Institute for Research and Innovation in Software for High Energy Physics (IRIS-HEP)

Presented by Henry Schreiner at ECHEP 2020

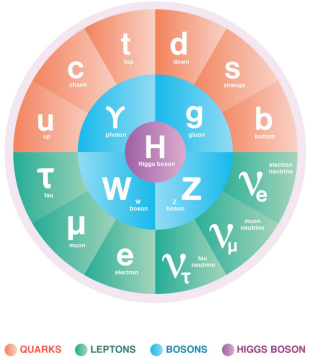
PI: Peter Elmer (Princeton), co-PIs: Brian Bockelman (Morgridge Institute), Gordon Watts (U.Washington) with UC-Berkeley, University of Chicago, University of Cincinnati, Cornell University, Indiana University, MIT, U.Michigan-Ann Arbor, U.Nebraska-Lincoln, New York University, Stanford University, UC-Santa Cruz, UC-San Diego, U.Illinois at Urbana-Champaign, U.Puerto Rico-Mayaguez and U.Wisconsin-Madison

February 17, 2020

http://iris-hep.org

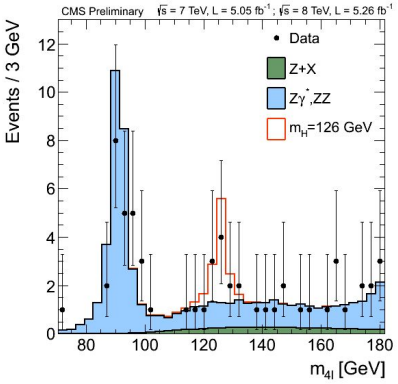
OAC-1836650

Science Driver: Discoveries beyond the Standard Model of Particle Physics

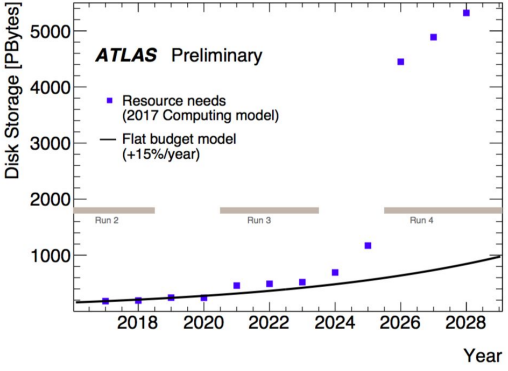


From "Building for Discovery - Strategic Plan for U.S. Particle Physics in the Global Context" - Report of the Particle Physics Project Prioritization Panel (P5):

1) Use the Higgs boson as a new tool for discovery
2) Pursue the physics associated with neutrino mass
3) Identify the new physics of dark matter
4) Understand cosmic acceleration: dark matter and inflation
5) Explore the unknown: new particles, interactions, and physical principles

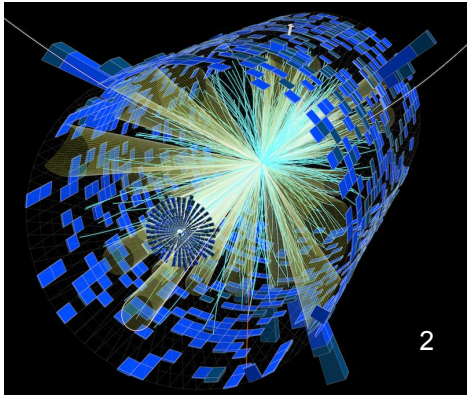


Computational and Data Science Challenges of the High Luminosity Large Hadron Collider (HL-LHC) and other HEP experiments in the 2020s

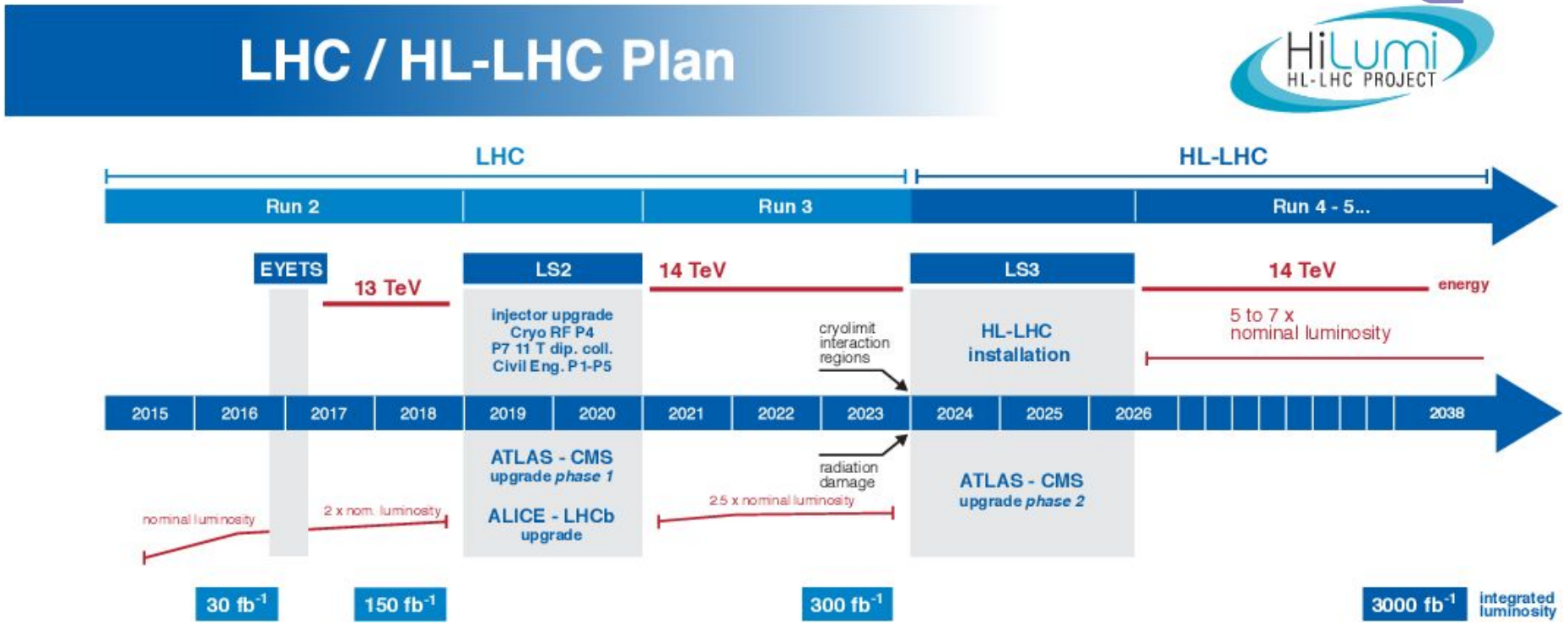


The HL-LHC will produce exabytes of science data per year, with increased complexity: an average of 200 overlapping proton-proton collisions per event.

During the HL-LHC era, the ATLAS and CMS experiments will record ~10 times as much data from ~100 times as many collisions as were used to discover the Higgs boson (and at twice the energy).



Timeline



CTDR

S2I2-HEP

IRIS-HEP Institute

Design | Execution

Snowmass

Institute Conceptualization and Community White Paper Process

CERN HL-LHC Planning - Computing Technical Design Reports (CTDR) - ATLAS/CMS

U.S. HEP Community Planning Process

Developing a Global R&D Roadmap

NSF funded the S2I2-HEP Conceptualization Project (s2i2-hep.org/) in July 2016

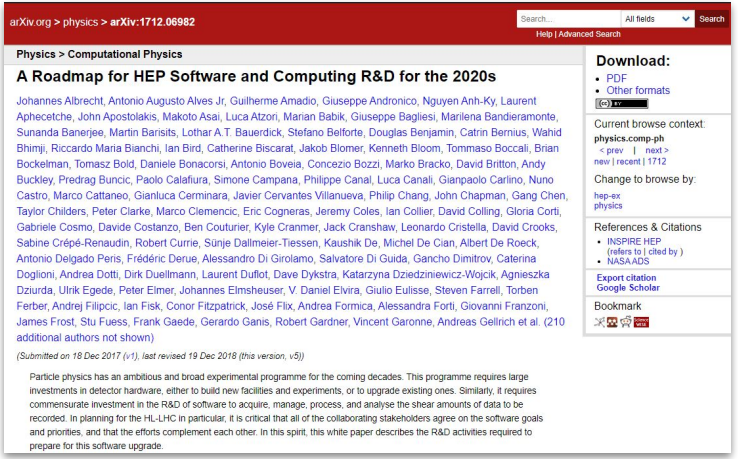
Community charge from the Worldwide LHC Computing Grid in July 2016:

- Anticipate a "software upgrade" in preparation for the HL-LHC
- Identify and prioritize the software research and developments investments
  1. to achieve improvements in software efficiency, scalability and performance and to make use of the advances in CPU, storage and network technologies
  2. to enable new approaches to computing and software that could radically extend the physics reach of the detectors
  3. to ensure the long term sustainability of the software through the lifetime of the HL-LHC

Community White Paper

January 2017
UCSD

June 2017
Annecy



arXiv.org > physics > arXiv:1712.06982

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Physics > Computational Physics

A Roadmap for HEP Software and Computing R&D for the 2020s

Johannes Albrecht, Antonio Augusto Alves Jr, Guilherme Amadio, Giuseppe Andronico, Nguyen Anh-Ky, Laurent Aphecetche, John Apostolakis, Makoto Asai, Luca Atzori, Marian Babik, Giuseppe Bagliesi, Marilena Bandieramonte, Sunanda Banerjee, Martin Barisits, Lothar A.T. Bauerdick, Stefano Belforte, Douglas Benjamin, Catrin Bernius, Wahid Bhimji, Riccardo Maria Bianchi, Ian Bird, Catherine Biscarat, Jakob Blomer, Kenneth Bloom, Tommaso Boccali, Brian Bockelman, Tomasz Bold, Daniele Bonacorsi, Antonio Boveia, Concezio Bozzi, Marko Bracko, David Britton, Andy Buckley, Predrag Buncic, Paolo Calafiura, Simone Campana, Philippe Canal, Luca Canali, Gianpaolo Carlino, Nuno Castro, Marco Cattaneo, Gianluca Cerminara, Javier Cervantes Villanueva, Philip Chang, John Chapman, Gang Chen, Taylor Childers, Peter Clarke, Marco Clemencic, Eric Cogneras, Jeremy Coles, Ian Collier, David Colling, Gloria Corti, Gabriele Cosmo, Davide Costanzo, Ben Couturier, Kyle Cranmer, Jack Cranshaw, Leonardo Cristella, David Crooks, Sabine Crépé-Renaudin, Robert Currie, Sünje Dallmeier-Tiessen, Kaushik De, Michel De Cian, Albert De Roeck, Antonio Delgado Peris, Frédéric Derue, Alessandro Di Girolamo, Salvatore Di Guida, Gancho Dimitrov, Caterina Doglioni, Andrea Dotti, Dirk Duellmann, Laurent Duflot, Dave Dykstra, Katarzyna Dziedziniewicz-Wojcik, Agnieszka Dziurda, Ulrik Egede, Peter Elmer, Johannes Elmsheuser, V. Daniel Elvira, Giulio Eulisse, Steven Farrell, Torben Ferber, Andrej Filipcic, Ian Fisk, Conor Fitzpatrick, José Flix, Andrea Formica, Alessandra Forti, Giovanni Franzoni, James Frost, Stu Fuess, Frank Gaede, Gerardo Ganis, Robert Gardner, Vincent Garonne, Andreas Gellrich et al. (210 additional authors not shown)

(Submitted on 18 Dec 2017 (v1), last revised 19 Dec 2018 (this version, v5))

Particle physics has an ambitious and broad experimental programme for the coming decades. This programme requires large investments in detector hardware, either to build new facilities and experiments, or to upgrade existing ones. Similarly, it requires commensurate investment in the R&D of software to acquire, manage, process, and analyse the shear amounts of data to be recorded. In planning for the HL-LHC in particular, it is critical that all of the collaborating stakeholders agree on the software goals and priorities, and that the efforts complement each other. In this spirit, this white paper describes the R&D activities required to prepare for this software upgrade.

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- NASA ADS

Export citation
Google Scholar

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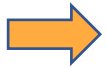
Many workshops, involving a diverse group
- International participants
- Computing Management from the Experiments and Labs
- Individuals interested in the problems
- Members of other compute intensive scientific endeavors
- Members of Industry
- http://s2i2-hep.org/
- https://hepsoftwarefoundation.org/

Individual Papers on the arXiv:

Careers & Training, Conditions Data, DOMA, Data Analysis & Interpretation, Data and Software Preservation, Detector Simulation, Event/Data Processing Frameworks, Facilities and Distributed Computing, Machine Learning, Physics Generators, Security, Software Development, Deployment, Validation, Software Trigger and Event Reconstruction, Visualization

Community White Paper & the Strategic Plan

arXiv 1712.06982 arXiv 1712.06592



IRIS-HEP

Community Building

IRIS-HEP came out of the S2I2-HEP: Conceptualization Process

This was a community building exercise:

- 17 workshops from 2016-2017
- More than 20 papers of ideas submitted to the physics archive
- Roadmap published in “Computing and Software for Big Science”


A Roadmap for HEP Software and Computing R&D for the 2020s

“The result: a Programme of Work for the field as a whole, a multifaceted approach to addressing growing computing needs on the basis of existing or emerging hardware.” – Eckhard Elsen (CERN Director of Research and Computing), editorial published with Roadmap

Part of IRIS-HEP’s mandate is to continue this process

- Blueprint meetings to build field-wide consensus on specific problems.
- The Fellows Program
- Topical Meetings: seminars on topics of interest.
- Sponsorship of conferences and workshops like PyHEP 2020, and LAWSCHEP 2019.

~900 have attended various small workshops we’ve run or sponsored

All CWP and S2I2 Workshops

- 26-27 Apr, 2018 - Reconstruction, Trigger, and Machine Learning for the HL-LHC
  - *Massachusetts Institute of Technology, Boston*
- 26-29 Mar, 2018 - Joint WLCG/HSF Workshop 2018
  - *Centro Congressi Federico II, Naples, Italy*
- 14 Dec, 2017 - Mini-workshop on Building Collaborations for ML in HEP
  - *Massachusetts Institute of Technology, Boston*
- 28-29 Nov, 2017 - S2I2/DOE-lab mini-workshop on HL-LHC Software and Computing R&D
  - *Catholic University of America, Washington DC*
- 16-17 Nov, 2017 - Data Organisation, Management and Access (DOMA) in Astronomy, Genomics and High Energy Physics
  - *Flatiron Institute (Simons Foundation), New York City*
- 23-26 Aug, 2017 - S2I2-HEP Workshop
  - *University of Washington, Seattle*
- 26-30 Jun, 2017 - HEP Software Foundation Workshop
  - *LAPP (Annecy)*
- 5-6 Jun, 2017 - CWP Event Processing Frameworks Workshop
  - *FNAL*
- 22-24 May, 2017 - HEP Analysis Ecosystem Retreat
  - *Amsterdam*
- 8-12 May, 2017 - DS@HEP 2017 (Data Science in High Energy Physics)
  - *FNAL*
- 1-3 May, 2017 - 2nd S2I2 HEP/CS Workshop
  - *Princeton University*
- 28-30 Mar, 2017 - CWP Visualization Workshop
  - *CERN (and Vidyo)*
- 23 Mar, 2017 - Community White Paper Follow-up at FNAL
  - *FNAL*
- 20-22 Mar, 2017 - IML Topical Machine Learning Workshop
  - *CERN,* The workshop includes a CWP session on Machine Learning
- 9 Mar, 2017 - Software Triggers and Event Reconstruction WG meeting
  - LAL/Orsay, session at Connecting The Dots workshop
- 8 Mar, 2017 - S2I2-HEP/OSG/USCMS/USAtlas Panel at OSG All Hands Meeting
  - SDSC/UCSD
- 23-26 Jan, 2017 - HEP Software Foundation Workshop
  - *University of California at San Diego / San Diego Supercomputer Center*
- 7-9 Dec, 2016 - S2I2 HEP/CS Workshop
  - *University of Illinois at Urbana-Champaign*

IRIS-HEP

Intellectual Hub for the HEP Community

Sustainable Software R&D objectives

1) Development of **innovative algorithms** for data reconstruction and triggering;

2) Development of highly performant **analysis systems** that reduce “time-to-insight” and maximize the HL-LHC physics potential; and

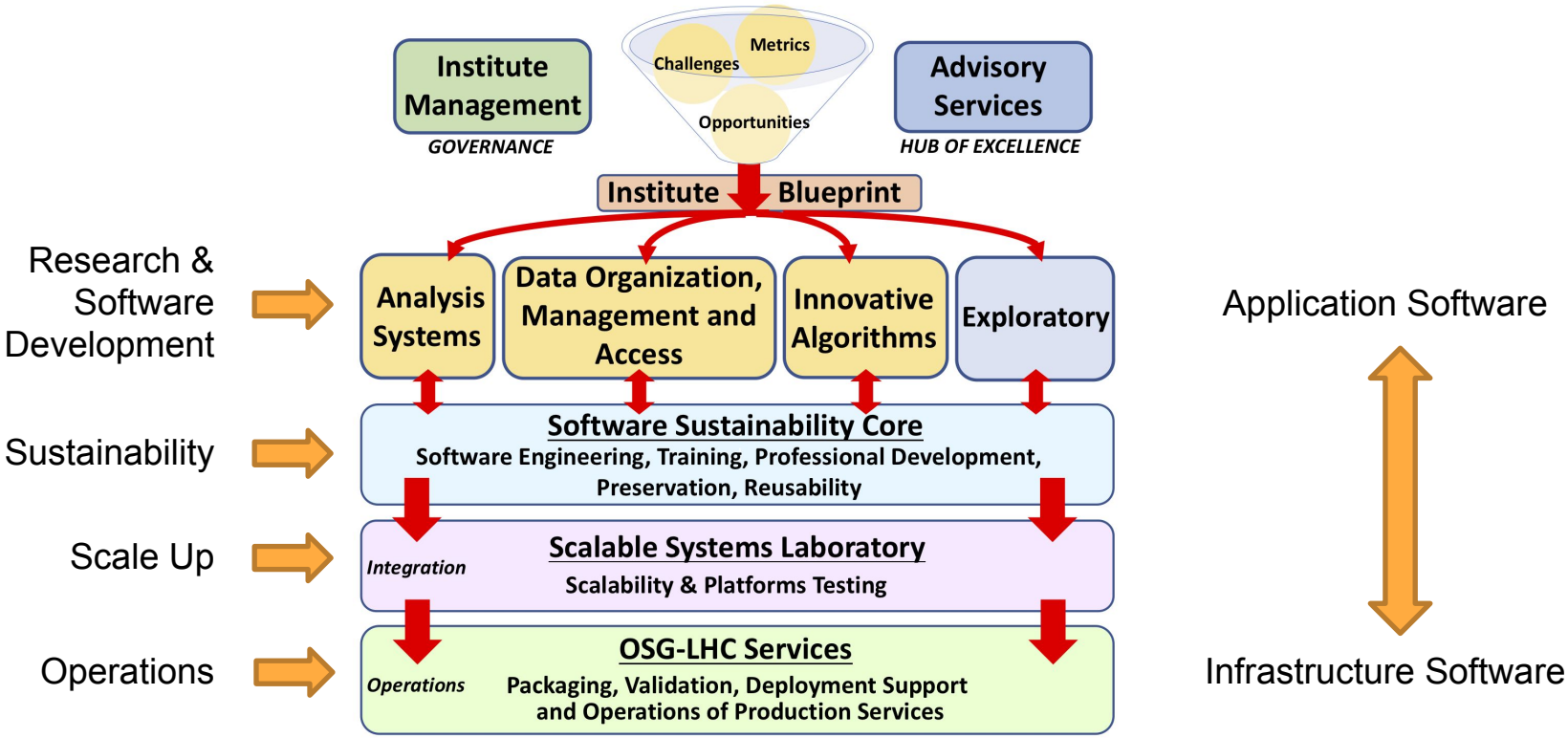
3) Development of **data organization, management and access systems** for the community’s upcoming Exabyte era.

4) Integration of software and scalability for use by **the LHC community on the Open Science Grid**, the Distributed High Throughput Computing infrastructure in the U.S.

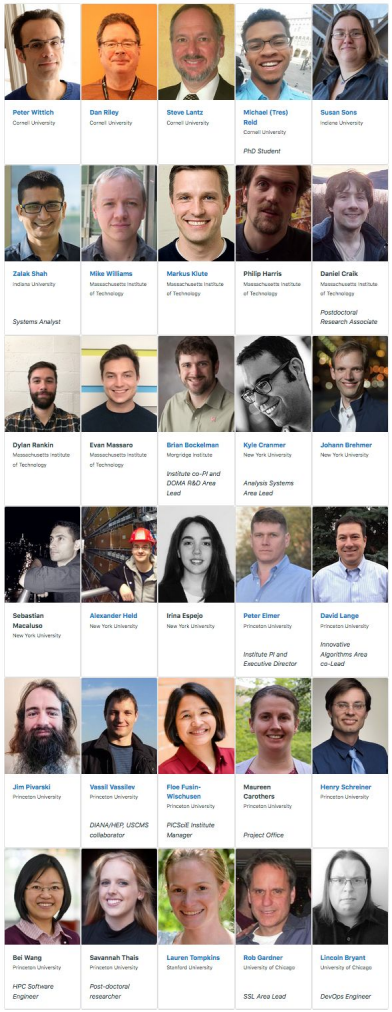
The plan for IRIS-HEP reflects a community vision developed by an international community process organized by the HEP Software Foundation (https://hepsoftwarefoundation.org). The S2I2-HEP conceptualization project (http://s2i2-hep.org) derived a Strategic Plan from the community roadmap which would leverage the strengths of the U.S. university community. IRIS-HEP aims to function as an **intellectual hub** for the national and international HEP community, through training, community workshops and the development of wider collaborations with the larger computer and data science communities.

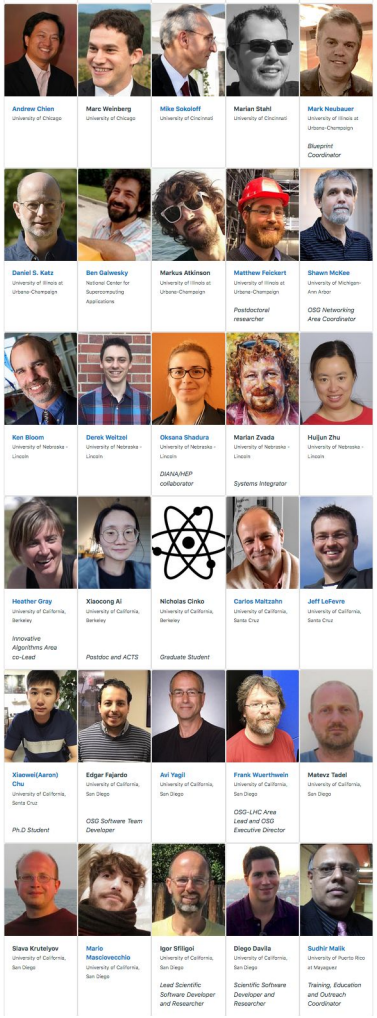
IRIS-HEP funded as a 5 year project from 1 Sep, 2018

Structure And R&D



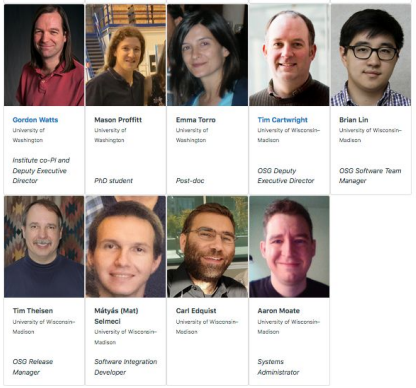
IRIS-HEP Team





http://iris-hep.org/about/team

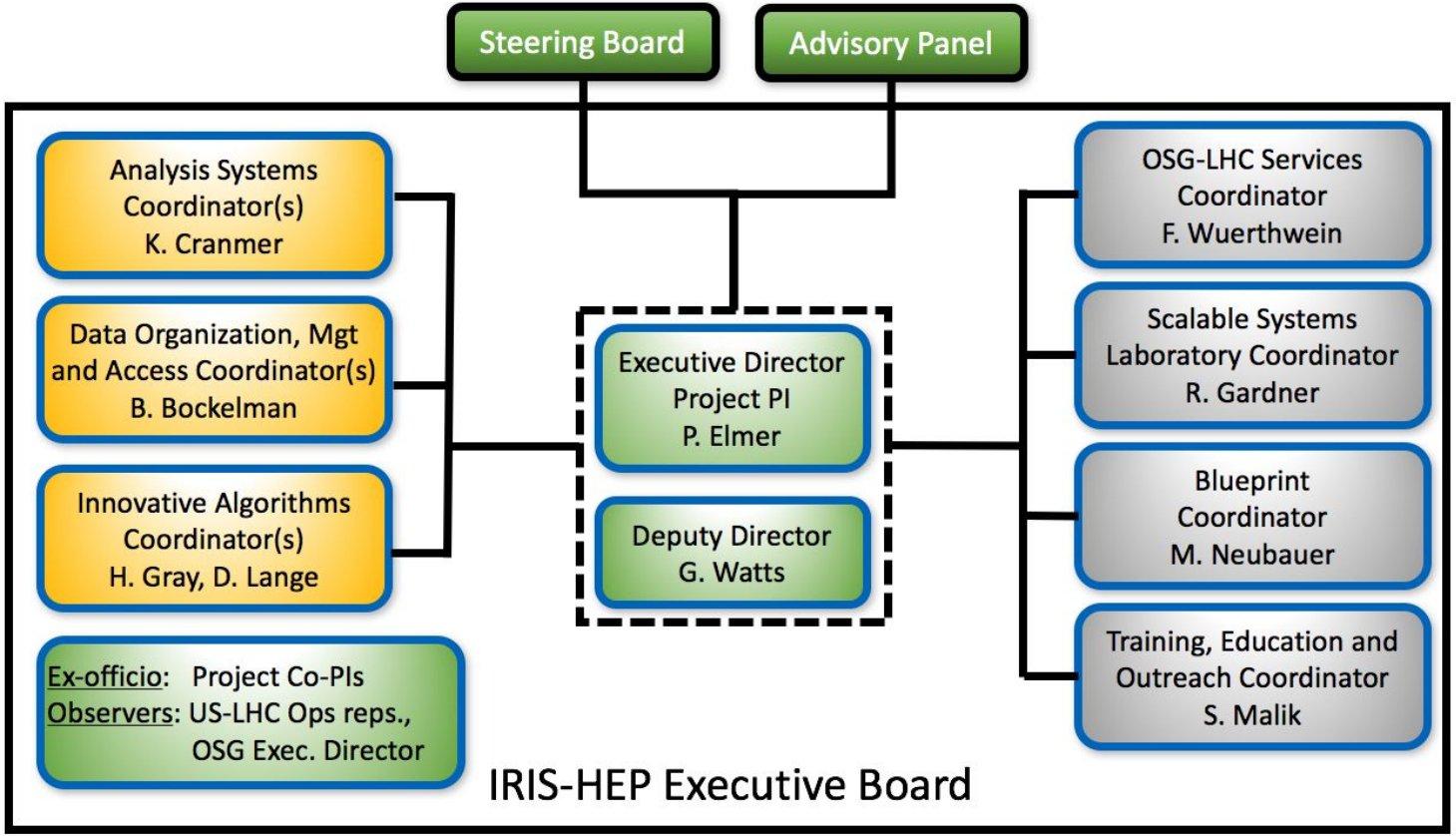
About 28 FTEs of funded effort spread over a larger number of people from 18 universities/institutions



Gender Diversity

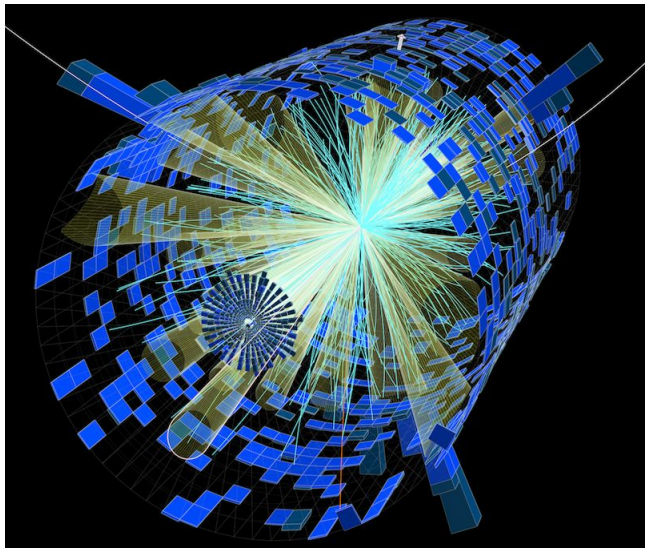
Exec Board: 10%
Subaward PIs: 16.7%
Full Team: 17%
For comparison:
CoDaS-HEP 2019: 25.9%
US-CMS Physicists 2017: 16%
US-CMS Grad Students 2017: 17%

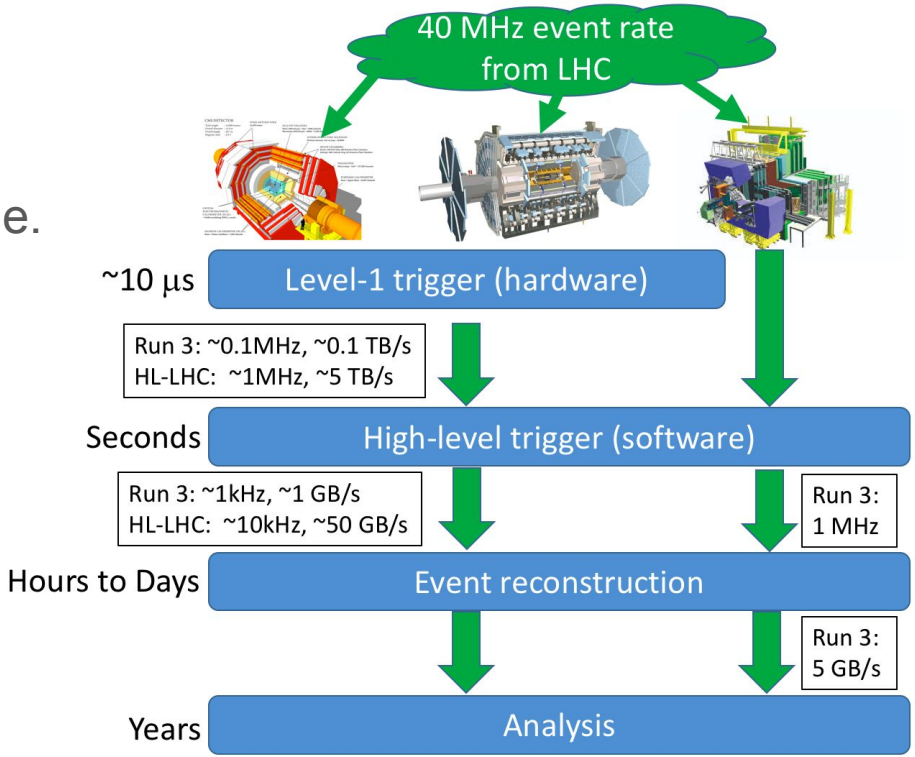
Management and Coordination



Innovative Algorithms - Trigger/Reconstruction

Algorithms for real-time processing of detector data in the software trigger and offline reconstruction are critical components of HEP's computing challenge.

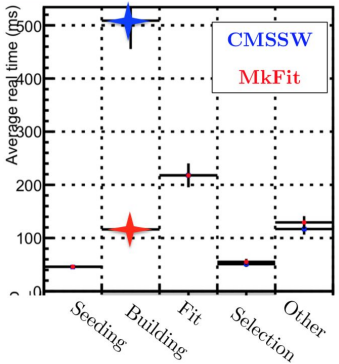




Innovative Algorithms: Highlights

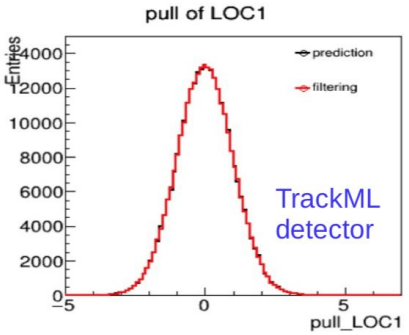
Parallel tracking contributions to MkFit

- Develop track finding/fitting implementations that work efficiently on many-core architectures (vectorized and parallelized algorithms):
- 4x faster track building w/ similar physics performance in realistic benchmark comparisons



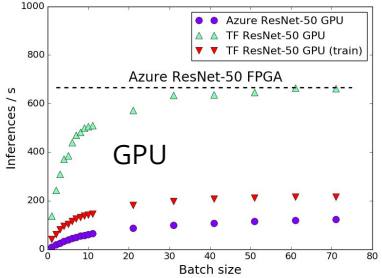
Tracking contributions to ACTS

- Development of the Kalman Filter
- Porting ACTS seeding code to run on GPUs
- Developing connections with other experiments (e.g. Belle-2, JLAB) who may be interested in using ACTS



ML on FPGAs contributions to HLS4ML/FastML

- identifying specific use cases and operational scenarios for use of FPGA-based algorithms in experiment software trigger, event reconstruction or analysis algorithms



https://arxiv.org/pdf/1904.08986.pdf

ML4Jets establishing and curating common metrics and data sets

- Aim to connect with diverse segments of machine learning community. Strong connections with theoretical community interested in jet physics
- Tree Neural network approach demonstrated on reference dataset

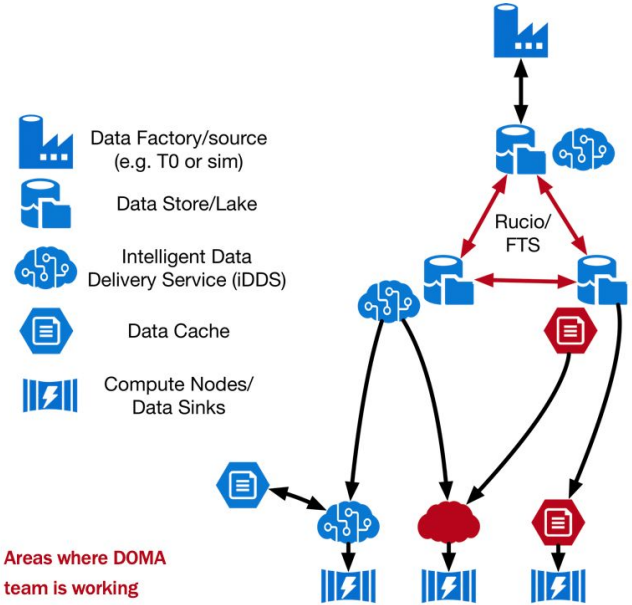
	AUC	Acc	$1/\epsilon_B$ ($\epsilon_S = 0.3$) single	mean	median	#Param
CNN [16]	0.981	0.930	914±14	995±15	975±18	610k
ResNeXt [30]	0.984	0.936	1122±47	1270±28	1286±31	1.46M
TopoDNN [18]	0.972	0.916	295±5	382± 5	378 ± 8	59k
Multi-body N-subjettiness 6 [24]	0.979	0.922	792±18	798±12	808±13	57k
Multi-body N-subjettiness 8 [24]	0.981	0.929	867±15	918±20	926±18	58k
TreeNiN [43]	0.982	0.933	1025±11	1202±23	1188±24	34k
P-CNN	0.980	0.930	732±24	845±13	834±14	348k
ParticleNet [47]	0.985	0.938	1298±46	1412±45	1393±41	498k
LBN [19]	0.981	0.931	836±17	859±67	966±20	705k
LoLa [22]	0.980	0.929	722±17	768±11	765±11	127k
Energy Flow Polynomials [21]	0.980	0.932	384			1k
Energy Flow Network [23]	0.979	0.927	633±31	729±13	726±11	82k
Particle Flow Network [23]	0.982	0.932	891±18	1063±21	1052±29	82k
GoaT	0.985	0.939	1368±140		1549±208	35k

https://arxiv.org/pdf/1902.09914.pdf

DOMA (Data Organization, Management, Access)

Fundamental R&D related to the central challenges of organizing, managing, and providing access to exabytes of data from processing systems of various kinds.

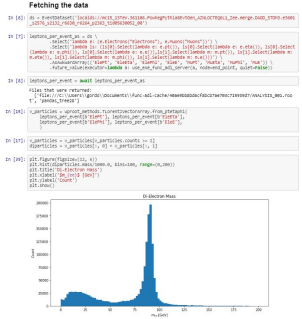
- Data Organization: Improve how HEP data is serialized and stored.
- Data Access: Develop capabilities to deliver filtered and transformed event streams to users and analysis systems.
- Data Management: Improve and deploy distributed storage infrastructure spanning multiple physical sites. Improve inter-site transfer protocols and authorization.



ServiceX / Intelligent Data Delivery

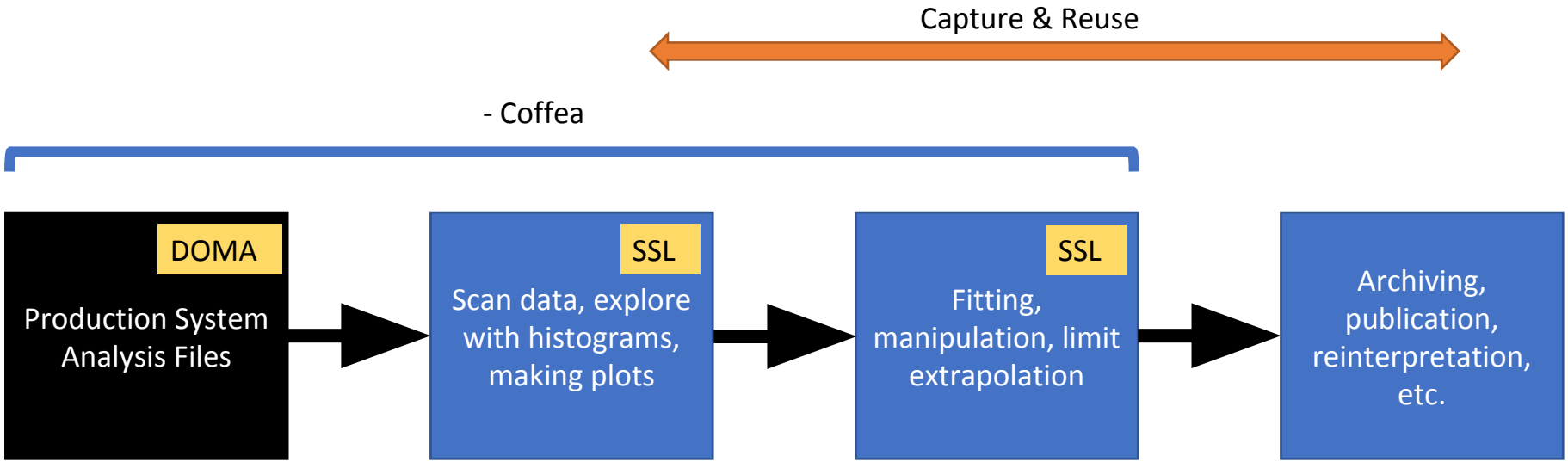
Low-latency delivery of numpy-friendly data transformed from experiment custom formats enabling the use of community supported data science tools.

(joint effort with Analysis Systems)



Jupyter Notebook

Analysis Systems: Data Flow and Projects



- Leverage & align with industry
- Training & workforce development

Partner Focus Area

We are a major Scikit-HEP contributor!

Analysis Systems, analysis & declarative languages (underlying framework)

Analysis Systems Highlight: Statistical Models

Implementation of widely used statistical tool in modern frameworks

NumPy TensorFlow PyTorch

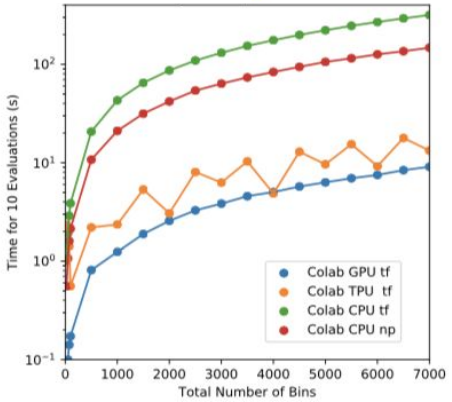
Installation:

```
$> pip install pyhf
```

pyhf differentiable likelihoods

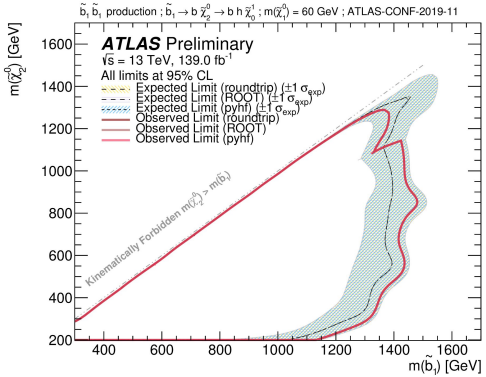
Hardware Acceleration

For ML-library tensor backends Computational graph can be transparently placed on hardware accelerators: **GPUs** and **TPUs** for order of magnitude speed-up in computation.



By leveraging these tools, we inherit benefits:

Reduce time to insight!



ROOT: 10+ hours
pyhf: <30 minutes

Auto-Differentiation:

Tensor libraries from ML community provide **exact gradients** for use in minimization. $\frac{\partial \mathcal{L}}{\partial \mu}, \frac{\partial \mathcal{L}}{\partial \theta_i}$

Optimizers

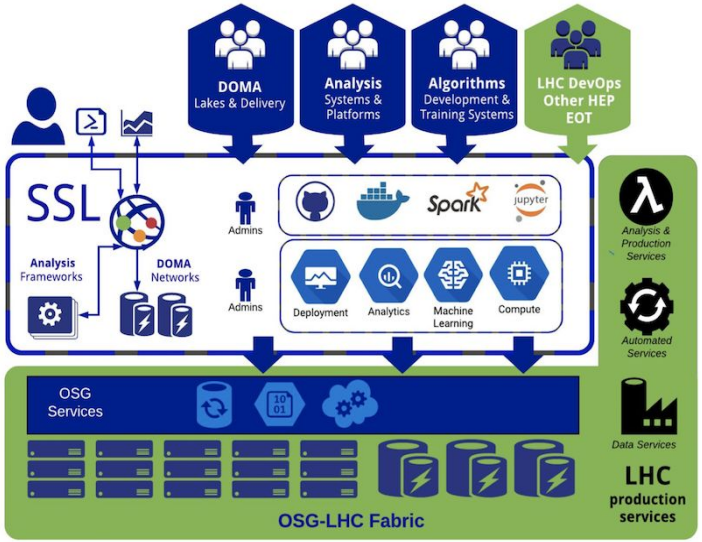
pyhf likeliehood are simple tensor-value python functions. Can use multiple minimization algorithms, such as `scipy.minimize` or MINUIT

Built into SciKit-HEP, a suite of Python packages that are being adopted by the community

Scalable Systems Laboratory

Goal: Provide the Institute and the HL-LHC experiments with scalable platforms needed for development in context. Facilities R&D

River – a repurposed UChicago CS research cluster now being used to test/run IRIS-HEP projects.



CoDaS-HEP school environment, ServiceX test bed.

Kubernetes based cluster, can run the OSG-LHC environment, school environments, etc. Experimenting with “no-ops” management.

Collaborating with a CyberTraining project (OAC-1829707, 1829729) as well as a growing number of international collaborators.

SSL Highlight: Cyberinfrastructure for training

- JupyterLab machine learning platform for 55 CODAS-HEP students provisioned by IRIS-HEP SSL Kubernetes hosted services. Leveraged NSF projects: SLATE, Pacific Research Platform, CHASE-CI & LHC Ops.

Purpose

A computational platform optimized for machine learning applications, supporting the second school on tools, techniques and methods for Computational and Data Science for High Energy Physics (CoDaS-HEP), 22-26 July, 2019, at Princeton University.

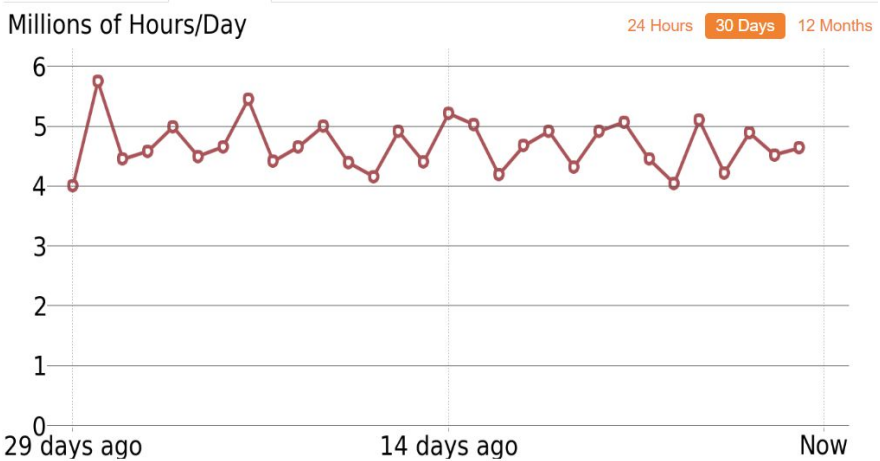
Links

- CODAS-HEP.org
- 2019 School Program
- HEP Software Foundation

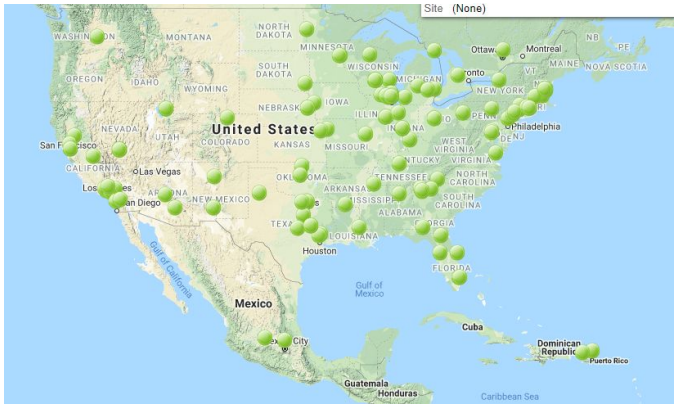
Open Science Grid - LHC

The OSG is a consortium dedicated to the advancement of all of open science via the practice of Distributed High Throughput Computing, and the advancement of its state of the art.

- IRIS-HEP supports LHC operations and development of the consortium.



Open Science Grid



- Work to separate local site hardware and software support by moving services into containers.
- Transitioning security service to use tokens

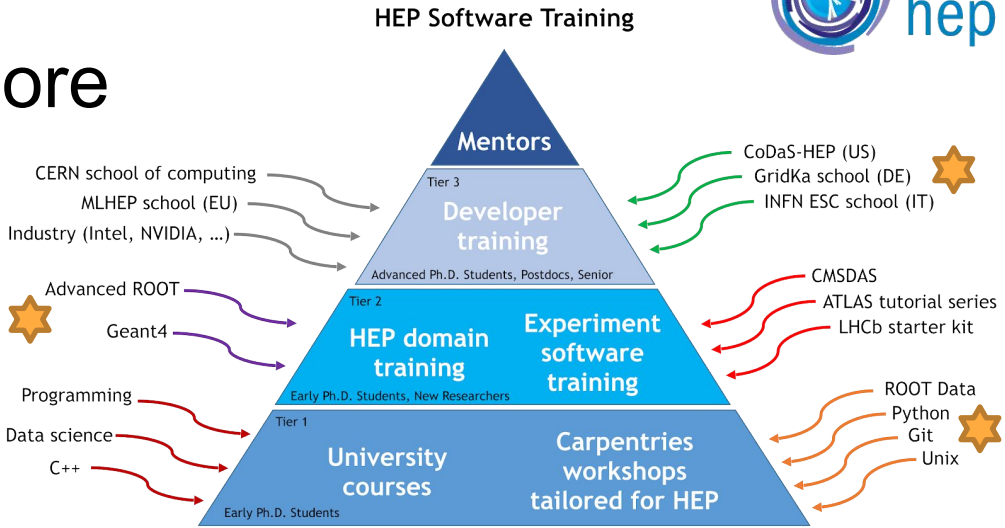
Particle physicists all over the world depend on these services and scheduling of processing hours (~10,000)

OSG Highlight: Transitioning away from Globus

- Globally, the LHC today depends on GSI for authentication and gridFTP for bulk data transfer.
  - Both are no longer supported by their original developers.
- OSG inherited the source code, and is maintaining it within the context of "Grid Community Toolkit" that was created for this purpose in 2018.
- We developed a roadmap for replacement of both GSI and gridFTP that has been socialized globally, and across science domains.
  - August 22nd 2019: Roadmap and schedule presented to LHC ops program via OSG council
  - September 12th 2019: Roadmap and schedule presented to WLCG via GDB
  - January 2020: First demo of a US-LHC site free of GSI and gridFTP (prototype & proof-of-concept)
  - January 2021: OSG production software without GSI and gridFTP is released
  - January 2022: End of support of GSI and gridFTP in OSG releases.

Software Sustainability Core

Training



[Sample Topics](): Git, OpenMP, SciPy, ML, Random Numbers, Columnar Data Analysis, Vectorization, etc.

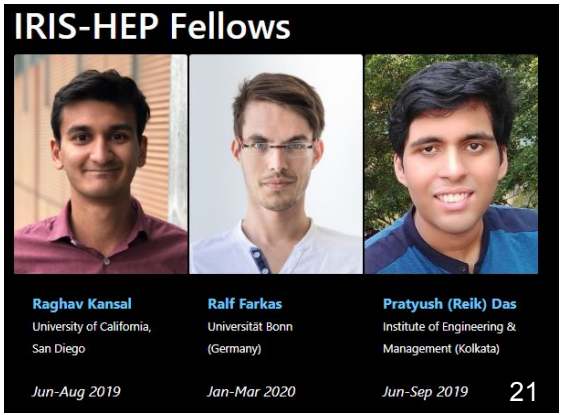
Direct Value to IRIS-HEP

We've had previous students become teachers, and previous students are now team-members in IRIS-HEP.
Not just value to the community!

~300 have attended various small trainings we've run or sponsored

Fellows Program

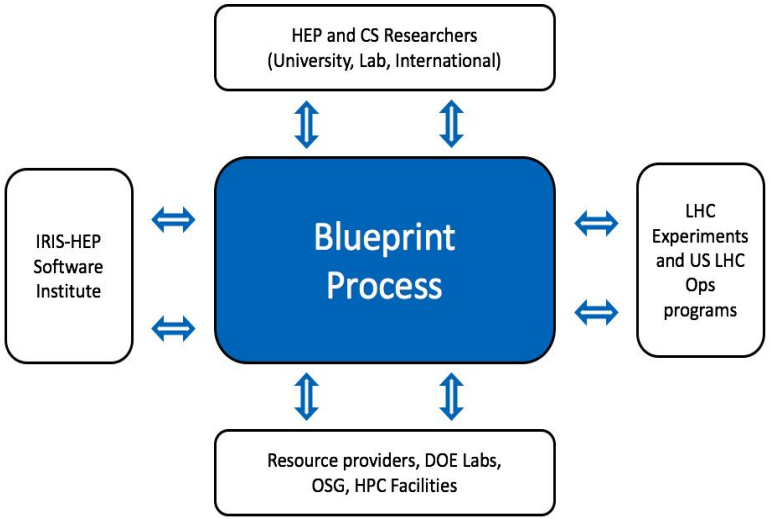
Provides opportunities for undergraduate and graduate students to connect with mentors within the larger HEP and Computational/Data Science community.



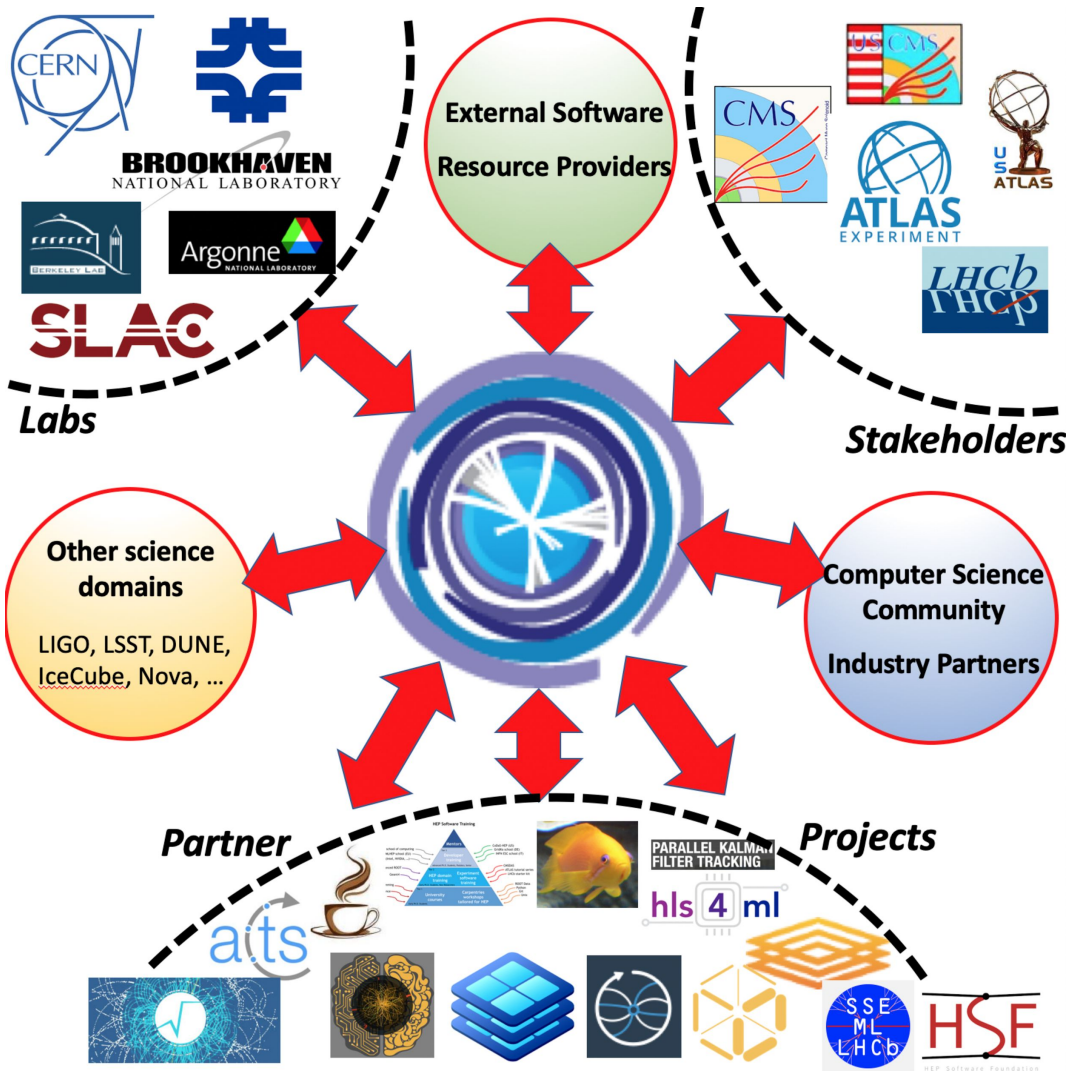
Blueprint Activity - Maintaining a Common Vision

- Small **"blueprint" workshops** 3-4 times per year with key personnel and experts
- Facilitate effective collaborations by building and maintaining a common vision
- Answer specific questions within the scope of the Institute's activities or within the wider scope of HEP software & computing.

- 21 Jun - 22 Jun, 2019 - Blueprint: Analysis Systems R&D on Scalable Platforms (*NYU*)
- 10 Sep - 11 Sep, 2019 - Blueprint: Accelerated Machine Learning and Inference (*Fermilab*)
- 23 Oct - 25 Oct, 2019 - Blueprint: A Coordinated Ecosystem for HL-LHC Computing R&D (*Catholic University of America, Washington DC*)
- Others (e.g. Training) in planning



Intellectual Hub



IRIS-HEP is establishing itself as an intellectual hub for HEP software & computing

We begin from a strong position built during the CWP & institute conceptualization period. Through strong partnerships with other projects, our stakeholders and activities like the blueprint workshops we continue to build this intellectual hub.

https://iris-hep.org/collaborations

Summary

- IRIS-HEP was funded on September 1st, 2018
  - We are approaching the end of the design phase
  - Projects in all phases (design, prototype, and production) exist.
  - We are fully staffed, ~30 FTE's
  - Full description of projects available on our website, http://iris-hep.org
- Community Impact
  - Software is being adopted by others, in some cases dramatically.
  - Facilities work in SSL and OSG is leading the international field
- Community Outreach
  - We've reached almost 1000 people with our workshops, and another 300 with our training efforts
  - We continue to organize Blueprint workshops to build community consensus.
- Next
  - Start "Execution Phase" September 2020
  - Work on integrating projects in prototype stage into coherent and scalable software for the community
  - The "Snowmass Process-2021" provides an opportunity for us to update the Community White Paper/Roadmap.

Summary

HEP faces major challenges in the 2020s: Data, Compute, Staffing

The HSF executed an important community process that produced the CWP.

The collaborative spirit continues to grow and bodes well for us (as a community) to meet those challenges.

IRIS-HEP

We are focusing on 3 R&D areas from the CWP: Innovative Algorithms, Analysis Systems, and DOMA.

Plus training, a dedicated integration activity and continuity for the OSG services for the LHC.

We are just beginning our activities and are looking forward to collaborating with many of you in the coming years!

Connecting with IRIS-HEP

Website: http://iris-hep.org

Public announcement mailing list: announcements@iris-hep.org [Subscribe]

Topical meetings: https://indico.cern.ch/category/10570/

Twitter: https://twitter.com/iris_hep

We will be continuing to organize, co-organize and host various events going forward, see the main project website above.