U.S. DEPARTMENT OF ENERGY | Office of Science

SciDAC PI Meeting HEP Overview

Lali Chatterjee

Program Manager, HEP

SciDAC PI Meeting July 17th, 2018

The High Energy Physics Program Mission

… To understand how the universe works at its most fundamental level –

- **It's particles, interactions, space – time**
- **from quarks and gluons – to the cosmos**

HEP Paths for Discovery Science:

- **projects, facilities, research program**

Research tools, techniques and technology developed along the way benefits society and the S&T ecosystem

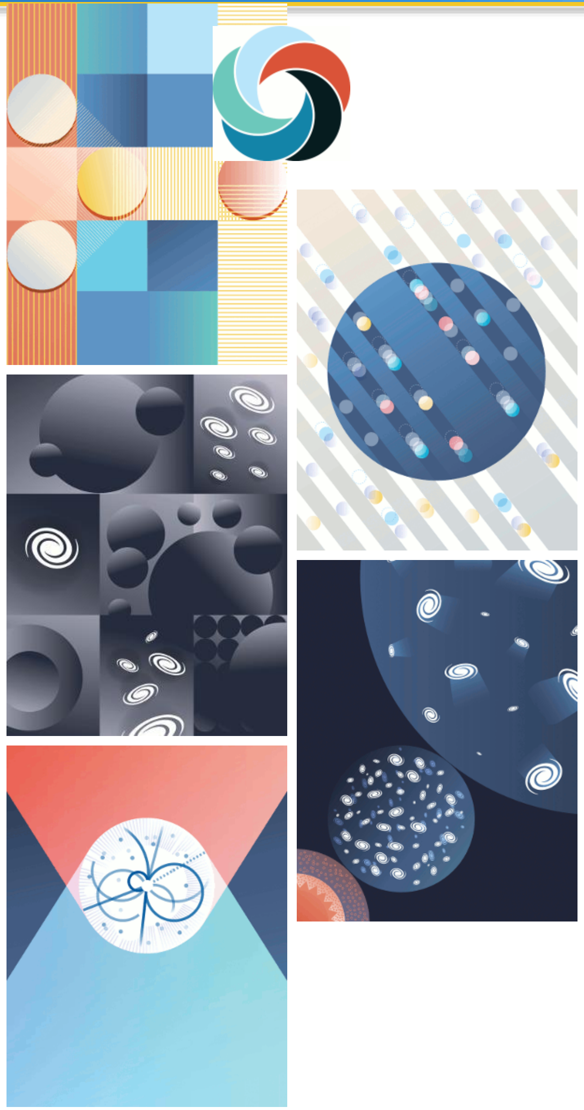
Pursuing the Next Discovery: The Science Drivers of Particle Physics

2014 Particle Physics Project Prioritization Panel (P5) report

The P5 report identified five **intertwined science drivers**, compelling lines of inquiry that show great promise for discovery:

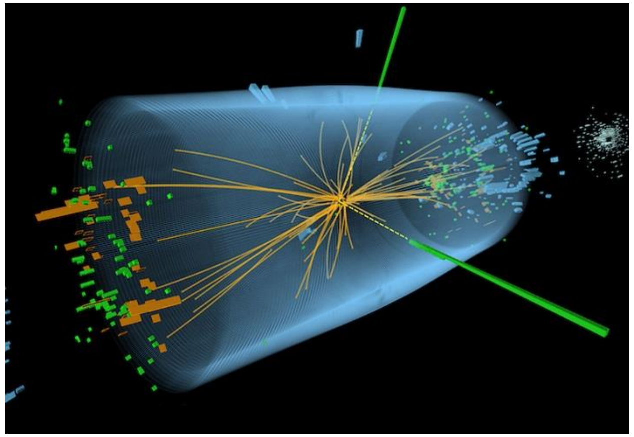
- Use the **Higgs boson** as a new tool for discovery **2013*
- Pursue the physics associated with **neutrino mass** **2015*
- Identify the new physics of **dark matter**
- Understand **cosmic acceleration**: dark energy and inflation **2011*
- **Explore the unknown**: new particles, interactions, and physical principles

** Since 2011, three of the five science drivers have been lines of inquiry recognized with Nobel Prizes*



The Higgs Boson

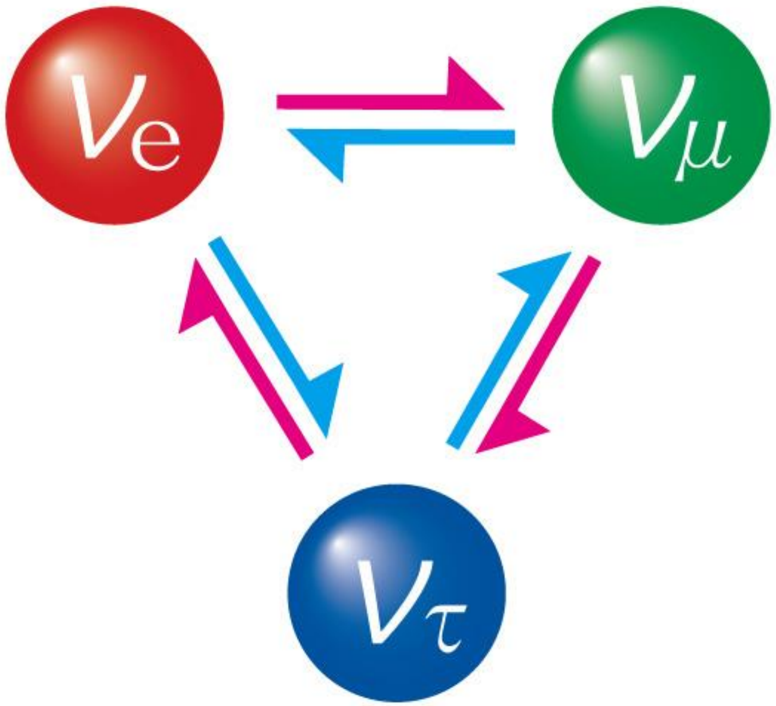
- Proposed in 1964, the Higgs boson completes the Standard Model by giving other particles mass
- Now the Higgs boson is a new tool to study the universe
  - Does it behave exactly as predicted?
  - Is there more than just one Higgs boson?
  - Can we use it to discover new particles?



2013 Nobel Prize in Physics:
Englert/Higgs for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider

Neutrino Mysteries

- Neutrinos are:
  - Electrically neutral
  - Have very small, but non-zero, masses
- Interact rarely:
  - Every second, 100 trillion neutrinos pass through your body
  - Only 1 in 4 chance that a neutrino interacts with you over in your life!
- Neutrinos *oscillate*, or change flavors
  - A muon neutrino (ν_μ) could turn into an electron neutrino (ν_e) as it travels
- Understanding their masses and interactions may lead to answers to big questions:
  - Do more than three types of these fundamental particles exist?
  - Why is there an imbalance of matter and antimatter in the universe?



2015 Nobel Prize in Physics:
Kajita/McDonald for the discovery of neutrino oscillations, which shows that neutrinos have mass

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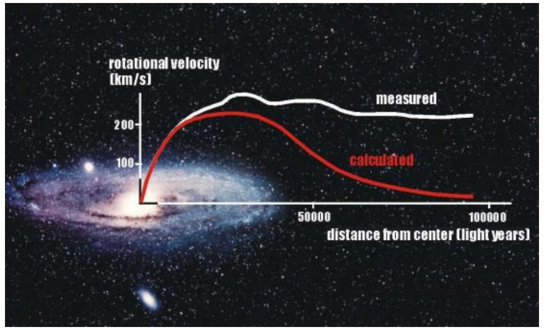
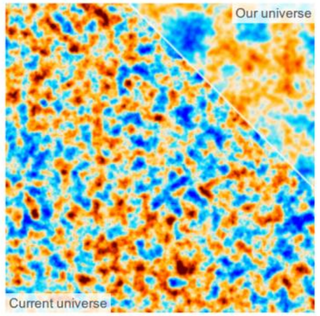
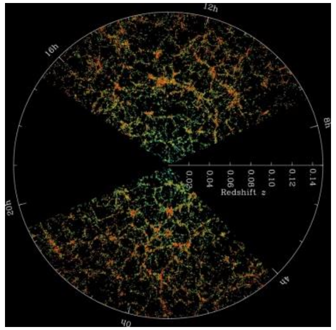
Dark Matter

- Dark matter accounts for 5 times as much of the universe as ordinary matter, but we don’t know what it is!
  - So far, only seems to interact through gravity
- Overwhelming evidence supports its existence:
  - Galaxy cluster motion
  - Galactic rotation
  - Cosmic microwave background
    - “Last light” of the early, hot universe
  - Bullet cluster analysis
  - Large scale structure of universe
- Dark matter is not a Standard Model particle
  - Discovering its nature will change our understanding of the universe!

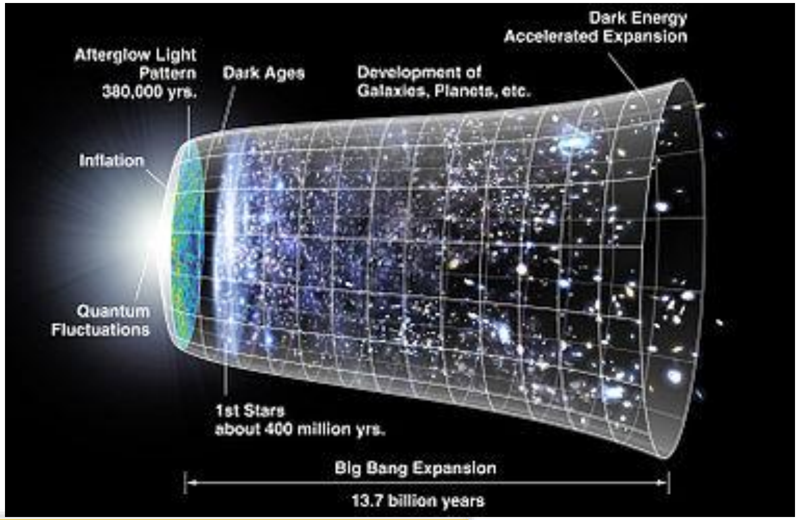


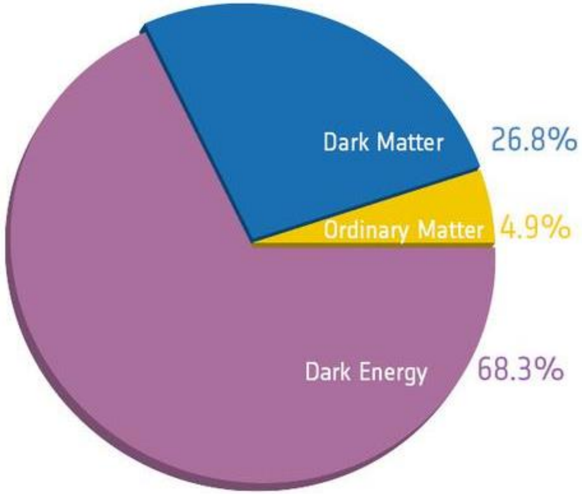




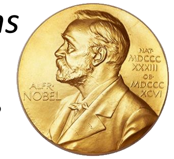
Cosmic Acceleration: Inflation and Dark Energy

- Our universe has two major phases of cosmic acceleration:
  - The moment of “inflation” during the Big Bang
  - Ongoing accelerating expansion, beginning ~9 billion years later
- Inflation explains why the cosmic microwave background is so uniform, but we don’t currently know what caused it to occur
- Ongoing expansion caused by dark energy, which accounts for ~70% of the total content of our universe!



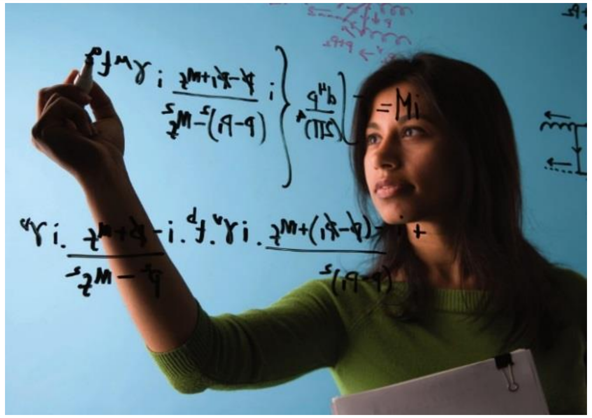


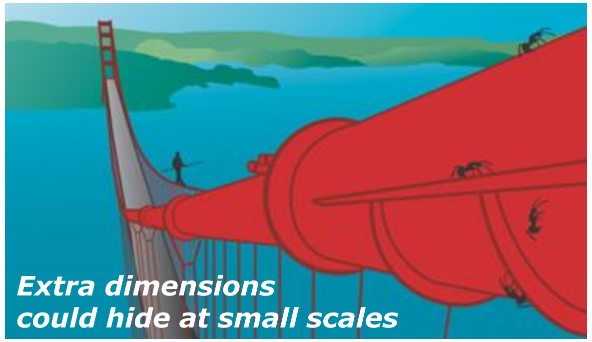
2011 Nobel Prize in Physics: Perlmutter/Schmidt/ Riess for the discovery of the accelerating expansion of the Universe through observations of distant supernovae



Exploring the Unknown

- "New physics," or new particles or forces not part of the Standard Model, might explain the mysteries of neutrinos, dark matter, and dark energy!
- Particle physicists invent a myriad of compelling alternative pictures to explain the mysteries of the universe and how it has come to be as it is today
  - For example, extra dimensions may explain why gravity is much weaker than other forces
  - Mathematical models find use in other sciences
  - New ideas inspire next generation of scientists
- History has also shown that we have stumbled upon new physics when pushing the boundaries of the known

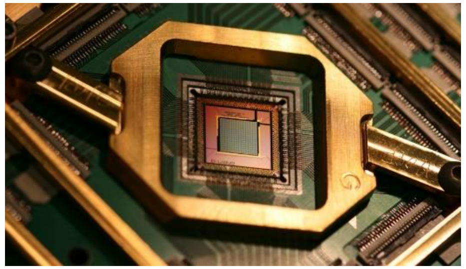


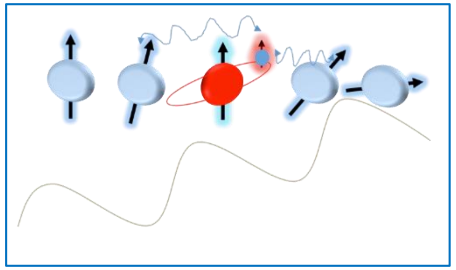


Extra dimensions could hide at small scales

Quantum Information Science & Technology (QIST)

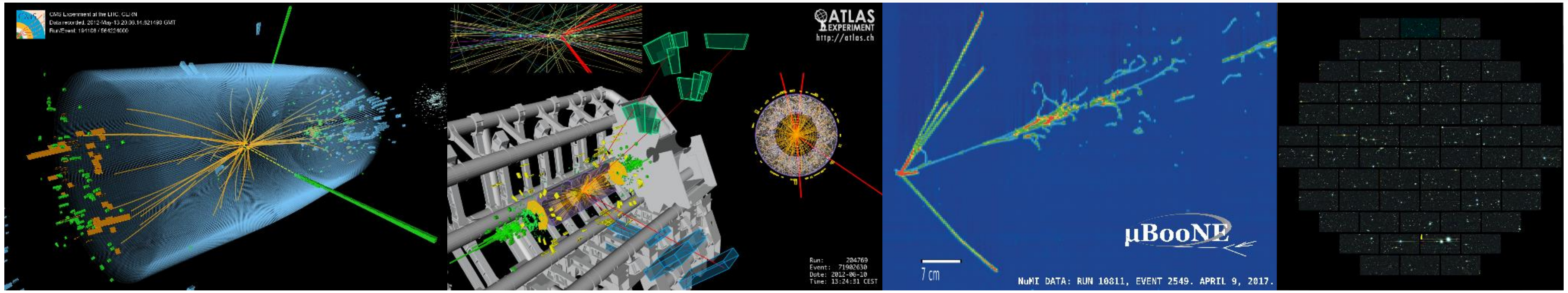
- Powerful new windows to accomplish HEP mission
- In turn - theoretical formulations and technical control systems developed in HEP - ADVANCE QIST
- Exciting new synergy
- Cosmos & Qubits





- Massive black holes far out in the cosmos connect to Quantum error correction and fault tolerance in qubits

Computing is an integral part of HEP science



- **HL-LHC, DUNE, and LSST will produce complex data at rates an order of magnitude or more beyond current experiments**
- **Successful implementation of the broad science program envisioned by P5 will require an equally broad and foresighted approach to the computing challenges**
- **HEP is undertaking a series of exercises to address these**
- **HEP Center for Computational Excellence is one path**
- **The HEP-ASCR SciDAC 4 portfolio also addresses these**

HEP Computing Strategy Development

- HEP has initiated this consultative process with the HEP community to:
  1. More accurately capture the largest expected computing needs and
  2. Look for opportunities where economies of scale and optimal use of resources can close the gap.
- Two roundtable meetings:
  - **Inventory of HEP Computing Needs Roundtable Meeting (Completed)**
    - Focused on hardware, software, and personnel needs for the next decade
  - **Commonalities Roundtable Meeting** – TBD
    - Focused on identifying common elements in software and workflows, HPC applicability, and integration with Exascale, HEP Community Studies, and other computing initiatives
- **A strategy encompassing all HEP computing needs that coordinates with ASCR is planned**

HEP Center for Computational Excellence - Labs

Advanced Scientific Computing Research (ASCR)
Research and Facilities

ASCR Programs

HEP-CCE

High Energy Physics (HEP)
Research and Facilities

Computational HEP Program Cross-Cuts

- **Primary Mission**
  - **Bring next-generation computational resources to bear on pressing HEP science problems**
  - **Develop cross-cutting solutions leveraging ASCR and HEP expertise and resources**

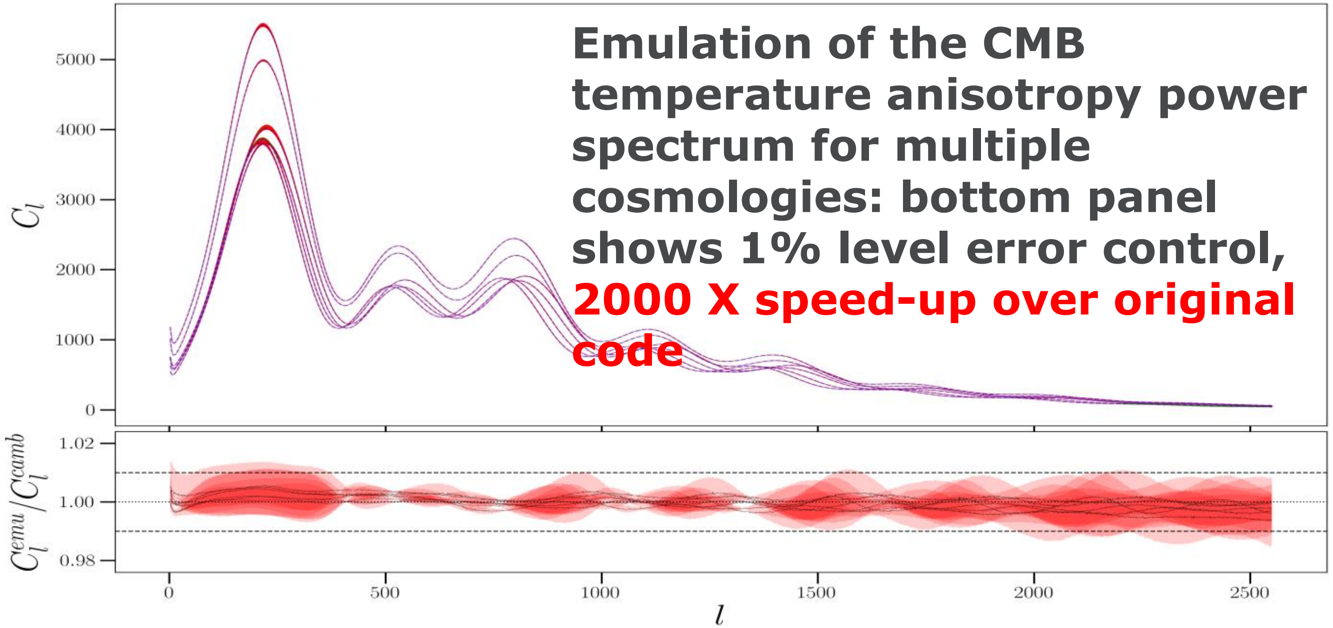
- **HEP-CCE Roles**
  - HEP computing is typically managed within HEP frontiers, programs, and projects
  - HEP-CCE provides a channel for links between ASCR programs (e.g., Exascale Computing Project, SciDAC) and cross-cut HEP computational activities
  - HEP-CCE identifies new ASCR-HEP interactions (e.g., edge services, containerization, petascale data transfer project, training/hack session opportunities, —)
  - Provides a platform for consideration of future technologies for HEP (e.g., post-Moore, neuromorphic computing, QIS, —)

Inference and Machine Learning at Extreme Scales

PI Salman Habib, ANL

http://press3.mcs.anl.gov/cpac/projects/scidac/

- **Opportunity:** Use of HPC resources as high-fidelity, large data-volume sources for state-of-the-art data-intensive statistical and machine learning (ML) methods
- **Project Thrusts:** Melding HPC and observational datasets with advanced statistical methods and ML to solve large-scale problems in scientific inference
- **Applications:** Cosmological parameter estimation, strong lensing image classification and lens characterization, fast generation of synthetic sky catalogs, fast prediction of summary statistics, fast likelihood estimation



Emulation of the CMB temperature anisotropy power spectrum for multiple cosmologies: bottom panel shows 1% level error control, 2000 X speed-up over original code

- **Example — Cosmic Microwave Background Emulation:**
  - Large training data set generated using the CAMB code
  - Nonlinear dimensional reduction via unsupervised learning
  - High-dimensional non-parametric regression
  - Emulator with factor of **~2000** speed-up compared to CAMB with 1% errors over the desired dynamic range

HEP Data Analytics on HPC

PI James B Kowalkowski, FNAL

1) HEP Data Analytics on HPC

Future experiments and HL-LHC will need dramatically increased computing resources compared to now. Must take advantage of High Performance Computing (HPC)

Objective

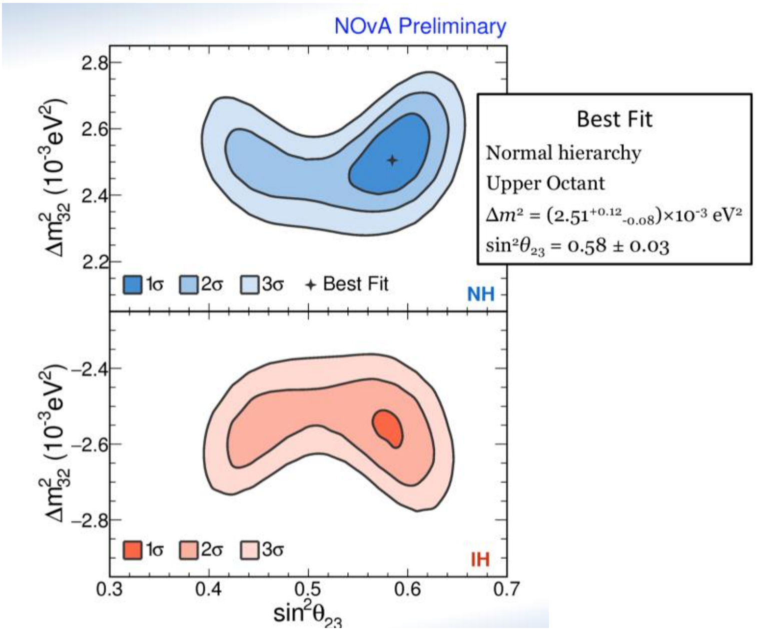
Revolutionize physics analysis through advanced scientific computing

Status

- **Completed final stage analysis of NOvA data on NERSC at LBNL (35M hours over two runs managed with HEPCloud)**
- **Results presented June 2018**

Plans

- **Optimization of physics simulation tuning with Lawrence Berkeley and Argonne National Labs Applied Math departments**
- **HPC Object Store for HEP Data with Argonne National Lab Computer Science department**



NOvA results (used 35M hours at NERSC)

NOvA neutrino oscillation analysis article:
http://news.fnal.gov/2018/07/fermilabcomputing-experts-bolster-nova-evidence-1-million-cores-consumed/

Accelerator Design and Optimization   PI J. Amundson, FNAL

The ComPASS4 collaboration

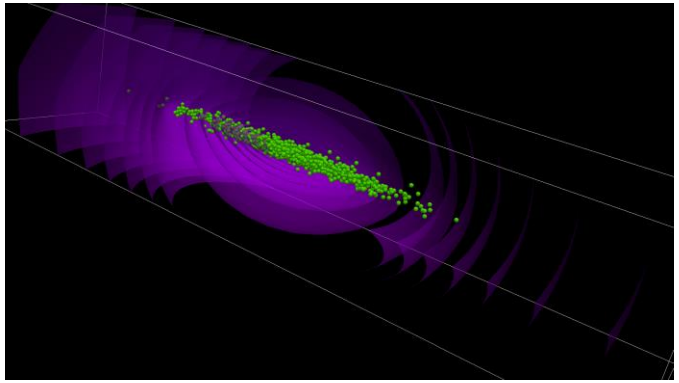
Modeling is crucial for design and optimization of future and current accelerators

Objective Apply High Performance Computing (HPC) to accelerator design and optimization

Plans

- Platform for Optimization of Particle Accelerators at Scale (POPAS) with ANL, LBNL and UCLA math departments
- Apply the optimization technology developed at ANL to the FNAL HPC accelerator simulation software Synergia
- Results will enable accelerator physics to take advantage of HPC technology to create better modifications for existing accelerators as well as better designs for new accelerators

Fermilab
UCLA
Argonne NATIONAL LABORATORY
BERKELEY LAB



Synergia Accelerator Simulation

HEP Event Reconstruction with Cutting Edge Computing Architectures **PI.** Giuseppe B. Cerati, FNAL

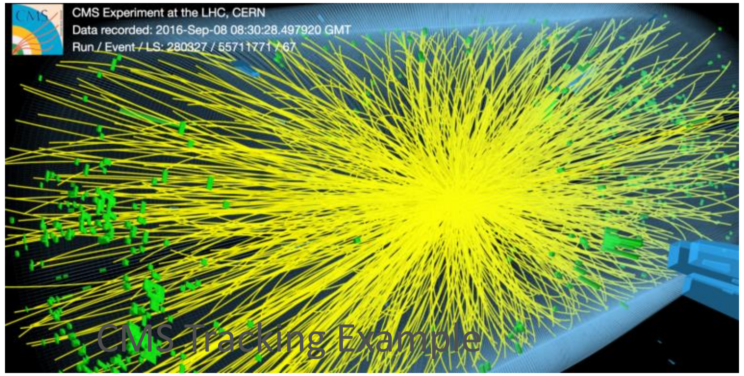
Reconstruction will be extremely challenging in future HL-LHC and neutrino/muon/heavy ion experiments. Need to leverage new computing architectures.

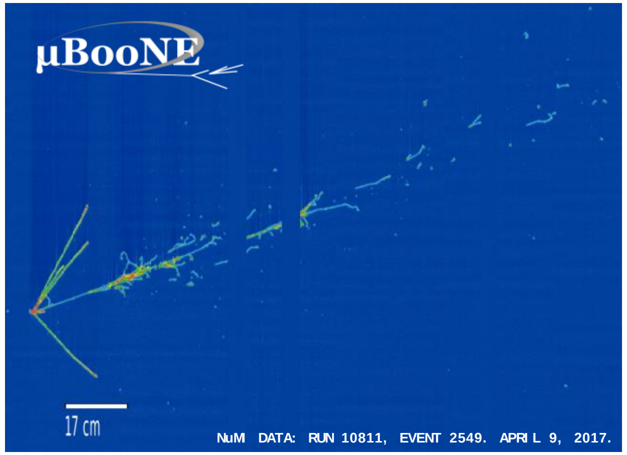
<u>Objective</u> Enable the efficient usage of modern compute architectures in HEP event reconstruction

<u>Status</u> Identifying key components and algorithms of event reconstruction that would benefit from optimization on parallel architectures

<u>Plans</u>

- **Partnership with University of Oregon (ASCR collaborator)**
- **Optimize algorithm for charged particle tracking initially developed by UCSD/Cornell/Princeton for CMS and apply to tracking in LArTPC detectors**
- **Profiling CMS tracker with the TAU profiler (from ASCR RAPIDS Institute)**





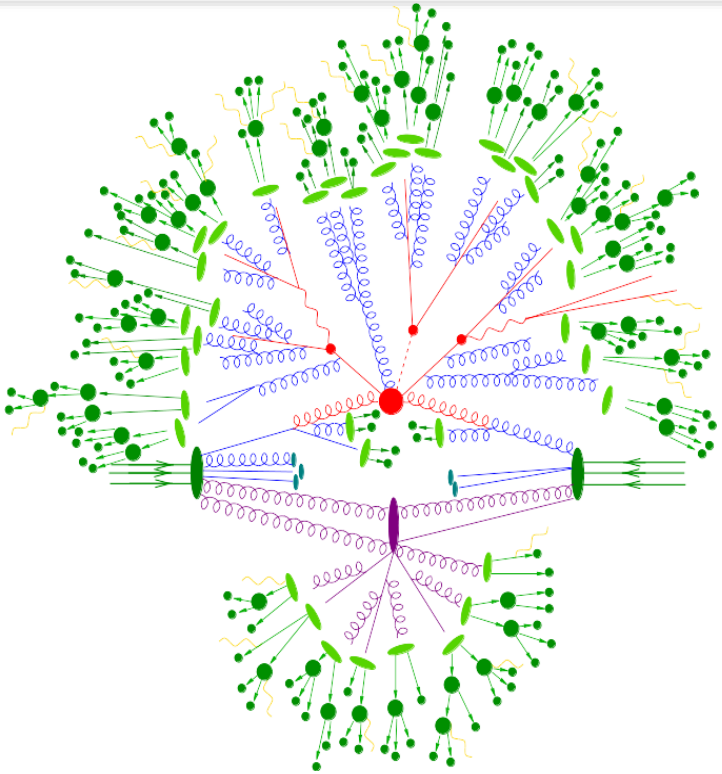
LArTPC Tracking Example

HPC framework for event simulation at colliders

PI S. Hoeche, SLAC

Aims at construction of

- New integrator for multi-particle calculations in perturbative QCD
- Event processing framework including resummation by means of parton showers



Progress in first year

- Replacement of event writer/reader previously xml → now HDF5
- Construction of toy event generator at leading order QCD (parton level) for discussion with HPC experts

Simulations connect experiment and theory by means of generating fully exclusive events as they are observed in the detector.".