightarrow 1 \times 3$
- 4) dimension reduction $3 \times 4 \times 5 \times 6 \rightarrow 4 \times 5 \times 6$
- 5) rebin one dimension $3 \times 4 \times 5 \times 6 \rightarrow 3 \times 2 \times 5 \times 6$

- 6) interpolation
- 7) merging



TMD
 SF
 X-sec



- 8) visualization

program

```
main { mypioncalc
init() {
ms.load("SF1")
ms.load("SF2")
ms.load("SF3")
ms.create(7, ...)
}
```

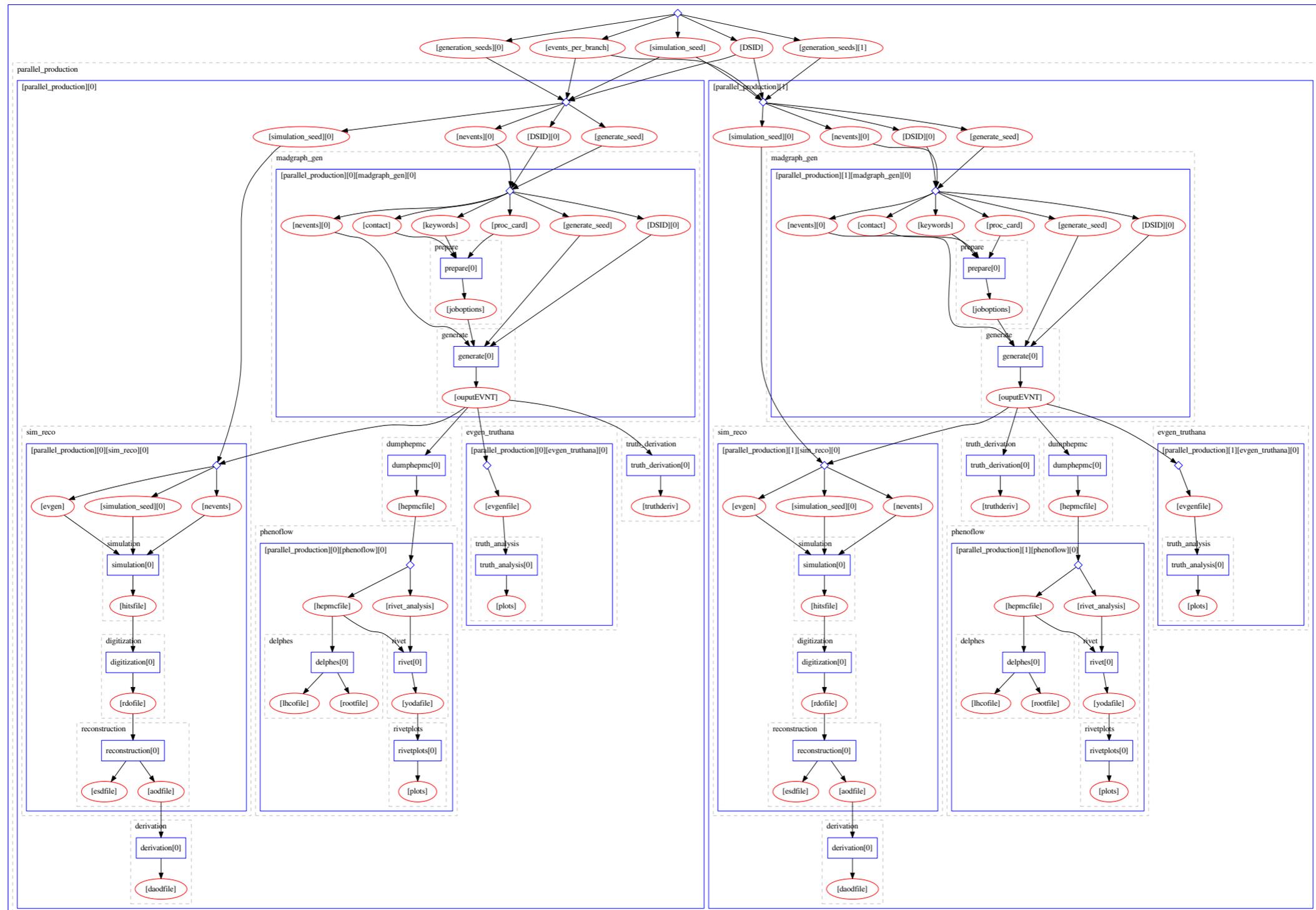
- 9) random generator $(x_i \dots x_n)$
- 10) event generator (e_i, \bar{n}, p)

x, y, z, p_x, p_y, p_z
 $x, y, z, M_T, P_T, \phi, \eta$

produce
 $xs = ms.get("SF1", Q?)$
 $ms.get("XSES").setBin(Q?, y, x, pT, xs);$

A FLEXIBLE WORKFLOW MODEL

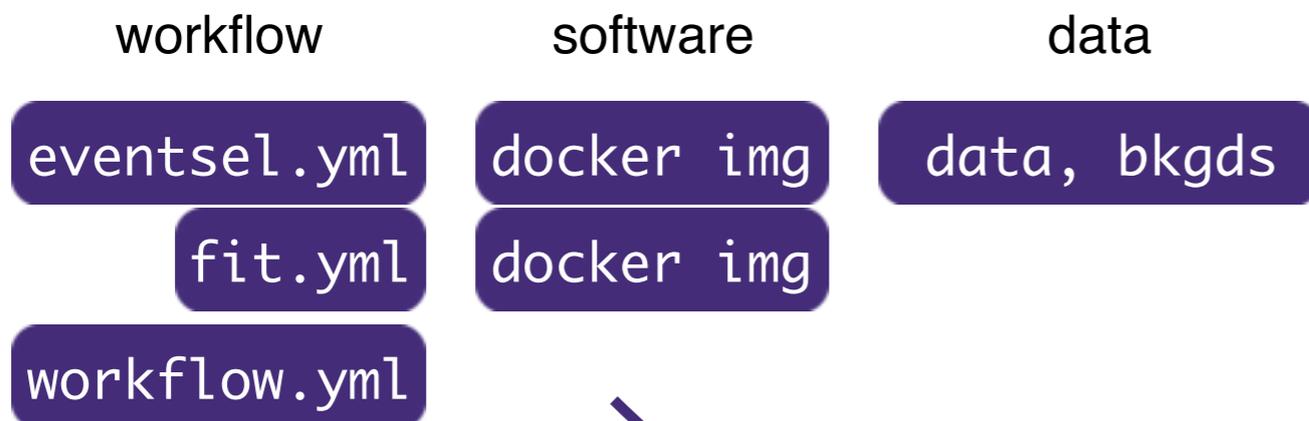
A workflow composed of sub-workflows that run Rivet, Delphes, and ATLAS analyses in parallel on the same input



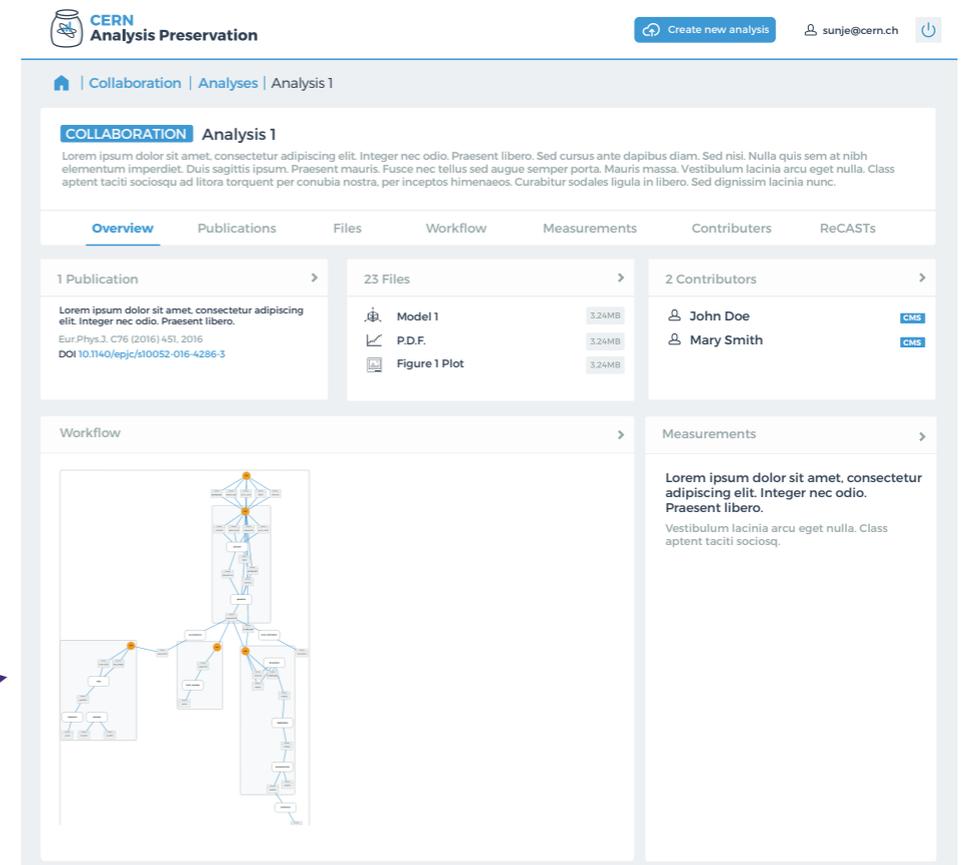
Technical Solution:

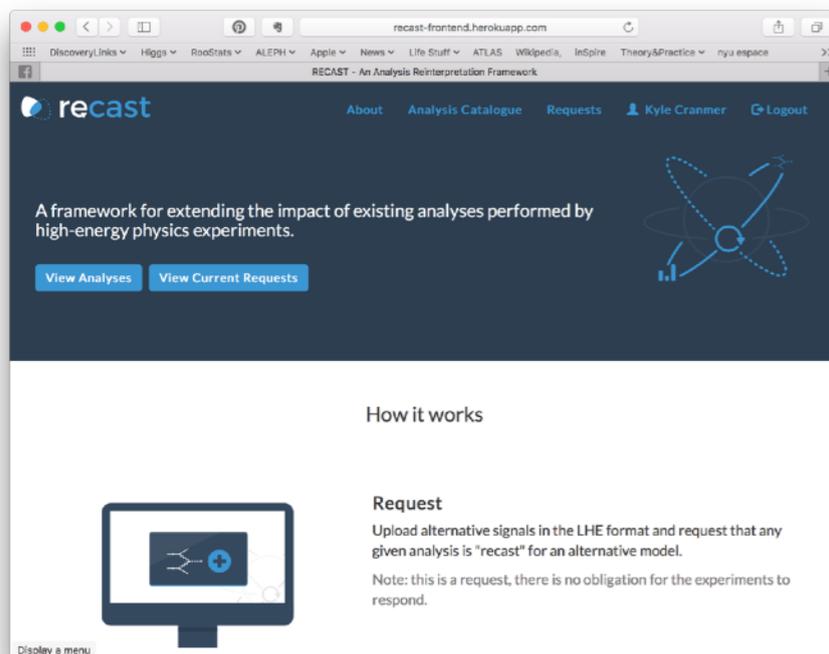
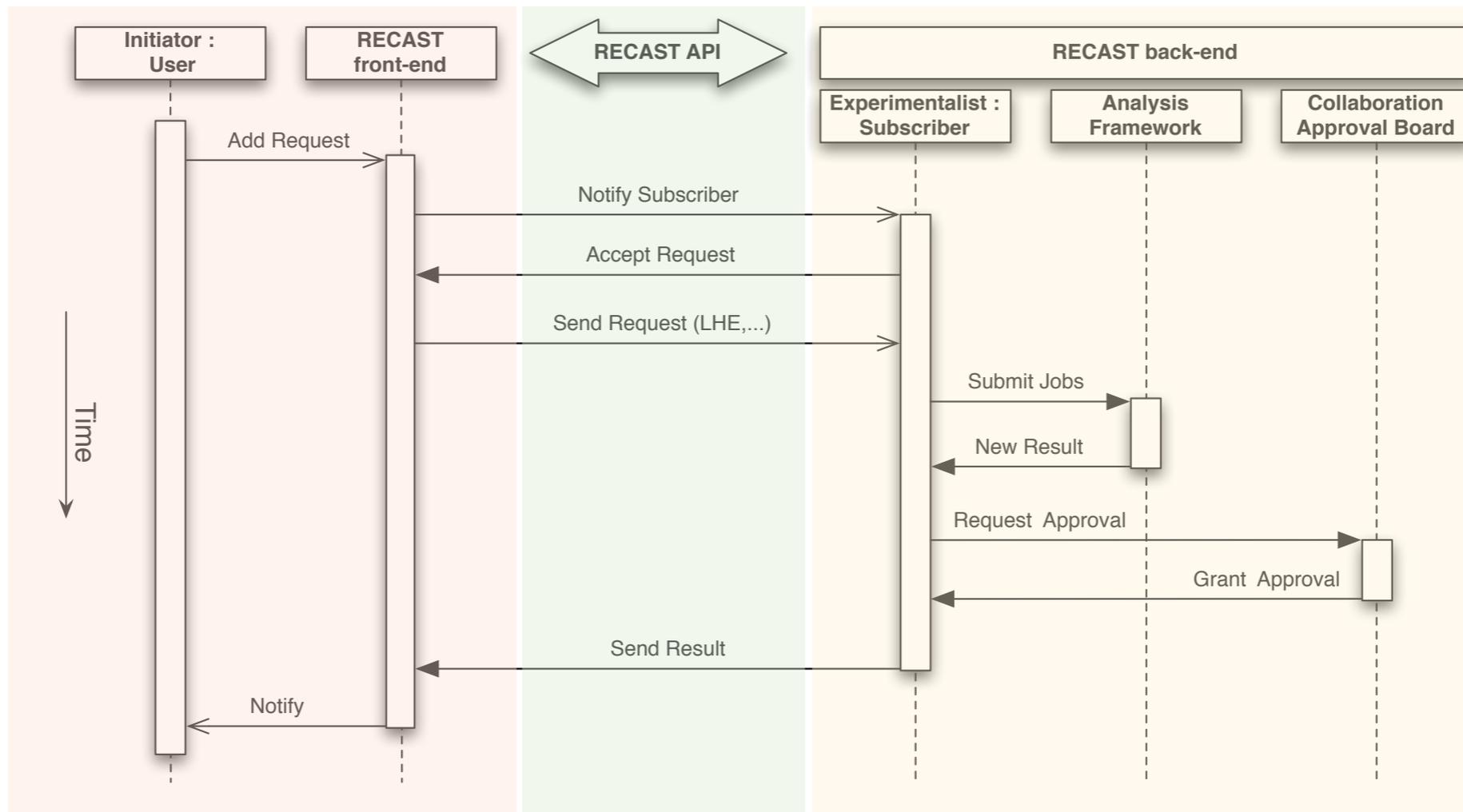
Workflow (i.e. logic which steps to run in which order: reconstruction → analysis → fit)

- in easy to write / read text based format (YAML)
- generic workflow language “**yadage**” based on graphs. No assumption on how you run your analysis. Should be able to accommodate your workflows.
- integrated into CERN Analysis Preservation.
- re-run workflow using tool that interprets info stored in CAP

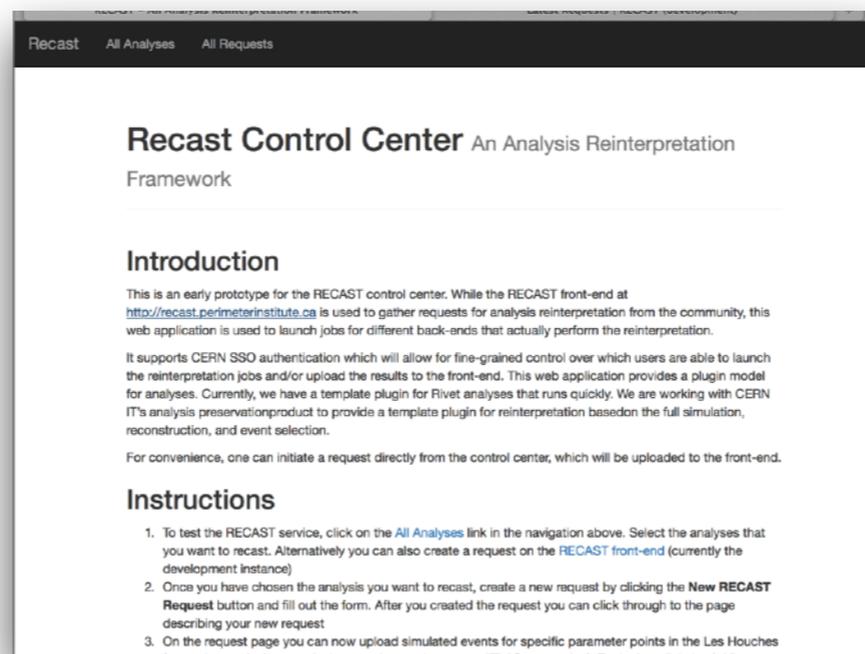


import analysis workflow

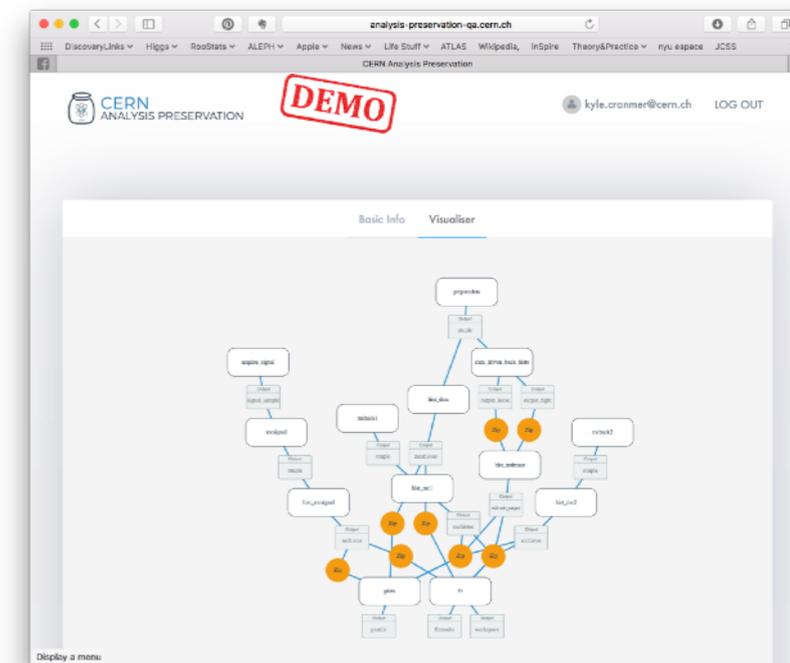




Front-End: public facing collects requests



Control Center: not public, uses CERN auth., oversees processing of jobs on back-end



CERN Analysis Preservation: Stores workflows, provides back-end computing resources

front-end (open)

Home » Analyses Catalog » Demo with working rivet-based back-end » List Requests » test for UCI

View Edit Edit Contact Requester Show Results Devel

1. request initiated

Analysis: Demo with working rivet-based back-end

Status: Completed

Requester: lheinric

Recast Audience: all

Model Name: CMSSM

Selected Subscriber(s): lheinric, cranmer

Mon, 02/02/2015 - 14:26 - Activated
Wed, 02/04/2015 - 03:06 - Completed

Request Description and Potential

Reason for request: because we can

Additional Information: No information available

5. response public

control center (closed to experiment)

Recast Request test for UCI

Request Details

analysis: Demo with working rivet-based back-end
status: 1
model-type: None
uuid: 4cdc558c-8f4a-eab4-fdbf-cd91a34db4b2
new-model-information: None
title: test for UCI
predefined-model: CMSSM
reason-for-request: because we can
requestor: lheinric
audience: None
subscribers: lheinric
additional-information: None

4. upload response

2. process request

+ Add Parameter Point Upload to RECAST

Parameter	Description	Number of Events	Cross-Section
parameter-0	test for UCI	1000	20

process results

3. review results

Home Analyses Catalog Requests My Subscriptions About Developers News Help



Home » Analyses Catalog » Demo with working rivet-based back-end » List Requests » test-upload-2 » Show Results » Recast Response for Request #test-upload-2

Recast Response for Request #test-upload-2

View Edit Devel

Submitted by lheinric on Sun, 01/18/2015 - 09:54

Request: test-upload-2
ROOT file with TH1: 20150118095414b5872abo-1a2b-10a4-c154-5cead413be8f.zip
Status: Completed

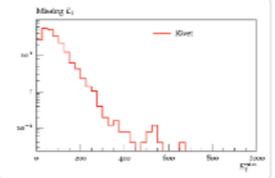
Results for request 4cdc558c-8f4a-eab4-fdbf-cd91a34db4b2 - parameter-0

Efficiency

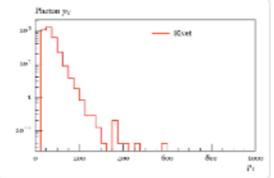
0.18272727272727274

Plots

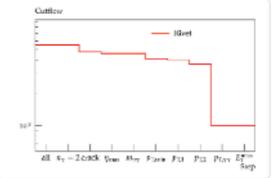
> MET:



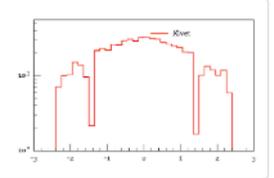
> PhotonPt:



> Cutflow:



> PhotonEta:



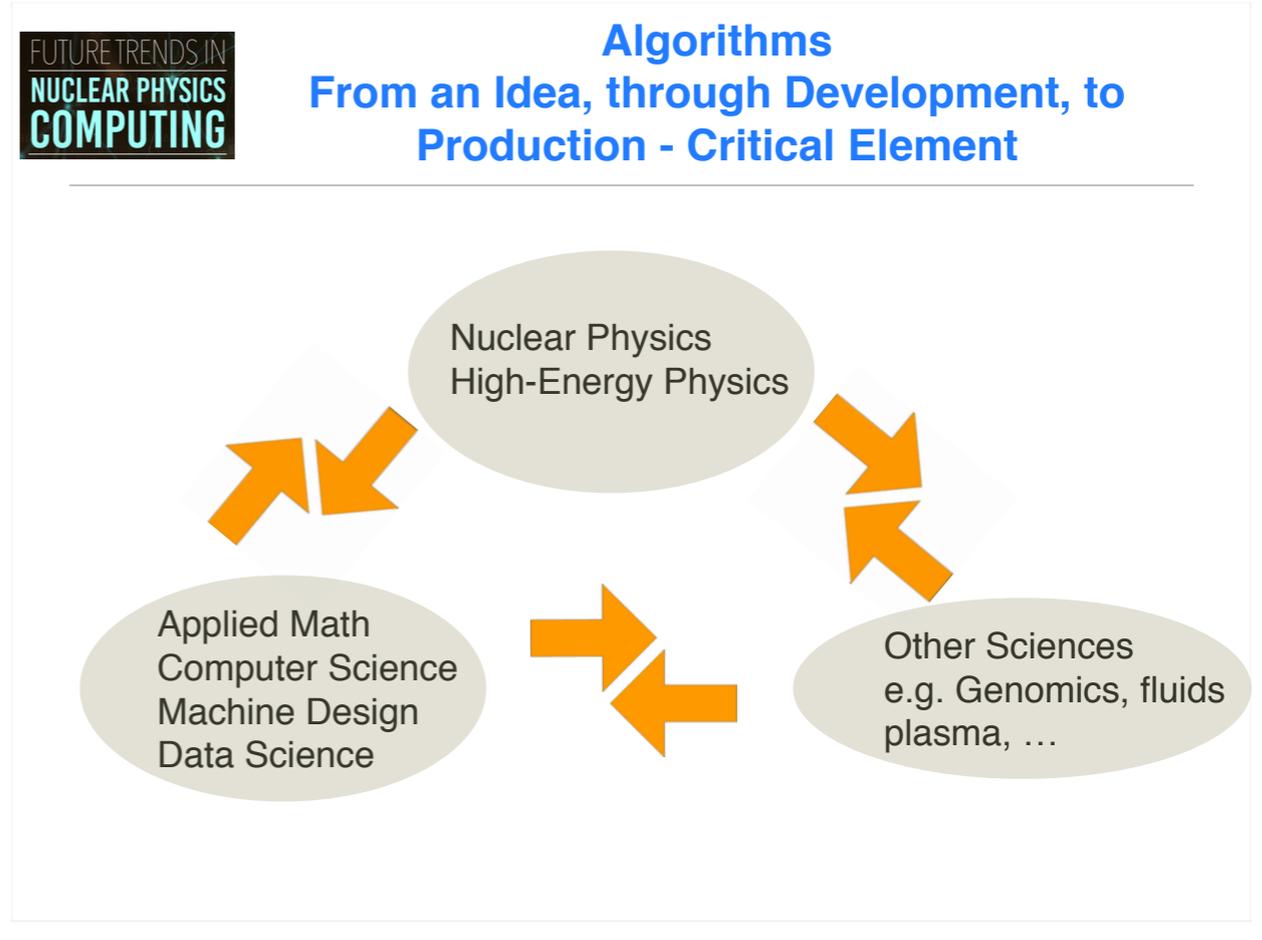
Abstracting the Problem for the Machine Learning Community

FUTURE TRENDS IN NUCLEAR PHYSICS COMPUTING

Nuclear Physics Computing in a Decade

Future Trends in Nuclear Physics Computing
Jefferson Laboratory, May 2, 2017

Martin J Savage
Institute for Nuclear Theory
University of Washington



FUTURE TRENDS IN NUCLEAR PHYSICS COMPUTING

New (disruptive?) Technologies

Quantum Computing

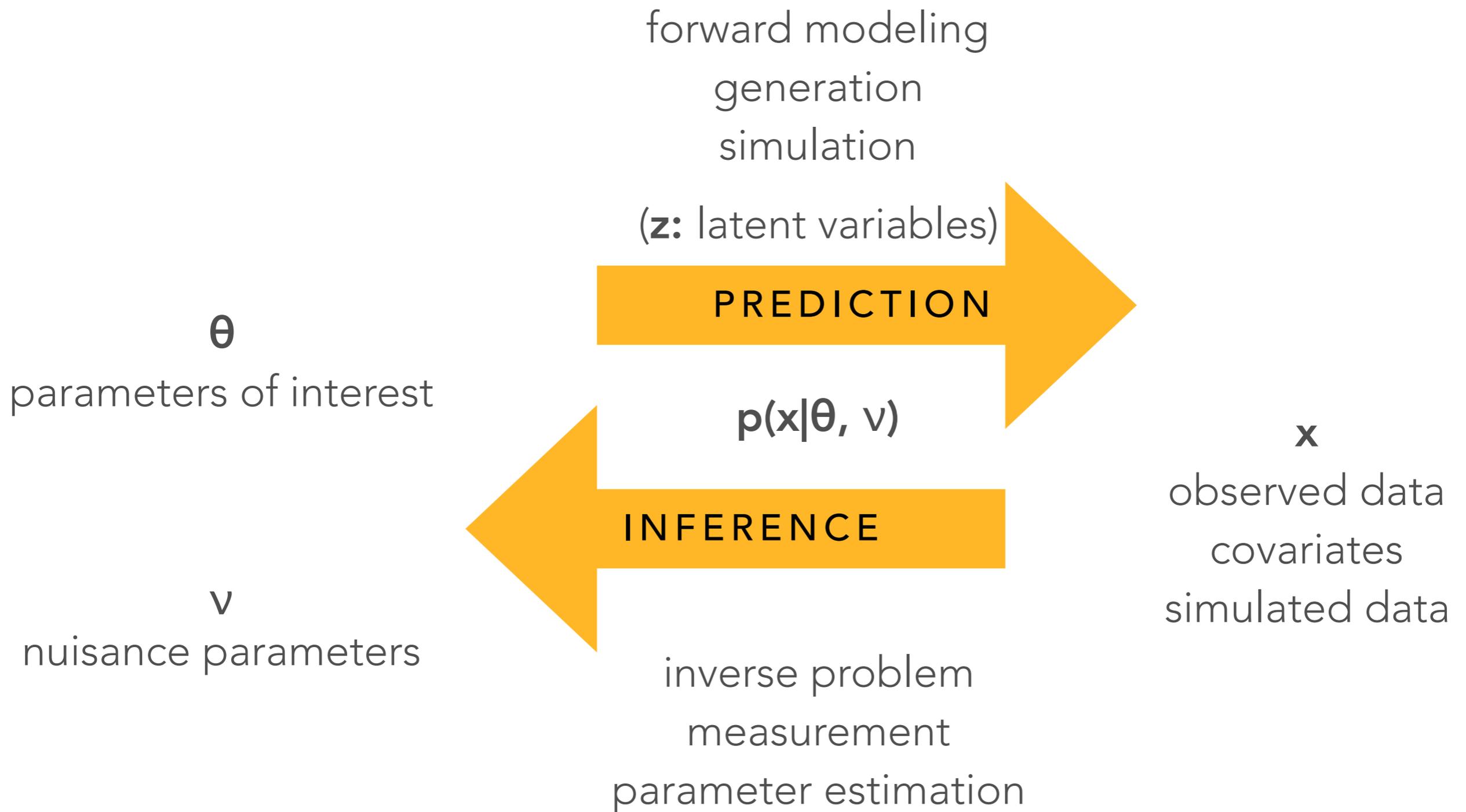
- NP has some computations that require exponential time on a classical computer - quantum computer?
- Microsoft, Google, IBM indicate ~50 qubit QC's up within a year
- NP could start exploring

Quantum Testbeds Stakeholder Workshop
Mayflower Hotel
1127 Connecticut Avenue NW
Washington, DC 20036
February 14 - 16, 2017

Machine Learning

- Already in use in HEP expt at some level
- Sophisticated pattern recognition - correlations in data
- Nonlinear regression on steroids+epo
- Some NP engagement, and much more, would likely be valuable

THE PLAYERS



THE FORWARD MODEL

$$\begin{aligned}
 \mathcal{L}_{SM} = & \underbrace{\frac{1}{4} \mathbf{W}_{\mu\nu} \cdot \mathbf{W}^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} G_{\mu\nu}^a G_a^{\mu\nu}}_{\text{kinetic energies and self-interactions of the gauge bosons}} \\
 + & \underbrace{\bar{L} \gamma^\mu (i\partial_\mu - \frac{1}{2} g \boldsymbol{\tau} \cdot \mathbf{W}_\mu - \frac{1}{2} g' Y B_\mu) L + \bar{R} \gamma^\mu (i\partial_\mu - \frac{1}{2} g' Y B_\mu) R}_{\text{kinetic energies and electroweak interactions of fermions}} \\
 + & \underbrace{\frac{1}{2} |(i\partial_\mu - \frac{1}{2} g \boldsymbol{\tau} \cdot \mathbf{W}_\mu - \frac{1}{2} g' Y B_\mu) \phi|^2 - V(\phi)}_{W^\pm, Z, \gamma, \text{ and Higgs masses and couplings}} \\
 + & \underbrace{g'' (\bar{q} \gamma^\mu T_a q) G_\mu^a}_{\text{interactions between quarks and gluons}} + \underbrace{(G_1 \bar{L} \phi R + G_2 \bar{L} \phi_c R + h.c.)}_{\text{fermion masses and couplings to Higgs}}
 \end{aligned}$$

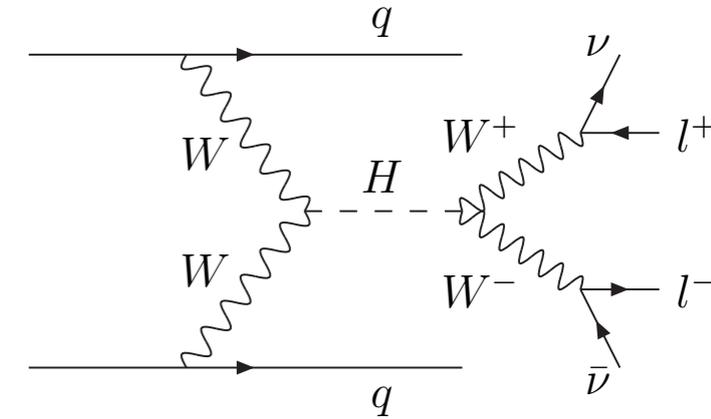
1) We begin with Quantum Field Theory

THE FORWARD MODEL

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 \end{aligned}$$

1) We begin with Quantum Field Theory

2) Theory gives detailed prediction for high-energy collisions



hierarchical: $2 \rightarrow O(10) \rightarrow O(100)$ particles

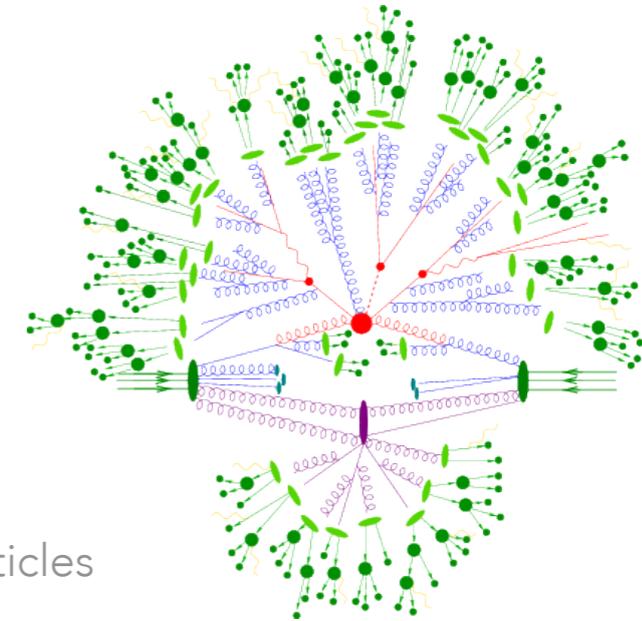
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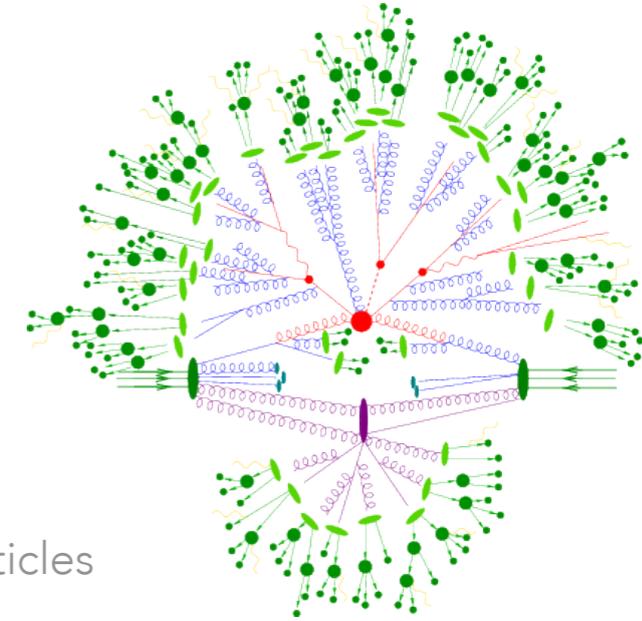
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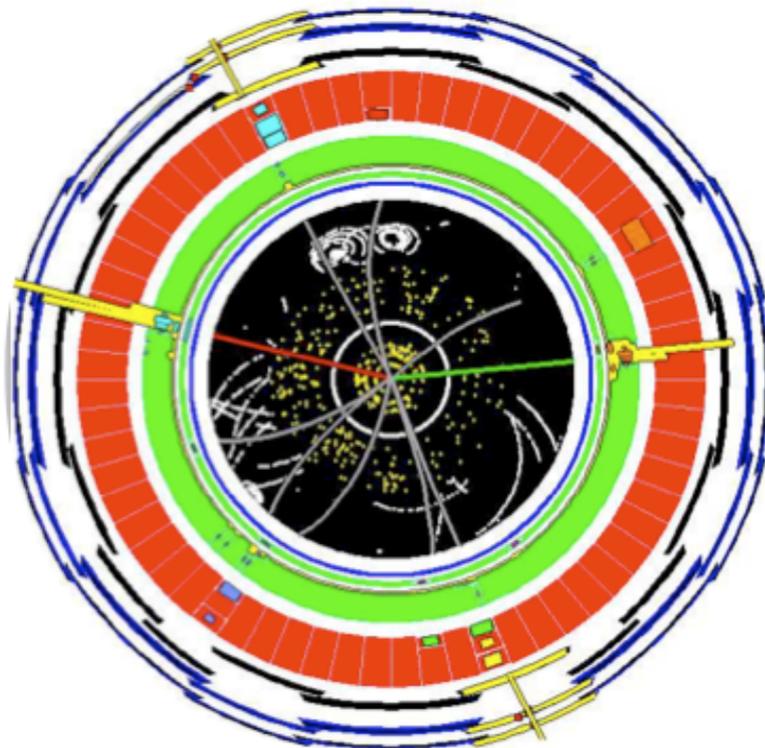
2) Theory gives detailed prediction for high-energy collisions

hierarchical: $2 \rightarrow O(10) \rightarrow O(100)$ particles



3) The interaction of outgoing particles with the detector is simulated.

>100 million sensors

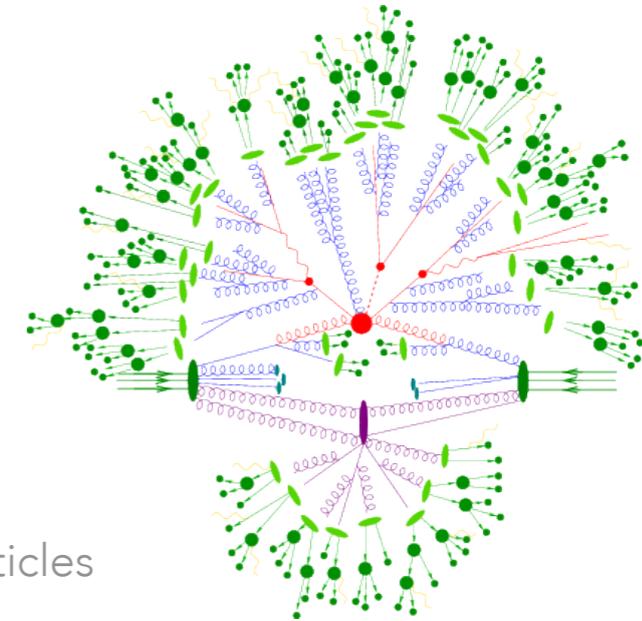


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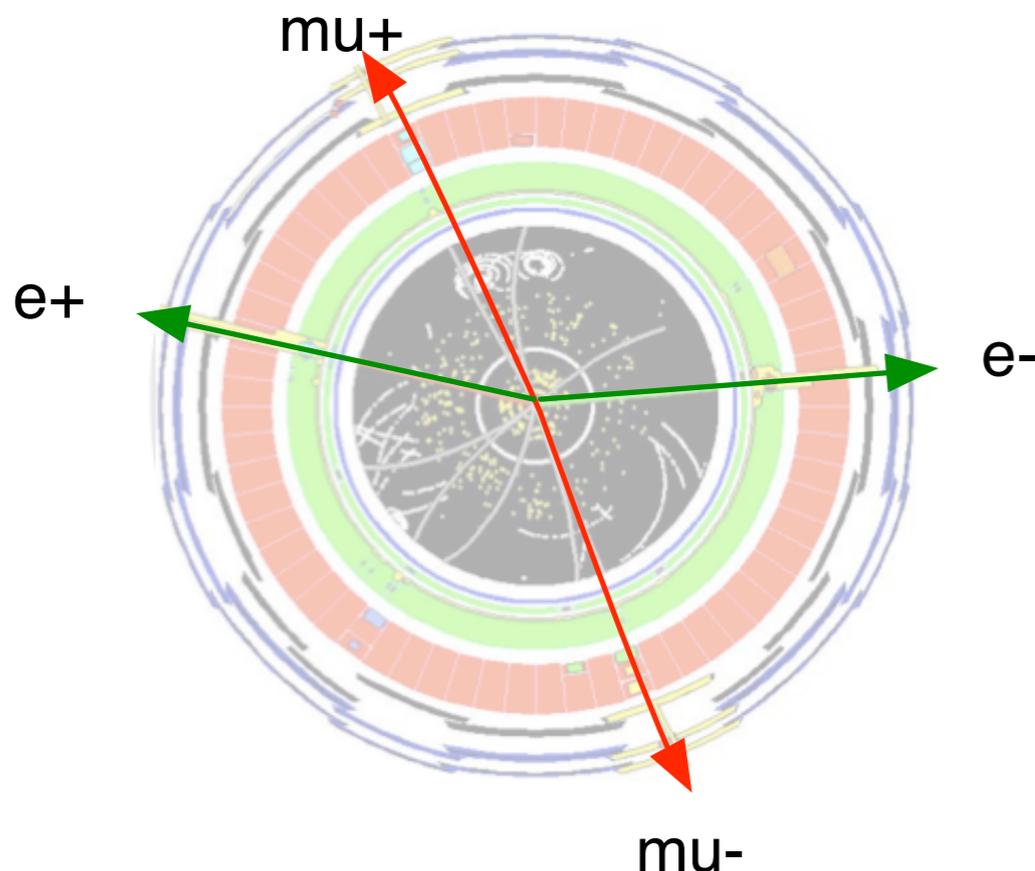
hierarchical: $2 \rightarrow O(10) \rightarrow O(100)$ particles

3) The interaction of outgoing particles with the detector is simulated.

>100 million sensors

4) Finally, we run particle identification and feature extraction algorithms on the simulated data as if they were from real collisions.

~10-30 features describe interesting part

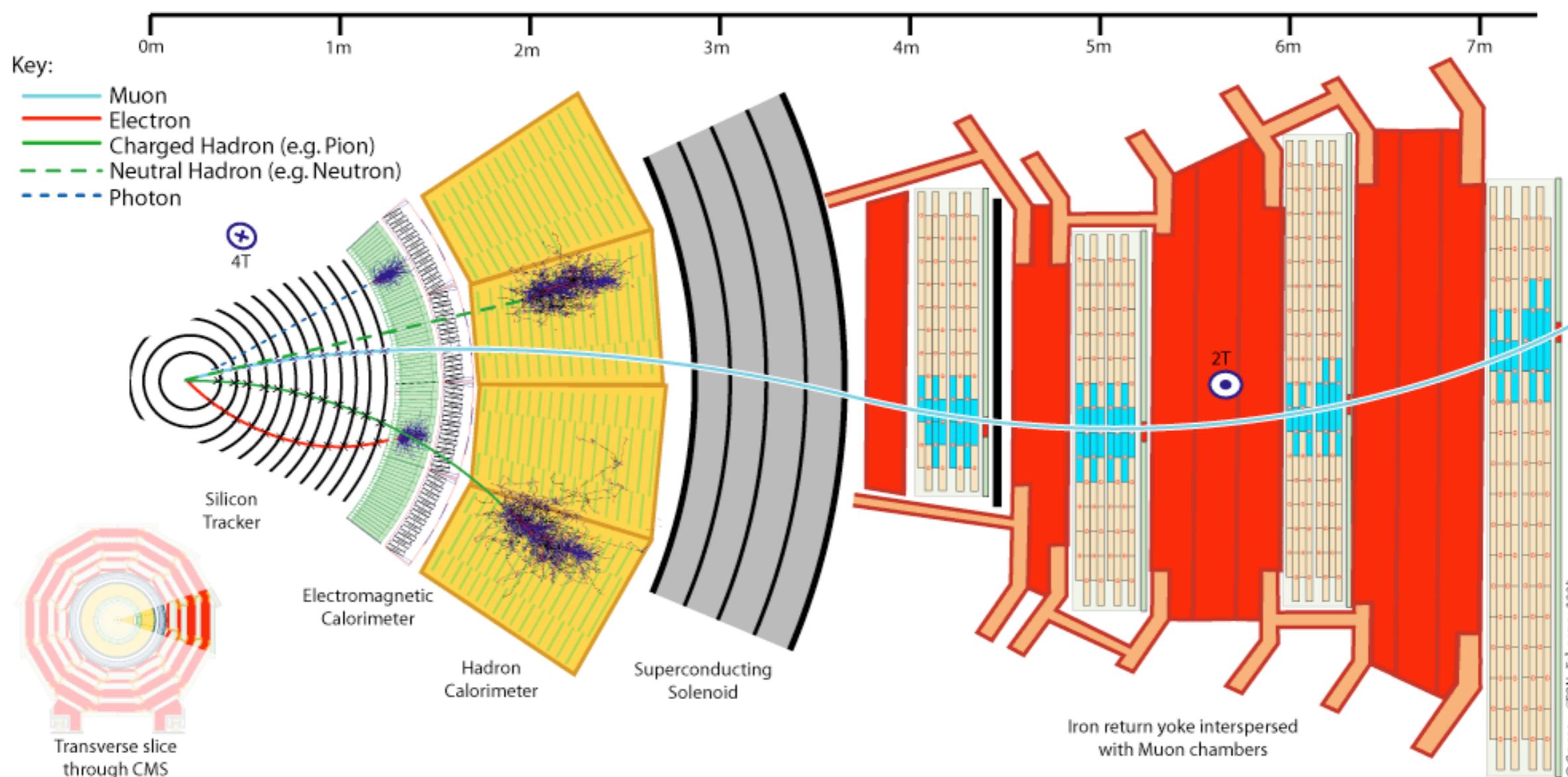


DETECTOR SIMULATION

Conceptually: $\text{Prob}(\text{detector response} \mid \text{particles})$

Implementation: Monte Carlo integration over micro-physics

Consequence: evaluation of the likelihood is intractable



DETECTOR SIMULATION

Conceptually: $\text{Prob}(\text{detector response} \mid \text{particles})$

Implementation: Monte Carlo integration over micro-physics

Consequence: evaluation of the likelihood is intractable

This motivates a new class of algorithms for what is called **likelihood-free inference**, which only require ability to generate samples from the simulation in the “forward mode”

A COMMON THEME

ABC

resources on approximate
Bayesian computational
methods

 Search

Home

Home

This website keeps track of developments in approximate Bayesian computation (ABC) (a.k.a. likelihood-free), a class of computational statistical methods for Bayesian inference under intractable likelihoods. The site is meant to be a resource both for biologists and statisticians who want to learn more about ABC and related methods. Recent publications are under Publications 2012. A comprehensive list of publications can be found under Literature. If you are unfamiliar with ABC methods see the Introduction. Navigate using the menu to learn more.

[ABC in Montreal](#)

[ABC in Montreal \(2014\)](#)

ABC in Montreal

Approximate Bayesian computation (ABC) or likelihood-free (LF) methods have developed mostly beyond the radar of the machine learning community, but are important tools for a large and diverse segment of the scientific community. This is particularly true for systems and population biology, computational neuroscience, computer vision, healthcare sciences, but also many others.

Interaction between the ABC and machine learning community has recently started and contributed to important advances. In general, however, there is still significant room for more intense interaction and collaboration. Our workshop aims at being a place for this to happen.

NIPS 2016

BARCELONA · SPAIN · DECEMBER 5 - 10, 2016 | <http://nips.cc/>

TUTORIALS

Deep Reinforcement Learning Through Policy Optimization
Pieter Abbeel (OpenAI, UC Berkeley) and John Schulman (OpenAI)

Large-scale Optimization: Beyond Stochastic Gradient Descent and Convexity
Francis Bach (INRIA, ENS) and Suvrit Sra (MIT)

Variational Inference: Foundations and Modern Methods
David Blei (Columbia), Shakir Mohamed (Google DeepMind) and Rajesh Ranganath (Princeton)

Natural Language Processing for Computational Social Science
Cristian Danescu-Niculescu-Mizil (Cornell) and Lillian Lee (Cornell)

Generative Adversarial Networks
Ian Goodfellow (OpenAI)

Theory and Algorithms for Forecasting Non-stationary Time Series
Vitaly Kuznetsov (Google) and Mehryar Mohri (Courant Institute, Google Research)

Deep Learning for Building AI Systems
Andrew Ng (Baidu, Stanford University)

ML Foundations and Methods for Precision Medicine and Healthcare
Suchi Saria (Johns Hopkins) and Peter Schulam (Johns Hopkins)

Crowdsourcing: Beyond Label Generation
Jenn Wortman Vaughan (Microsoft Research)

INVITED SPEAKERS

Reproducible Research: the Case of the Human Microbiome
Susan Holmes (Stanford University)

Dynamic Legged Robots
Marc Raibert (Boston Dynamics)

Intelligent Biosphere
Drew Purves (Google DeepMind)

Predictive Learning
Yann LeCun (Facebook and New York University)

Machine Learning and Likelihood-Free Inference in Particle Physics
Kyle Cranmer (New York University)

Learning About the Brain: Neuroimaging and Beyond
Irina Rish (IBM T.J. Watson Research Center)

Engineering Principles From Stable And Developing Brains
Saket Navlakha (The Salk Institute for Biological Studies)

SYMPOSIA

Recurrent Neural Networks and other Machines that Learn Algorithms
Alex Graves (Google DeepMind)
Juergen Schmidhuber (IDSIA)
Rupesh Srivastava (IDSIA)
Sepp Hochreiter (Johannes Kepler University)

Deep Learning
Navdeep Jaitly (Google)
Roger Grosse (University of Toronto)
Yann LeCun (New York University & Facebook)

Machine Learning and the Law
Adrian Weller (Cambridge, Alan Turing Inst.)
Conrad McDonnell (Gray's Inn Tax Chambers)
Jatinder Singh (University of Cambridge)
Thomas Grant (University of Cambridge)

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Microsoft Research
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Kun Zhang, CMU



Conclusions

CONCLUSIONS

A large portion of the scientific process involves interaction between theory and experiment

- The scientific process does not end when the results of an analysis are published in a paper!
- this requires a different type of infrastructure
- often neglected or addressed post-facto

I recommend targeted approach to theory/experiment interface

- An open-ended approach often gets bogged down
- start by identifying problems of scientific value with limited scope

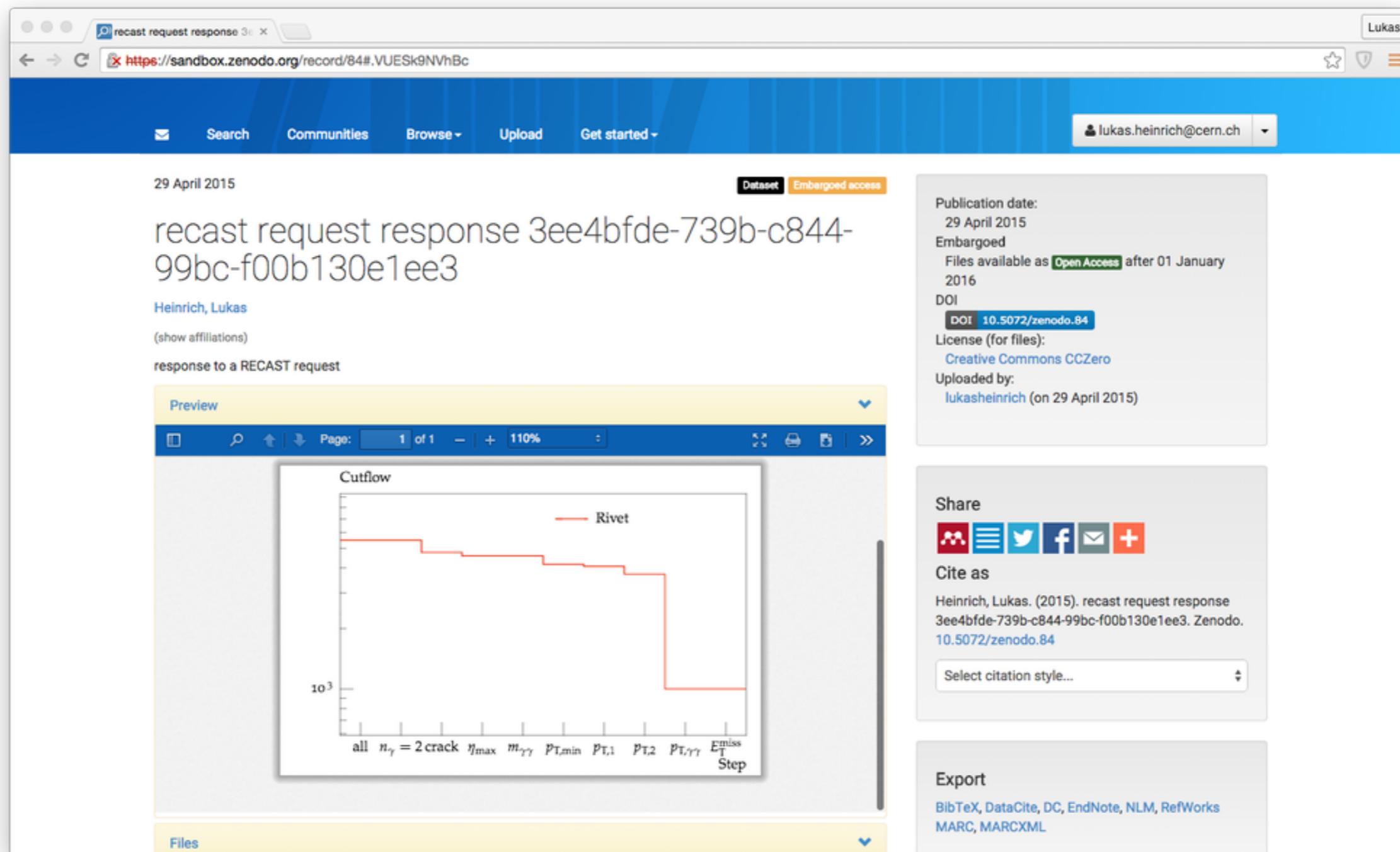
Reusable & composable workflows are incredibly helpful and recent technology from industry makes it possible

Backup

EXAMPLE RECAST → HEPDATA / ZENODO

After re-running analysis on new physics model, experiments might want to push result of new interpretation to HEPData. Technically we can do this with Zenodo. Discussing with HEPData and INSPIRE to have API connection to upload result. Both are based on Invenio, so should be easy.

- this allows for new results to get a DOI and be associated with the original analysis publication



The screenshot shows a Zenodo record page for a dataset titled "recast request response 3ee4bfde-739b-c844-99bc-f00b130e1ee3" by Heinrich, Lukas, dated 29 April 2015. The page is marked as "Dataset" and "Embargoed access". The DOI is 10.5072/zenodo.84. The license is Creative Commons CCZero. The dataset is available as Open Access after 01 January 2016. The upload date is 29 April 2015 by lukasheinrich.

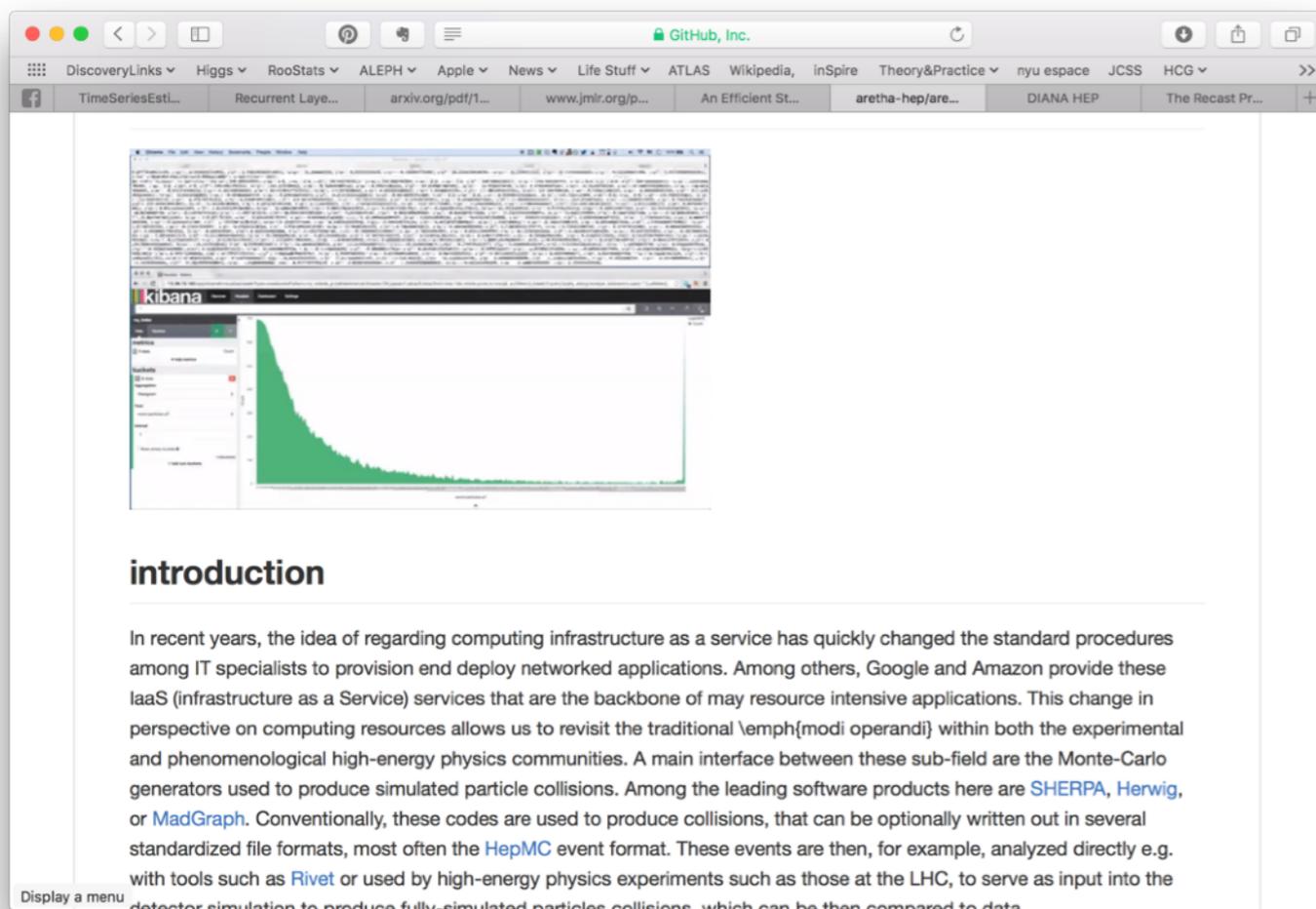
The main content is a preview of a plot titled "Cutflow". The plot shows a red line representing the "Rivet" cutflow. The y-axis is on a logarithmic scale with a tick at 10^3 . The x-axis is labeled "Step" and includes categories: all, $n_\gamma = 2$, crack, η_{max} , $m_{\gamma\gamma}$, $p_{T,min}$, $p_{T,1}$, $p_{T,2}$, $p_{T,\gamma\gamma}$, and E_T^{miss} . The cutflow starts at a high value and decreases stepwise through these categories, ending at a value around 10^3 .

On the right side, there are sections for "Share" (with social media icons) and "Export" (with options like BibTeX, DataCite, DC, EndNote, NLM, RefWorks, MARC, MARCXML).

"NETFLIX FOR MONTE CARLO"

Lukas has prototyped a web service called Aretha that encapsulates Monte Carlo tools and wraps them as a web service.

- Specific version of "cards" configuring Monte Carlo generator
- specific installation (stored in a docker container) that ensures version of generator and other dependencies (compiler etc.)



<https://github.com/aretha-hep/aretha-doc>

- ideally, give DOIs to the generator cards and docker container
- can generate more consistent MC on demand

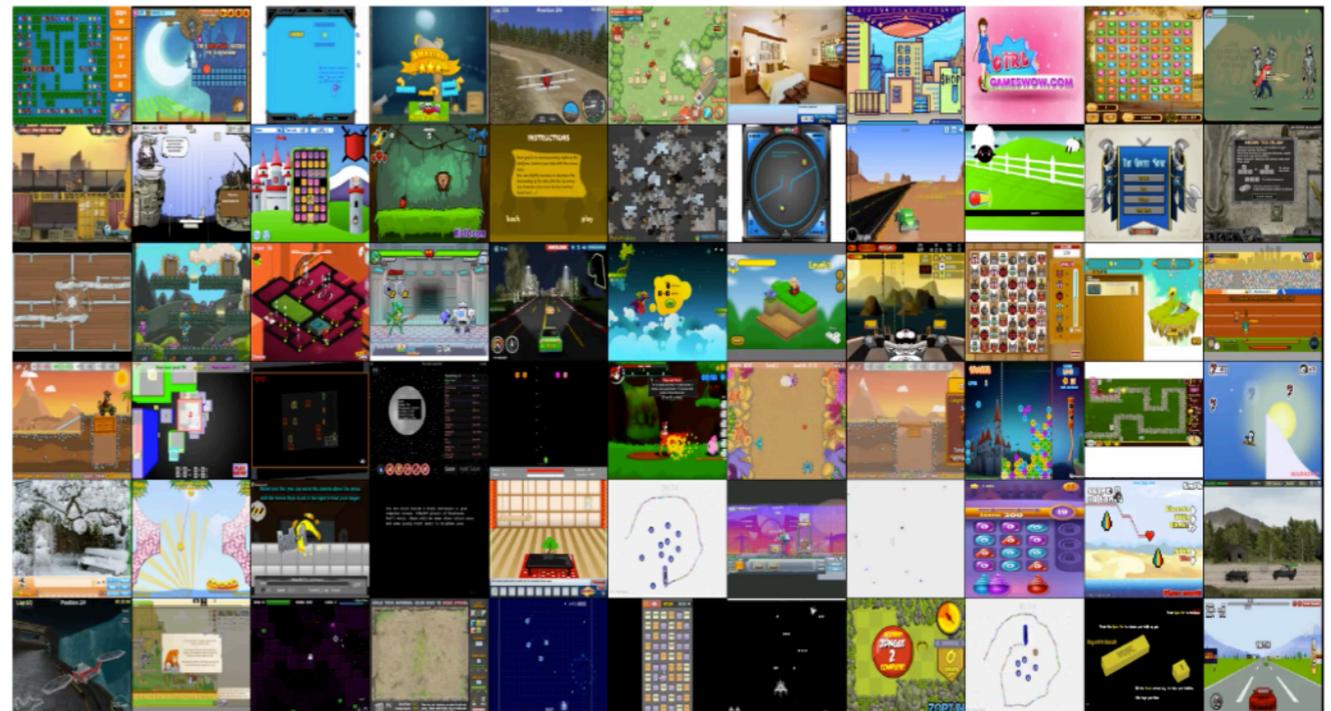
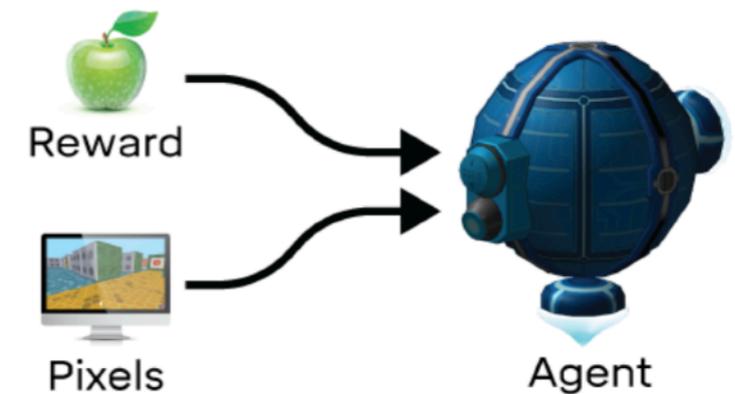
LIKELIHOOD FREE INFERENCE

DeepMind and OpenAI releasing simulators to train advanced machine learning models

Similarly, HEP could / should release simulation tools and analysis workflows to produce training data for ML.

Also, new “likelihood-free” inference techniques (like Approximate Bayesian Computation) require running the simulation

Observations



A sample of Universe game environments played by human demonstrators.

Create standalone simulation tools to facilitate collaboration between HEP and machine learning community

By [Pierre Baldi](#), [Peter Sadowski](#), [Daniel Whiteson](#), [Christian Lorenz Müller](#), [Michael Williams](#), [Lukas Heinrich](#), [Steven Schramm](#), [Maurizio Pierini](#), [Sergei Gleyzer](#), [Amir Farbin](#), [jean-roch vlimant](#), [Tim Head](#), [Juan Pavez](#), [Peter Elmer](#), [Balázs Kégl](#), [Andrey Ustyuzhanin](#), [Vladimir Gligorov](#), [Gilles Louppe](#), [Kyle Cranmer](#)

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Metadata

DOI [10.5281/zenodo.46864](#)

Published: 26 Feb, 2016



[dslhc](#) [machinelearning](#) [datascience](#) [open data](#) [simulation](#)

Discussions at recent workshops have made it clear that one of the key barriers to collaboration between high energy physics and the machine learning community is access to training data. Recent successes in data sharing through the [HiggsML](#) and [Flavours of Physics](#) Kaggle challenges have borne much fruit, but required significant effort to coordinate.

While static simulated datasets are useful for challenges, in the course of investigating new machine learning techniques it is advantageous to be able to generate training data on demand (e.g. Refs. [1](#), [2](#), [3](#)).

Therefore we recommend efforts be made to produce the ingredients required to facilitate such collaboration:

- Specific challenges for HEP experiments should be fully specified such that minimal domain-specific knowledge is required to attack them.
- Stand-alone simulators should be made open source. They should be developed to be easy to use without domain-specific expertise, while still being representative of real experimental challenges. Such a simulation will permit non-HEP researchers to generate realistic HEP datasets for training and testing. These simulators could range from truth-level simulation of a hard scattering to fast simulation like [Delphes](#), to full [GEANT4](#) simulation of sensor arrays.
- Performance metrics (objective functions) and operational constraints should be defined to evaluate proposed solutions.

ENCAPSULATING THE SIMULATION



<https://github.com/lukasheinrich/weinberg-test>

README.md

Run HEP workflows from the web.

by [Kyle Cranmer](#) and [Lukas Heinrich](#)

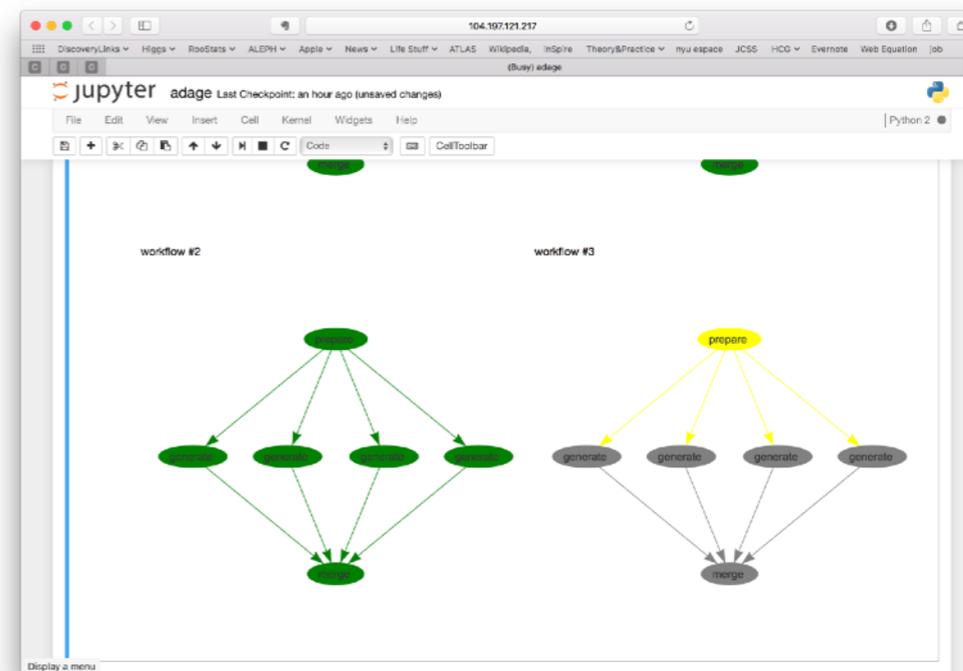
An example notebook on how to generate simulated high energy physics collision events using the generator package MadGraph. Simulated datasets obtained from this notebook can then be used to train and evaluate the performance of generative models for physics.

Usage:

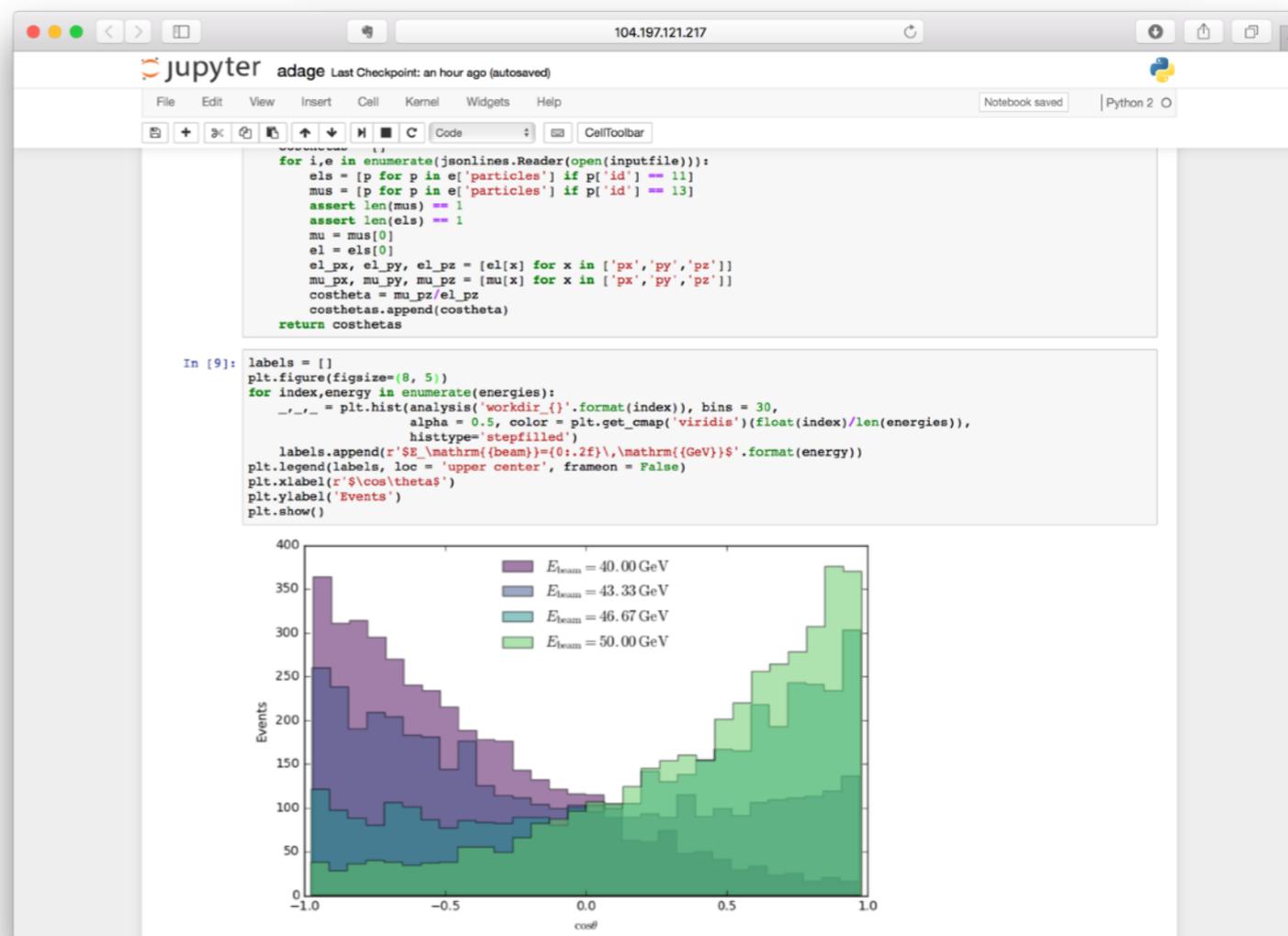
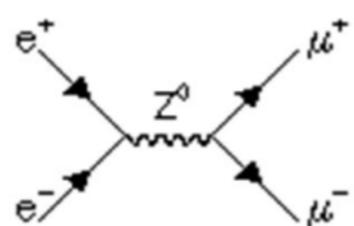
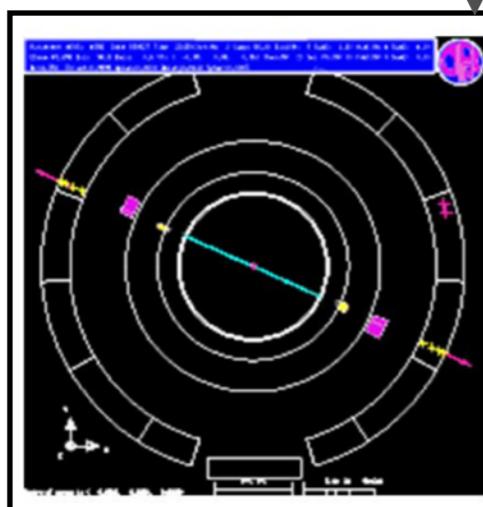
This repository has been equipped with a Dockerfile to encapsulate its software environment. It can be used with the [mybinder](#) service to launch an ephemeral jupyter notebook server to run the notebook.

Click on the below badge and open the notebook `adage.ipynb`.

[launch binder](#)



$$\begin{aligned}
 \mathcal{L}_{SM} = & \underbrace{\frac{1}{4} \mathbf{W}_{\mu\nu} \cdot \mathbf{W}^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} G_{\mu\nu}^a G_a^{\mu\nu}}_{\text{kinetic energies and self-interactions of the gauge bosons}} \\
 & + \underbrace{\bar{L} \gamma^\mu (i\partial_\mu - \frac{1}{2} g\tau \cdot \mathbf{W}_\mu - \frac{1}{2} g' Y B_\mu) L + \bar{R} \gamma^\mu (i\partial_\mu - \frac{1}{2} g' Y B_\mu) R}_{\text{kinetic energies and electroweak interactions of fermions}} \\
 & + \underbrace{\frac{1}{2} |(i\partial_\mu - \frac{1}{2} g\tau \cdot \mathbf{W}_\mu - \frac{1}{2} g' Y B_\mu) \phi|^2 - V(\phi)}_{\text{W}^\pm, Z, \gamma, \text{ and Higgs masses and couplings}} \\
 & + \underbrace{g'' (\bar{q} \gamma^\mu T_a q) G_\mu^a}_{\text{interactions between quarks and gluons}} + \underbrace{(G_1 \bar{L} \phi R + G_2 \bar{L} \phi_c R + h.c.)}_{\text{fermion masses and couplings to Higgs}}
 \end{aligned}$$



Analysis as a function mapping data and models to results

$$\text{result} = f_{\text{analysis}}(\text{data} | \text{model})$$

observable distributions,
confidence intervals
on model parameters

reconstruction, event
selection, stat. evaluation

collision data from LHC detector

model hypothesis
(SM, many SUSY models,
etc..)



Analysis Preservation: two-step process

Modern HEP analysis:

- Multiple steps/code-bases, possibly developed by independent teams, with differing software requirements. Example: one team developing the event selection, another team developing the statistical analysis

Need to capture:

1. Individual processing steps

- code bases
- software environments
- identify binaries, scripts in code base
- templates how to run binaries (semantic description of arguments, naming etc..)
- description of step output, what are the relevant data fragments

2. How to connect these steps

- How to wire individual steps together
- What outputs of which steps, are used as inputs for other steps, ...

Goal: capture all this with least amount of work for analysis teams, preferably *while analysis is being developed*. *Should not take more than a few days*



How to preserve $f_{\text{analysis}}(\cdot)$?

1. Problem: Preserve Individual Processing Steps

(Example: Run Detector Simulation + Reconstruction on MC events)

Example:

```
process:
  process_type: 'string-interpolated-cmd'
  cmd: 'DelphesHepMC {delphes_card} {outputroot} {inputhepmc}'
publisher:
  publisher_type: 'frompar-pub'
  outputmap:
    rootfile: outputroot
environment:
  environment_type: 'docker-encapsulated'
  image: lukasheinrich/root-delphes
```

python package: “packtivity”

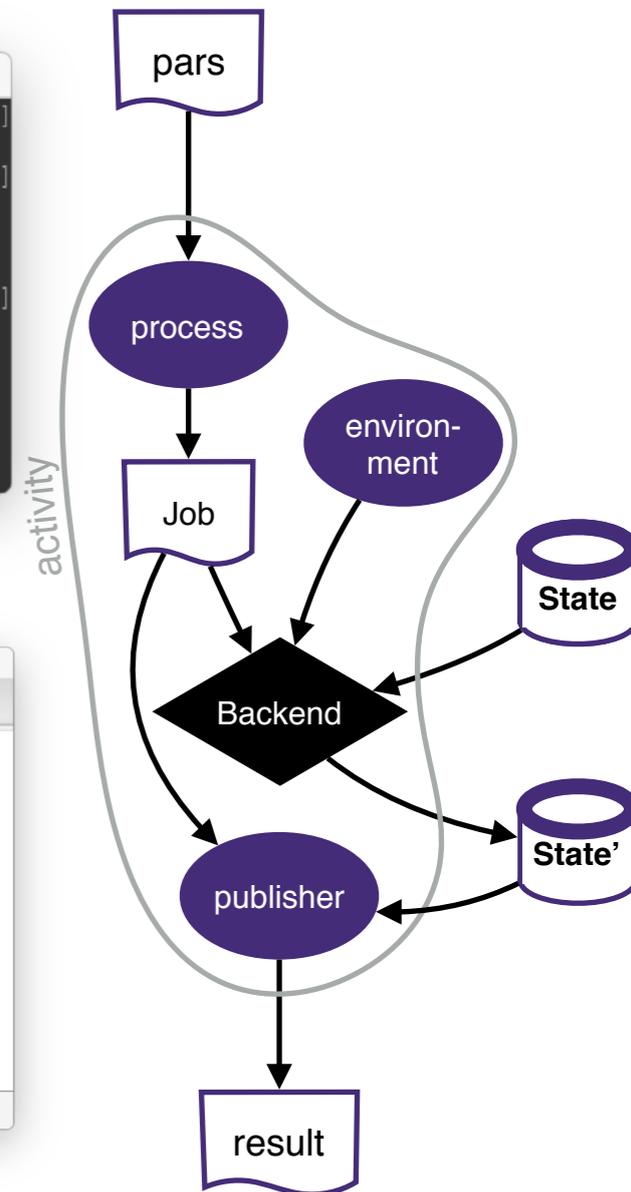
- executes packtivities according to JSON spec for given parameters
- cli tool and python bindings
- multi-host / remote execution ready via e.g. Docker Swarm

CLI tool

```
172-27-219-223 — -zsh — 64x12
[$> ls
delphes.yml input.hepmc pars.yml
[$> pygmentize -g pars.yml
delphes_card: 'delphes/cards/delphes_card_ATLAS.tcl'
inputhepmc: '{workdir}/input.hepmc'
outputroot: '{workdir}/out.root'
[$> packtivity-run delphes.yml pars.yml
{'rootfile': '/Users/lukas/chep2016/out.root'} (prepublished)
[$>
```

python bindings

```
pack.py — /Users/lukas/chep2016
pack.py
1 import os
2 import capschemas
3 from packtivity import packtivity
4 from packtivity.statecontexts.poxisfs_context import make_new_context
5 packtivity_description = capschemas.load(
6     'delphes.yml', os.curdir,
7     'packtivity/packtivity-schema')
8 pars = {
9     delphes_card: 'delphes/cards/delphes_card_ATLAS.tcl',
10    inputhepmc: '{workdir}/input.hepmc',
11    outputroot: '{workdir}/out.root'
12 }
13 packtivity(packtivity_description, parameters, make_new_context(os.curdir))
Line 0 File 0 Project 0 ✓ No Issues pack.py* 15:1 LF UTF-8 Python 3 updates
```



How to preserve $f_{\text{analysis}}(\cdot)$?

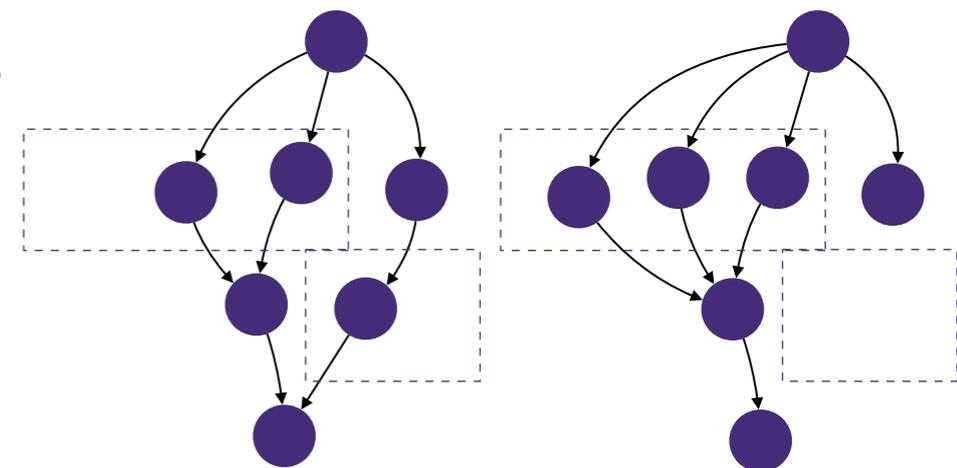
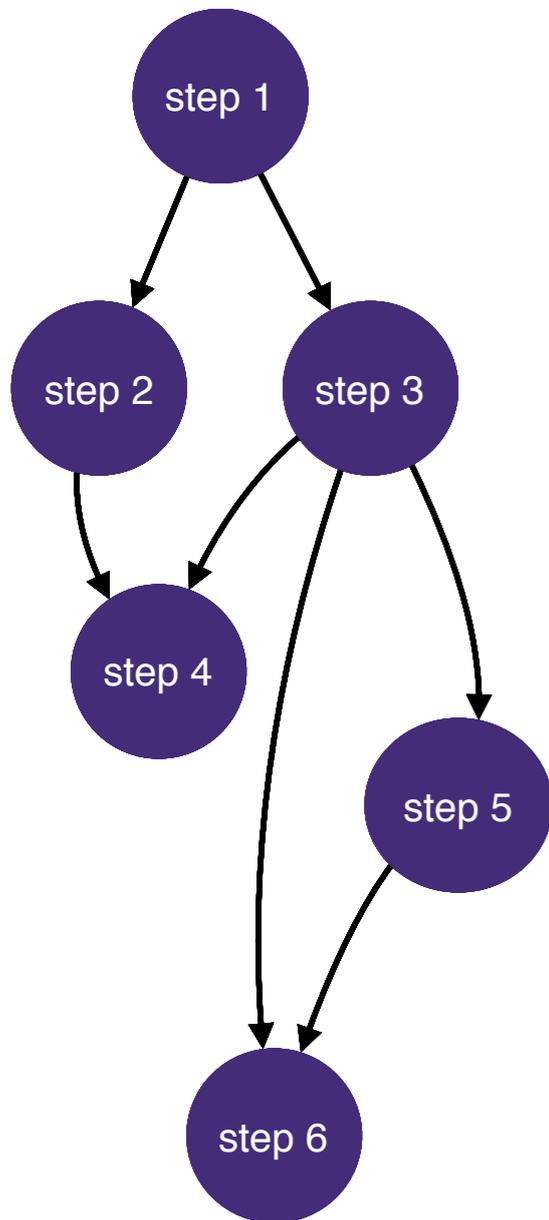
2. Problem: Preserve Parametrized Workflow

Natural Data Model: *directed acyclic graphs (DAGs)*

- **nodes**: individual steps
- **edges**: dependency relations

Two place where parametrization enter:

1. individual steps parametrized: covered by “packtivities”
graph topology may *depend on the parameters* of the analysis and only emerge during run-time
2. Examples:
 - variable number of created files during execution,
 - conditional choices (if/else)/flags do enable/disable steps, e.g. run systematics / not



Par. Set 1

Par. Set 2

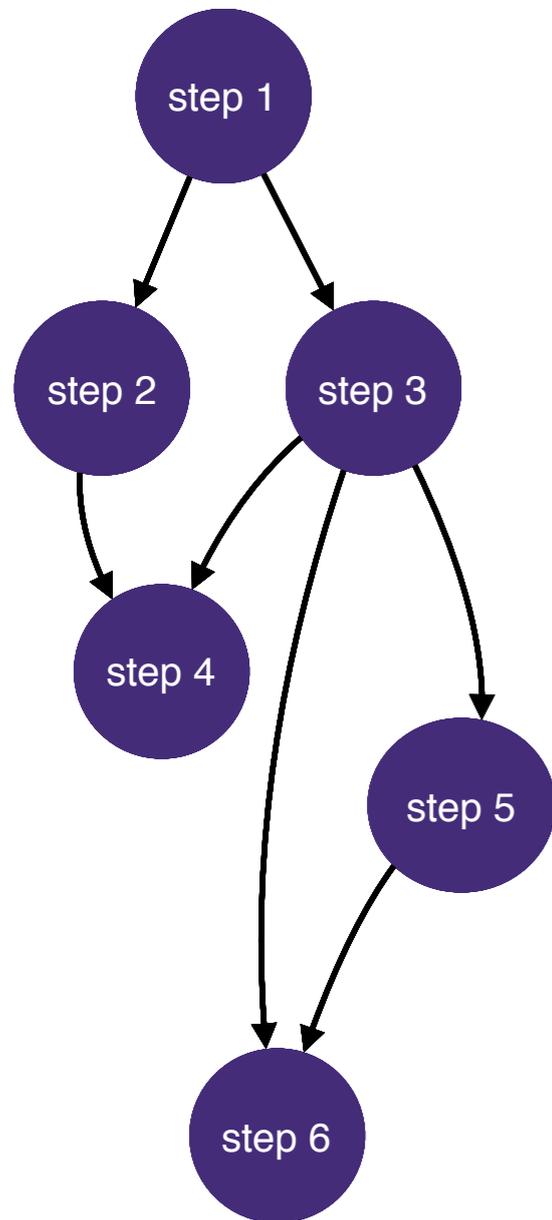


How to preserve $f_{\text{analysis}}(\cdot)$?

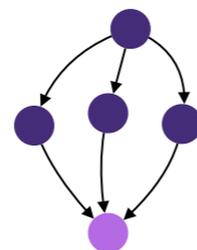
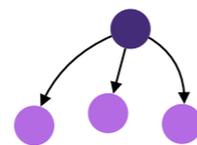
2. Problem: Preserve Parametrized Workflow

Therefore: Sequentially build up graph, as sufficient information becomes available, using a number of stages that add nodes and edges

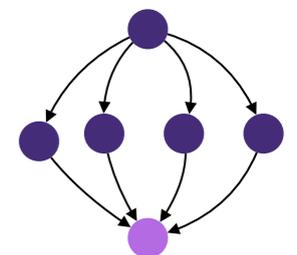
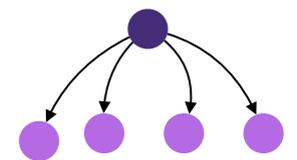
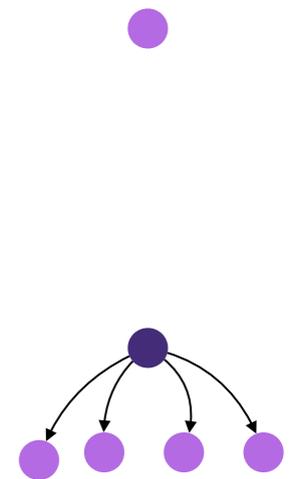
To capture analysis workflow, capture the stages.



**Example:
Parametrized
Map-Reduce**



Par. Set 1



Par. Set 2

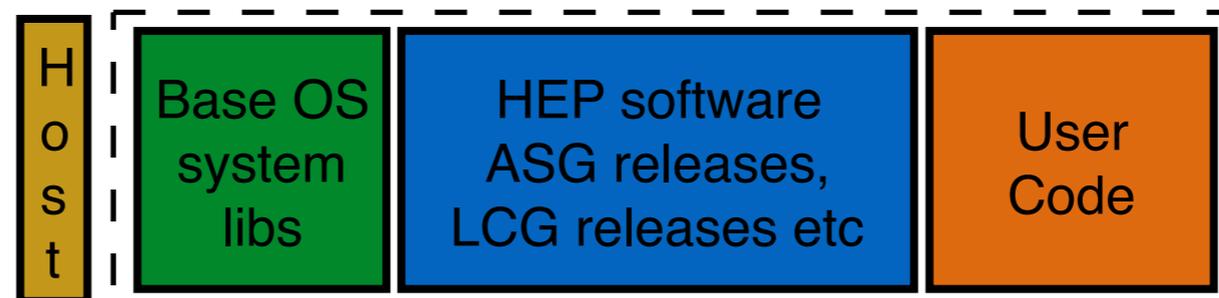


Technical Solution:

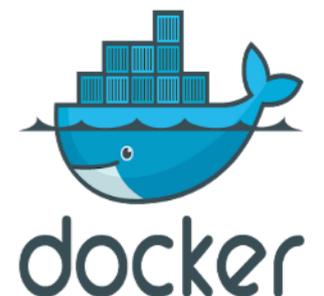
Preserve Software using industry standard Linux Containers (Docker)

- industry backed (Google, Amazon, ...) solution for reproducible software environments. Like a VM, but boots in milliseconds.
- complete freedom for analysis team on software choices. Makes no assumption on how you run your code (“snapshot your work directory”)
- can capture using a script or in an interactive session :

```
lxlus> docker run ... #start snapshot session  
container> svn co ...  
container> make ...  
lxlus> docker commit ... #save snapshot of workdir
```



Docker Image. Think: executable filesystem snapshot



Many people contributing now. Contributions from CERN, DASPOS, DIANA, GitHub, Moore-Sloan Data Science Environment at NYU, Notre Dame, Nebraska, ...

Using **yadage** and **packtivity** JSON schemas developed by Lukas Heinrich and described in draft DASPOS technical report for packaging realistic LHC analyses

CERN Analysis Portal (CAP) is able to store and serve up analysis workflows stored in this format.

New front-end webpage thanks to Christian Bora (Nebraska, DASPOS) and Eamonn Maguire (CERN)

