Operated by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

The Science & Computing @Fermilab

Sharan Kalwani
w/numerous contributions from ***everyone*** @ Fermilab
Chicago UniForum meetup.com
Tuesday, October 28, 2014

What is Fermilab? What do we do here?

Fermilab is America's particle physics and accelerator laboratory.

Our vision is to solve the mysteries of matter, energy, space and time for the benefit of all. We strive to:

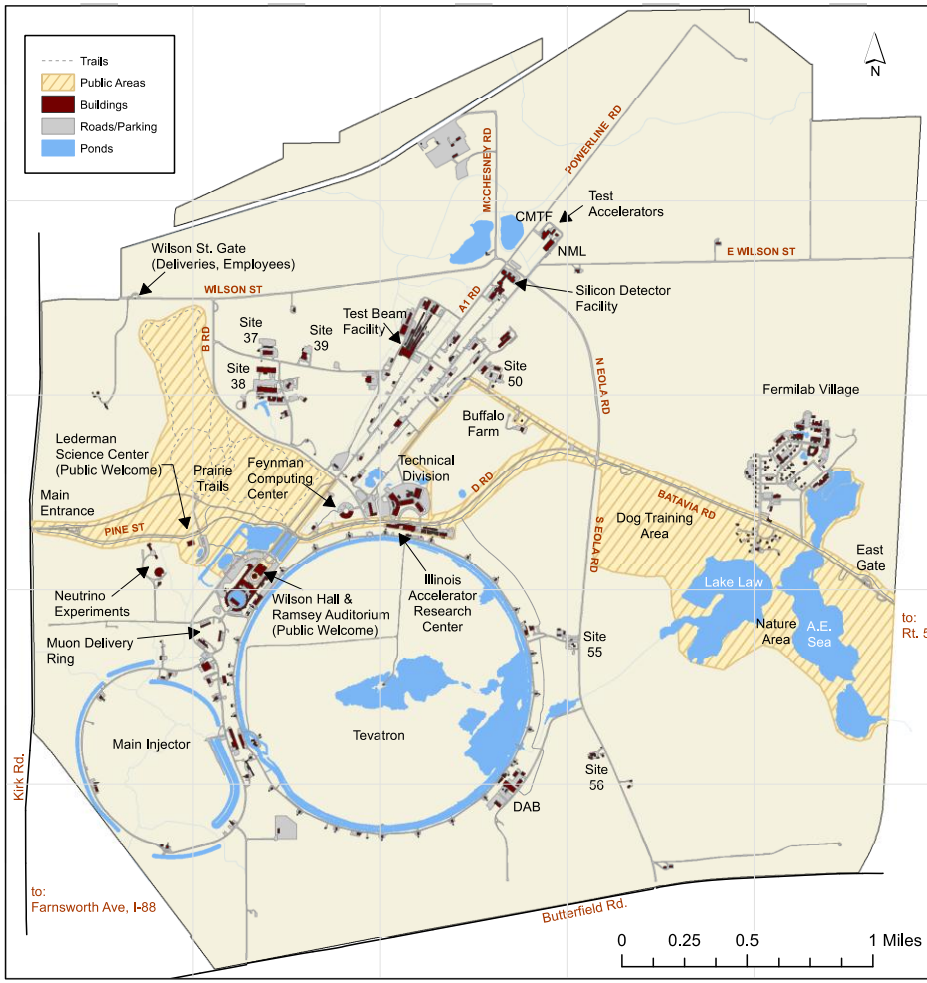
- lead the world in neutrino science with particle accelerators
- lead the nation in the development of particle colliders and their use for scientific discovery
- advance particle physics through measurements of the cosmos

Our mission is to drive discovery by:

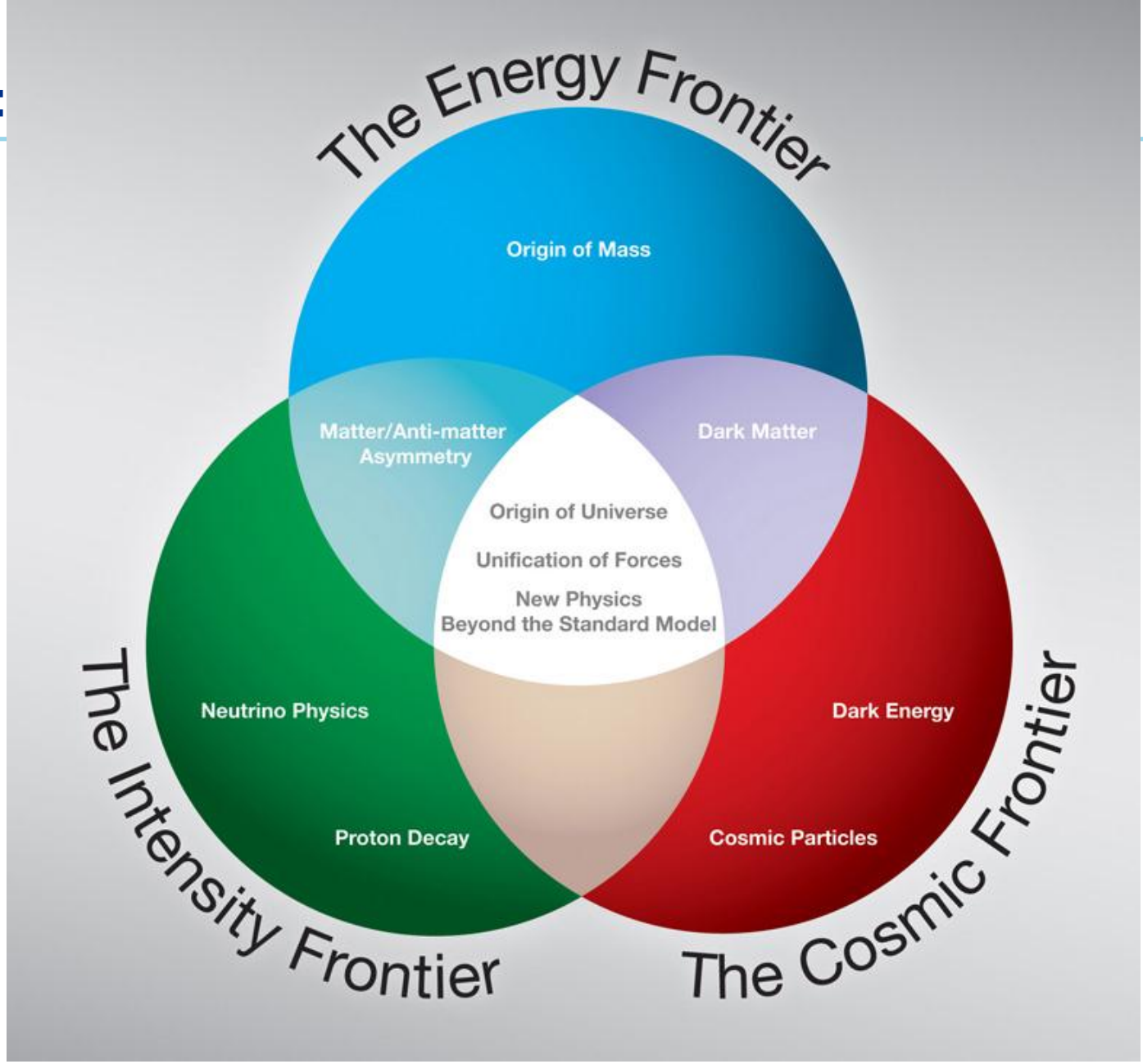
- building and operating world-leading accelerator and detector facilities
- performing pioneering research with national and global partners
- developing new technologies for science that support U.S. industrial competitiveness

Quick facts

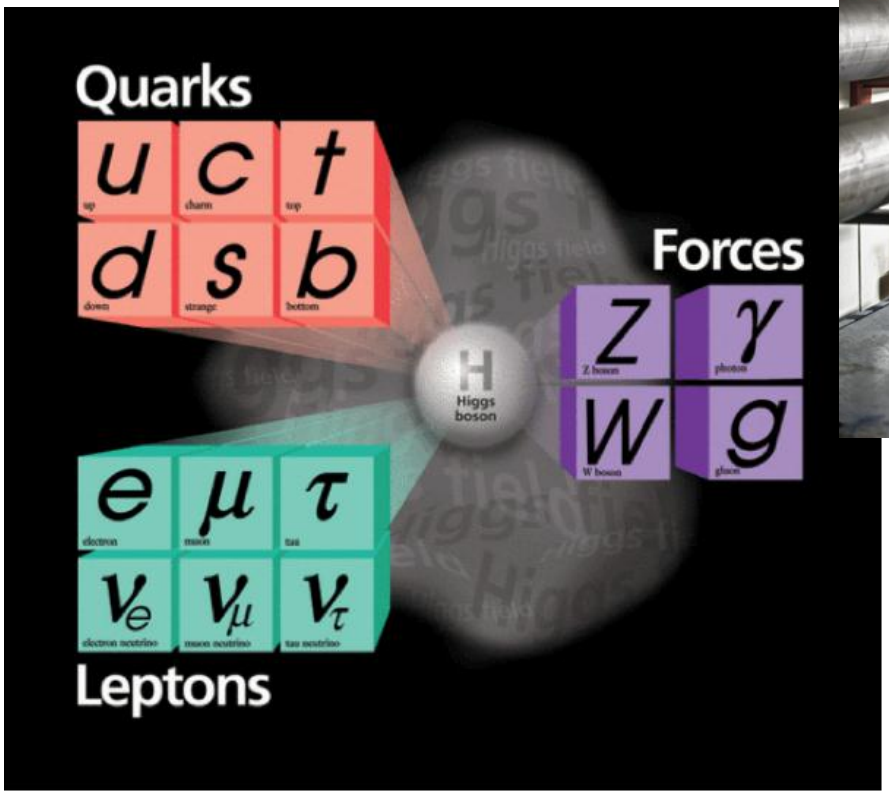
- We are located in Batavia, IL (~45 miles or 65 km west of Chicago)
- The premier US based HEP lab,
- Provides services to US HEP program
- Hosts experiments in the Energy, Intensity and Cosmic frontiers,
- Strong collaborator with the Open Science Grid (OSG) and the World-wide LHC Computing Grid (WLCG),
- Hosts the US Tier 1 facility for the CMS collaboration,
- Is the home of Scientific Linux.

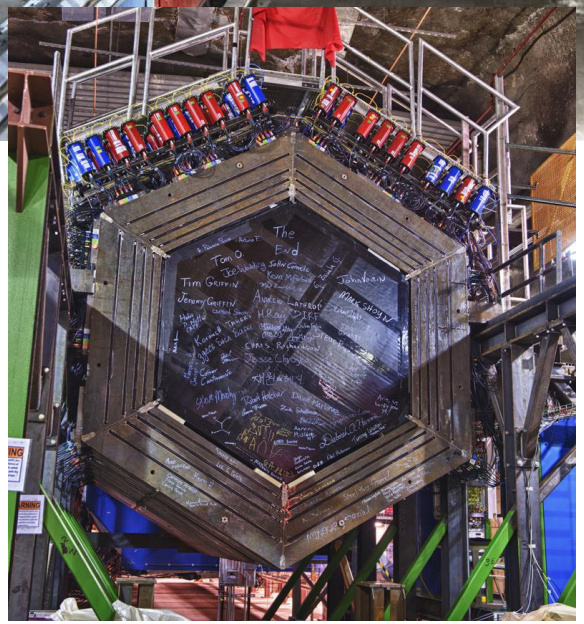


Frontiers:


The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Dark Energy
Proton Decay
Cosmic Particles
The Intensity Frontier
The Cosmic Frontier

Particle Physics 101





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How particle physics improves your life

Fermilab

Some quick statistics

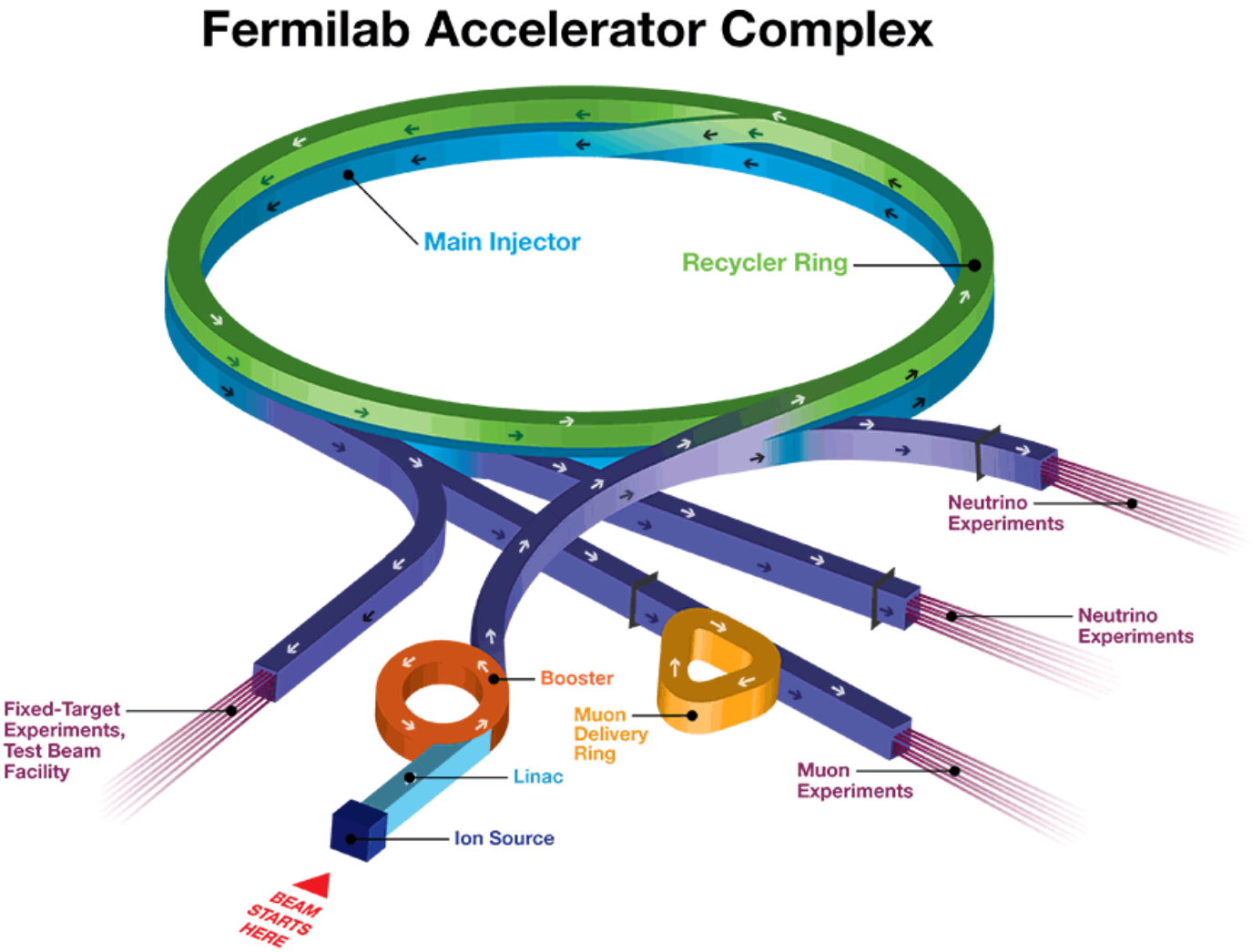
- Fermilab has 1,700 employees.
- 90% live in the Fox Valley or western DuPage.
- 2,300 visiting scientists from around the world.
- 6,800 acre site.
- About 21,000 people (including student groups) took public tours at Fermilab in 2013.
- In FY 2010:
  - Fermilab created 4,529 jobs in Illinois.
  - 87% of those jobs were in the Chicago region.
  - Fermilab pumped $643 million into the Illinois economy.

A quick look back

- Fermilab was founded in 1968.
- Using the Tevatron, the most powerful particle accelerator in the world at the time, scientists discovered the top quark and the bottom quark, two of the fundamental particles of our universe.
- Fermilab scientists also first observed the tau neutrino, an elusive fundamental particle.

The Tevatron ran from 1985 to 2011.

Main Accelerator



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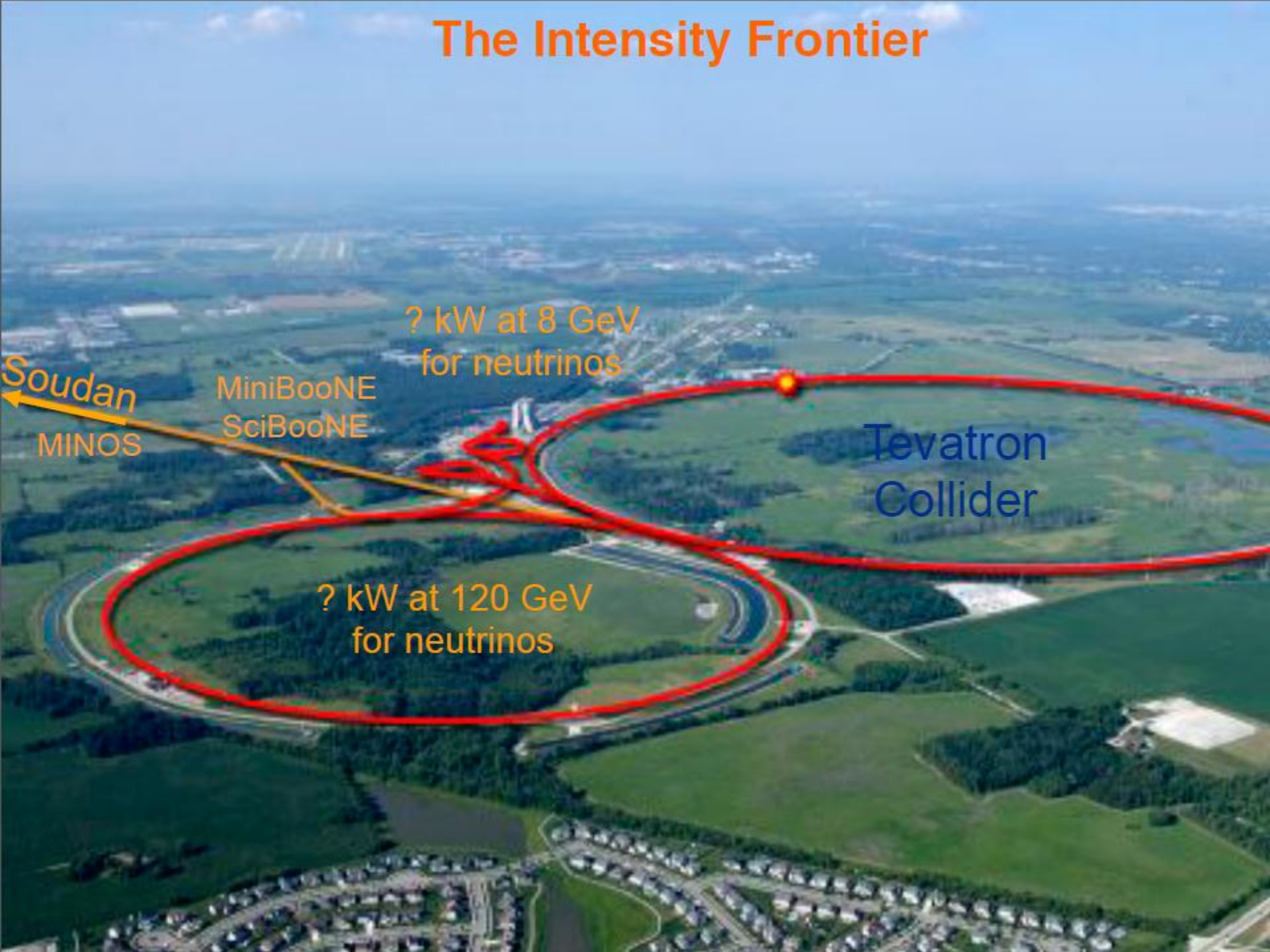
Another view

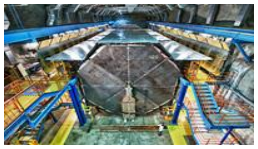
The Intensity Frontier



Current Major Science Projects





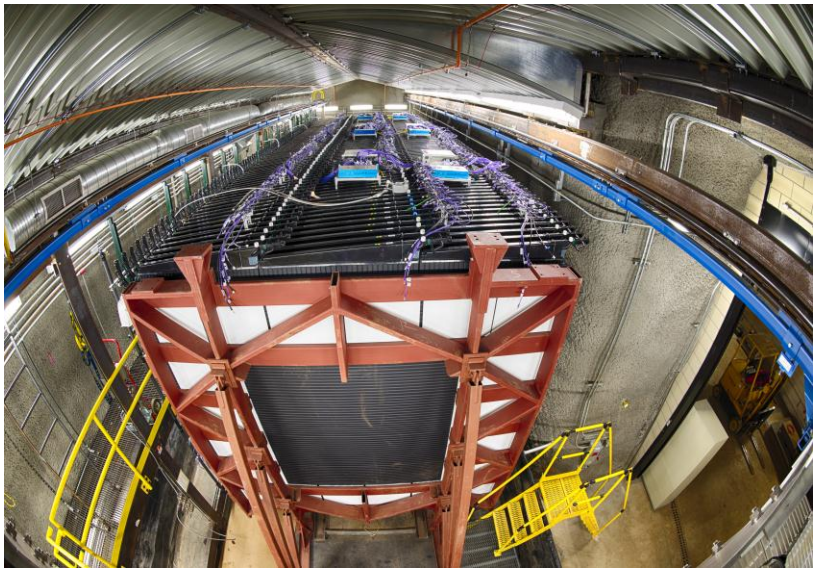


- Long-Baseline Neutrino Facility: LBNF
  - A proposed international neutrino experiment that would be the largest of its kind.
- NOvA (NuMI Off-Axis ve Appearance Experiment)
  - Fermilab's current flagship neutrino experiment,
  - Sends a beam of neutrinos to a 200-ton particle detector 500 miles away in Minnesota.
- MicroBooNE (Micro Booster Neutrino Experiment)
  - A multi-ton liquid-argon neutrino detector.
- MINERvA (Main Injector Experiment for v-A)
  - Designed to study neutrino-nucleus interactions with unprecedented detail.
- MINOS (Main Injector Neutrino Oscillation Search)
  - A neutrino oscillation experiment with a far detector also in Minnesota.
- Mu2e
  - Search for the hypothesized conversion of muons into their lighter cousins, electrons.
- Muon g-2
  - This experiment will use Fermilab's powerful accelerators to explore the interactions of short-lived particles called muons. If the properties of these particles differ from theoretical predictions, it is a sign that other, undiscovered particles are at work.

Current Major Science Projects/Collaborations with LHC

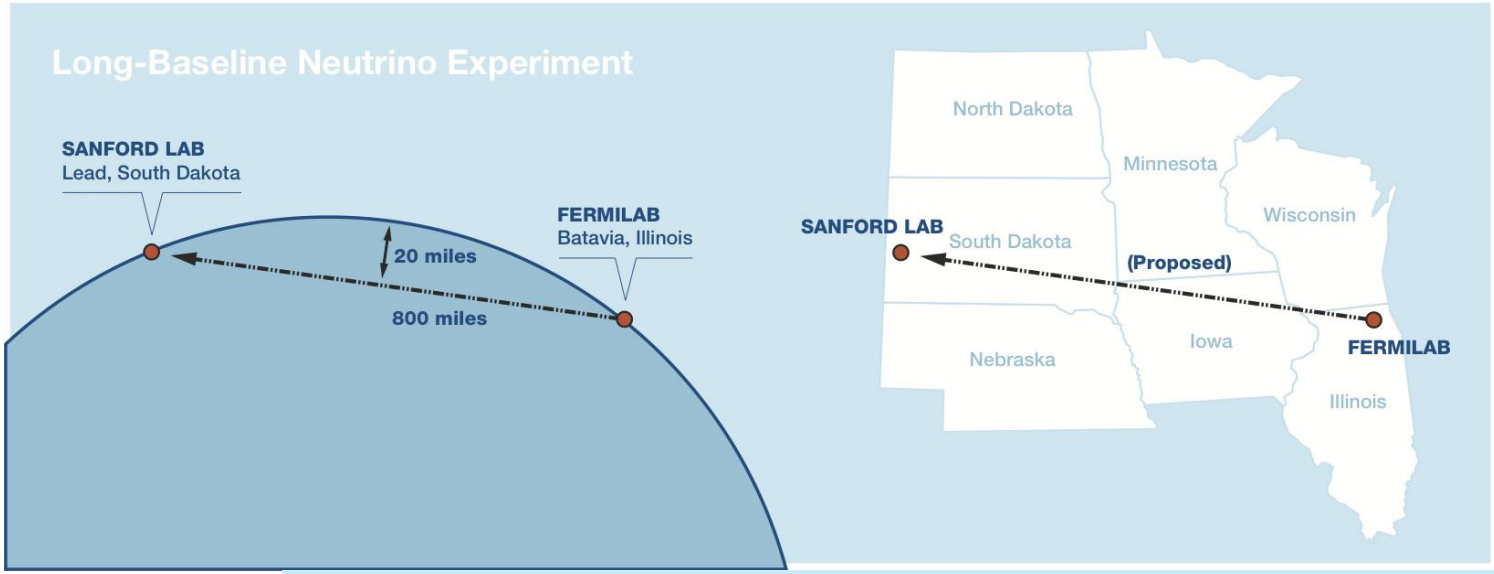
- CMS
  - One of the two general-purpose experiments at CERN LHC.
  - Research into the building blocks of the universe.
- LHC Physics Center
  - Central location for physicists to participate in LHC research in the US
  - Serves as a resource and analysis hub for
    - 630 physicists and graduate students
    - from 47 US universities and laboratories
- LHC Remote Operations Center
  - Supports the operations of the CMS detector
    - 4,000 miles from Cessy, France.
  - Allows US physicists and students to take detector monitoring shifts during US daytime hours, lessening the burden on CERN-based scientists to serve night shifts and helping US personnel fulfill their operational responsibilities in the CMS collaboration from an on-shore location.

Neutrino experiments: NOvA

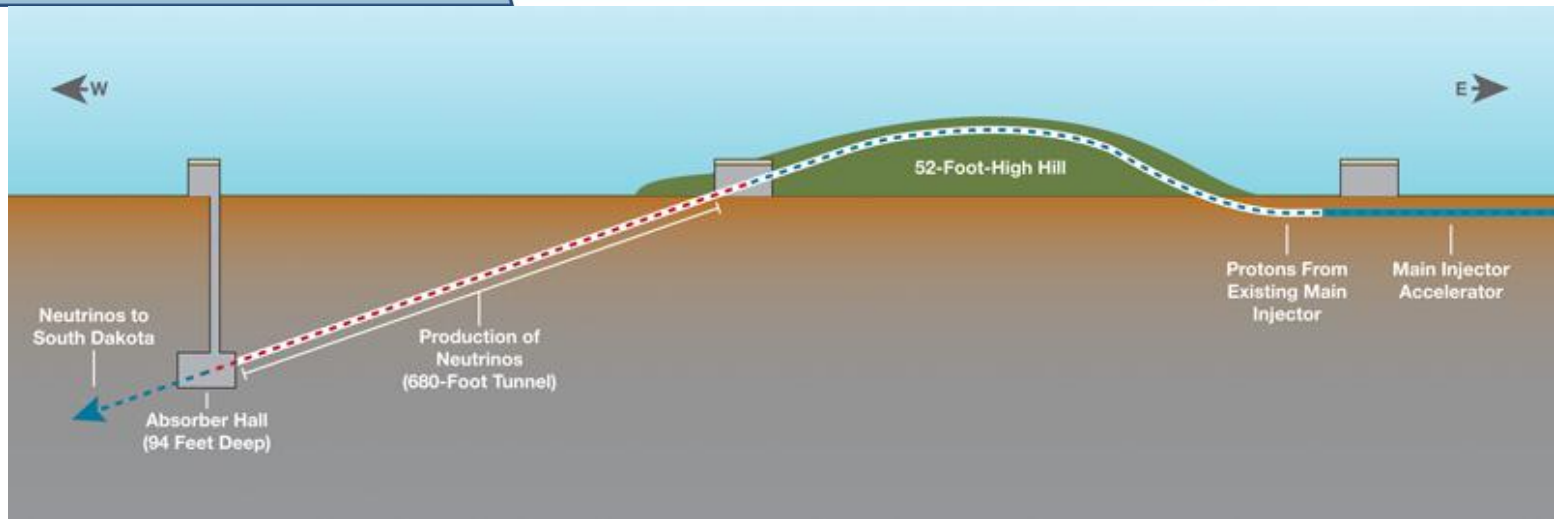


Started taking data in 2013

Neutrino experiments: LBNE



Construction starts in 2015



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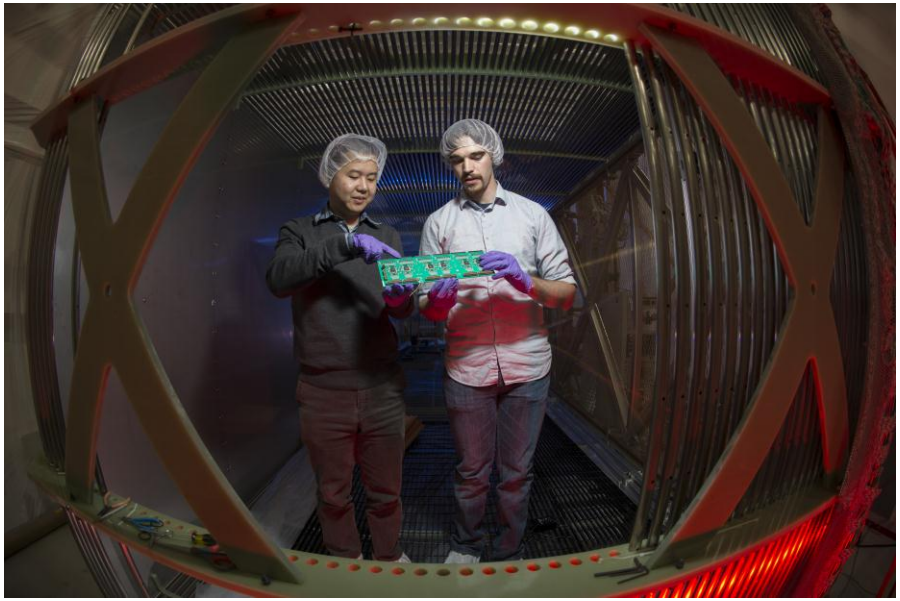
Neutrino experiments: MicroBooNE

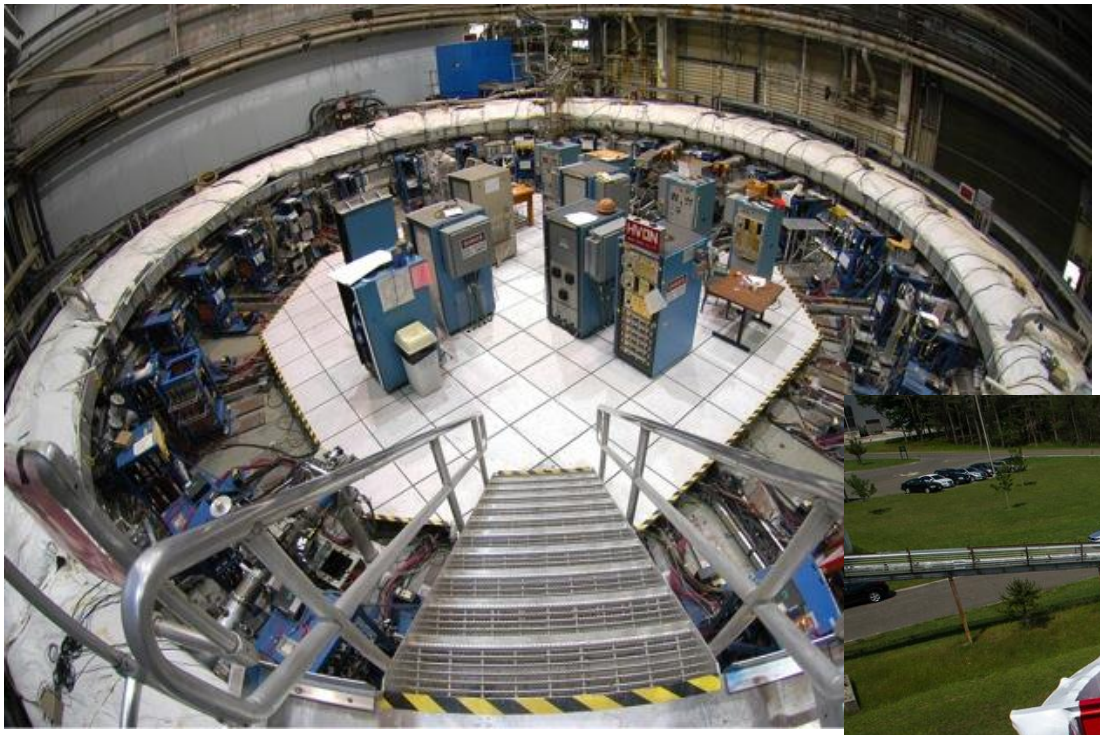


Early version of LBNE far detector.
Begins taking data this year.

Muon experiments: Muon Campus

Muon g-2 building nearly complete, will be occupied this year.

Muon experiments: Muon g-2

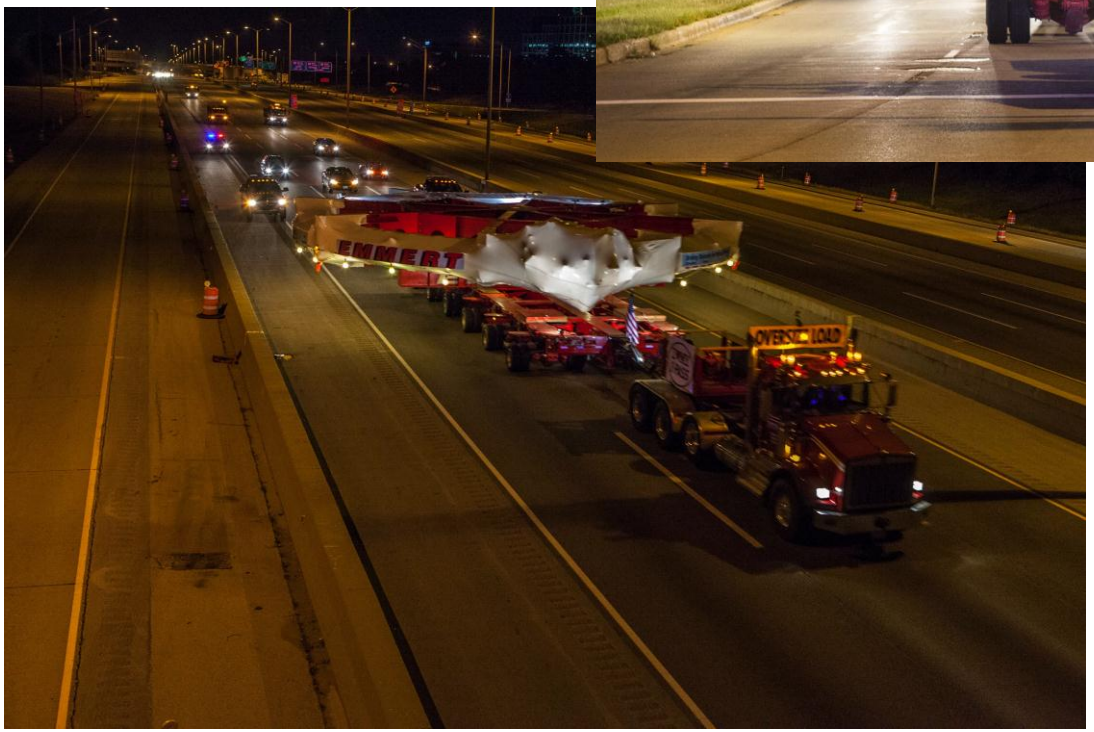


52-foot-wide electromagnetic ring for catching muons

Transported from Long Island to Fermilab summer 2013

Muon experiments: Muon g-2

Arrived at
Fermilab at
4:07 a.m. on
July 26, 2013

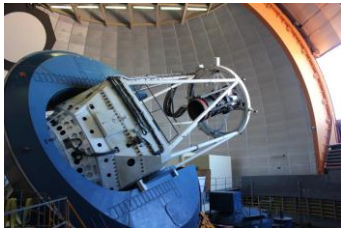


Muon experiments: Muon g-2

- Summary version of original clip:
- http://www.youtube.com/watch?v=rGLpMigWIIs

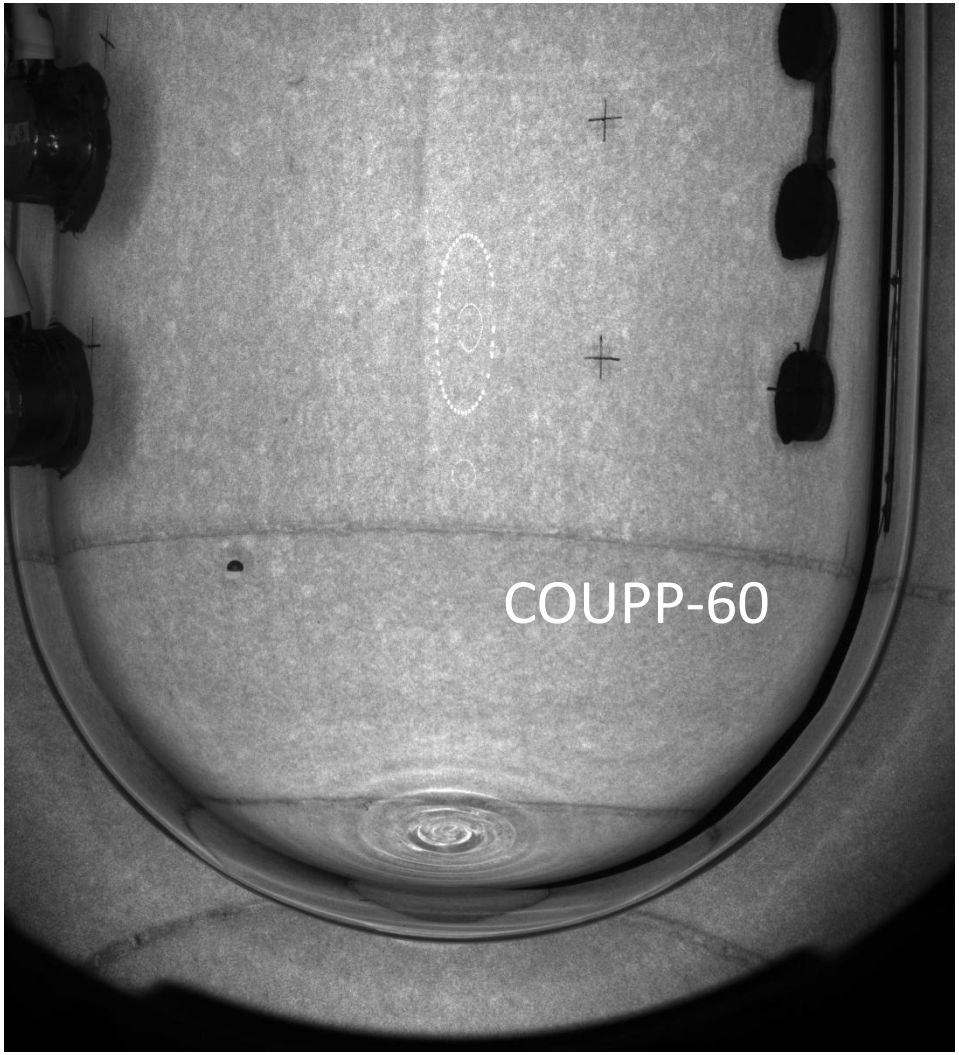
- See also http://muon-g-2.fnal.gov/bigmove/ as well as http://muon-g-2.fnal.gov/bigmove/gallery.shtml

Dark Energy Survey



First season finished, will run for four more years.

Dark matter experiments



Large Hadron Collider/CMS experiment

Fermilab's Remote Operations Center collects real-time data from the CMS Experiment

Illinois Accelerator Research Center

IARC's mission is to partner with industry to translate technology developed in the pursuit of science into the next generation of industrial accelerators, products and applications.

IARC's vision is to be the preeminent technology source for accelerator-based products and services, serving as the seed for industry growth.

Educational outreach

In 2013:

- 14,524 students participated in activities at Fermilab.
- 24,637 students were visited in their schools by Fermilab staff.
- 156 teachers attended workshops at Fermilab.
- 139 teachers used our Teacher Resource Center.

Educational outreach

Fermilab's Education Office holds a STEM career fair and a family open house each year, a Saturday Morning Physics course for about 300 high school students, and helps manage the national QuarkNet program.

The Lederman Science Center offers hands-on science exhibits and hosts about 3,000 visitors a year.

Environmental stewardship

- Fermilab is a National Environment Research Park.
- More than 1,100 acres of restored prairie, wetland and woodland.
- Fermilab Natural Areas offers volunteer opportunities throughout spring, summer and fall.

Arts and Lecture Series

- Concerts and lectures from around the world.

Calendar at www.fnal.gov/culture

New website: www.fnal.gov

Community newsletter

www.fnal.gov/pub/science_next_door

Monthly guide to everything happening at the laboratory. Emailed for FREE!

Science Next Door

Fermilab's Community Newsletter

March 2014 Subscribe | Fermilab Home

Welcome to Science Next Door, Fermilab's community newsletter. Once a month, we'll give you the rundown about what's happening here at the laboratory and provide information about our public events. If you would prefer not to receive this newsletter, you can click the "unsubscribe" button below. Thank you!

A Big Month for the NOvA Experiment

It's all coming together for Fermilab's NOvA experiment. The biggest project of its kind in the United States, NOvA is designed to study ghostly particles called neutrinos with great precision. It consists of two large detectors – one smaller one underground at Fermilab, and one larger one in northern Minnesota. Fermilab sends a beam of neutrinos 500 miles through the earth (with no tunnel required) to the Minnesota detector, with the goal of seeing the rare interactions between neutrinos and other matter.

Calendar

Science Adventures: Girls Scientific Salon
Sat., Mar. 1, 9 a.m.-2 p.m.
Grades 4-7

Get to Know the Lederman Science Center FREE
Sat., Mar. 1, 10 a.m.-noon
Grades 4 and up

Alan Kelly Gang
Sat., Mar. 1, 8 p.m.

Ask-a-Scientist: Accelerators for the Energy Frontier
Sun., Mar. 2, 1-4 p.m.
Grades 6 and up

English Country Dancing FREE
Sun., Mar. 2, 2-5 p.m.

Brush Cutting Volunteer Day FREE
Mon., Mar. 3, 1-3 p.m.

Scottish Country Dancing FREE

Come visit us

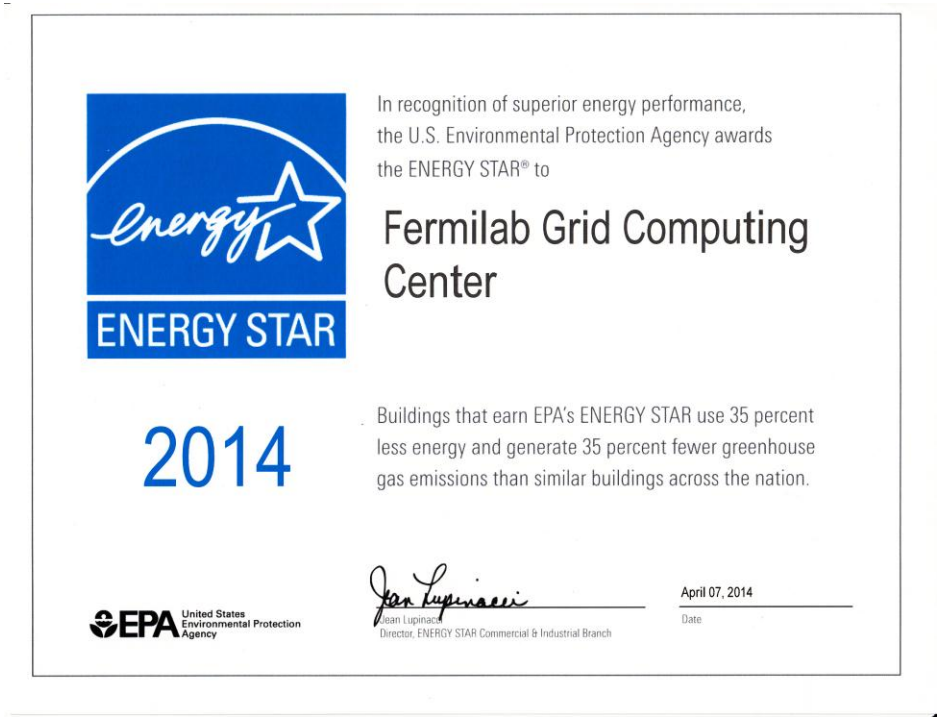
- Site is open every day from 8 a.m. to 8 p.m. during the summer months, 8 a.m. to 6 p.m. the rest of the year.
- Only need a photo ID to get in.
- Free public tours every Wednesday at 10:30 a.m.
- And yes, we have bison!

Always leave them with the bison

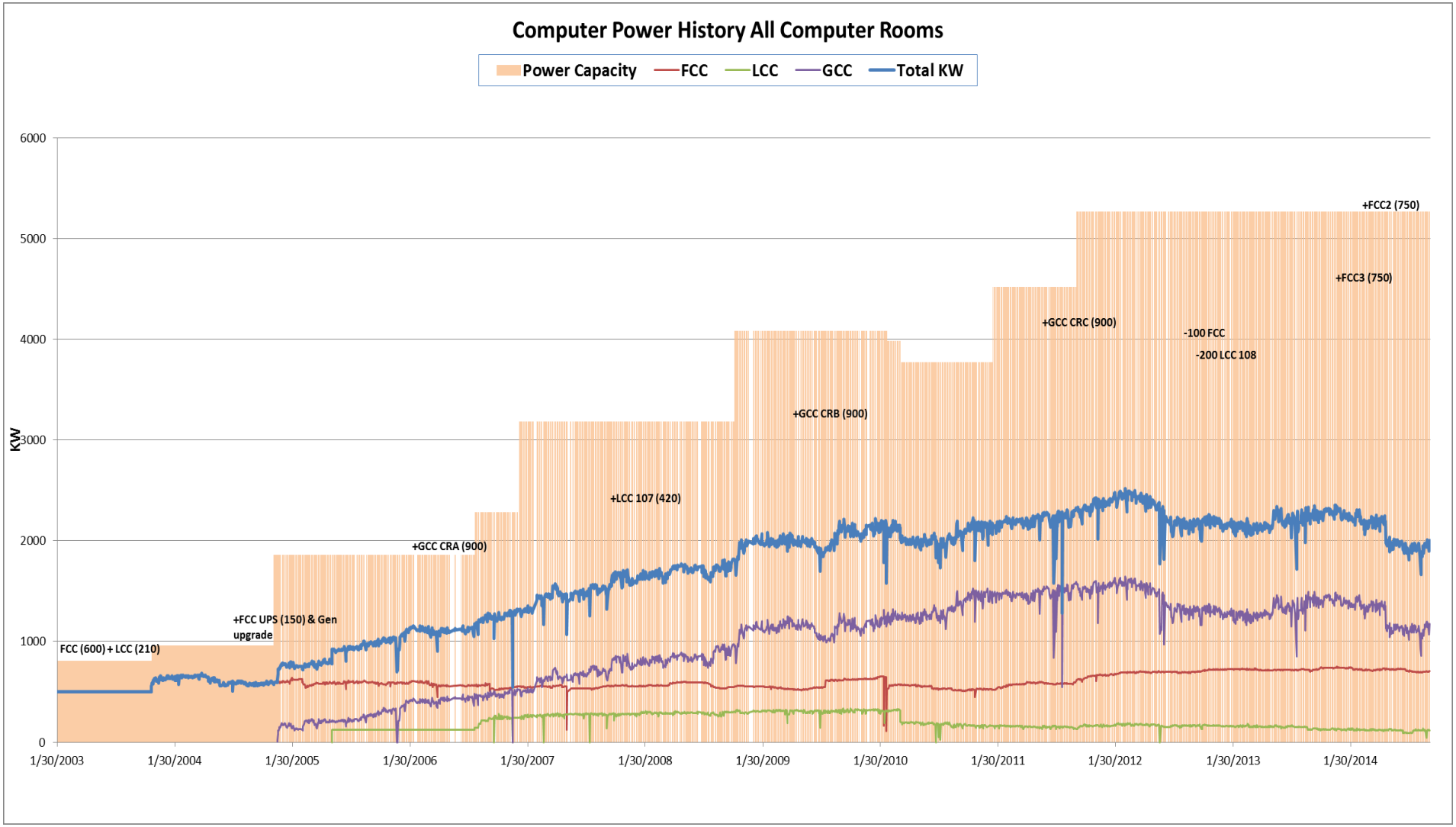
Break

Computing @ Fermilab

- FCC:
  - The FCC3 computer rooms continue to operate without any disruptions since commissioning in December 2010
- GCC:
  - Recently installed condensers are located on the roof of the building (also helped by a very “mild” summer)
- LCC:
  - LCC had >99.9% uptime
- The GCC computer center received an energy star certificate for 2014
  - This is the fourth year in a row that this building has received the award



Computing Capacity @ Fermilab



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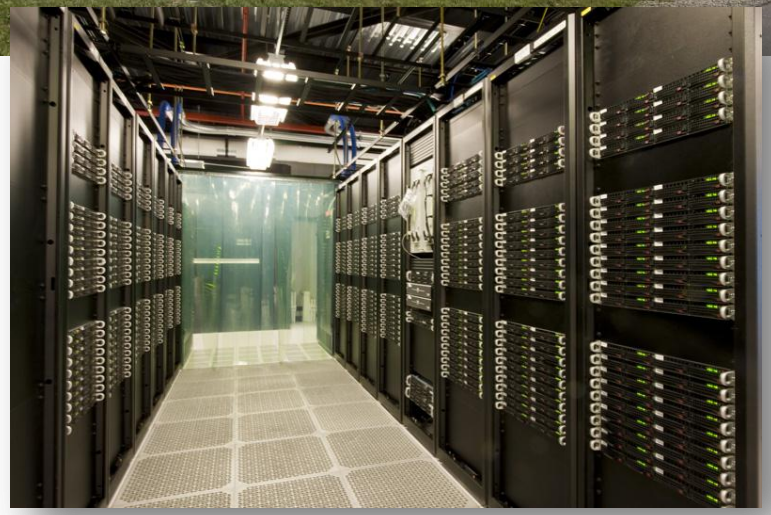
Grid Computing Center @ Fermilab

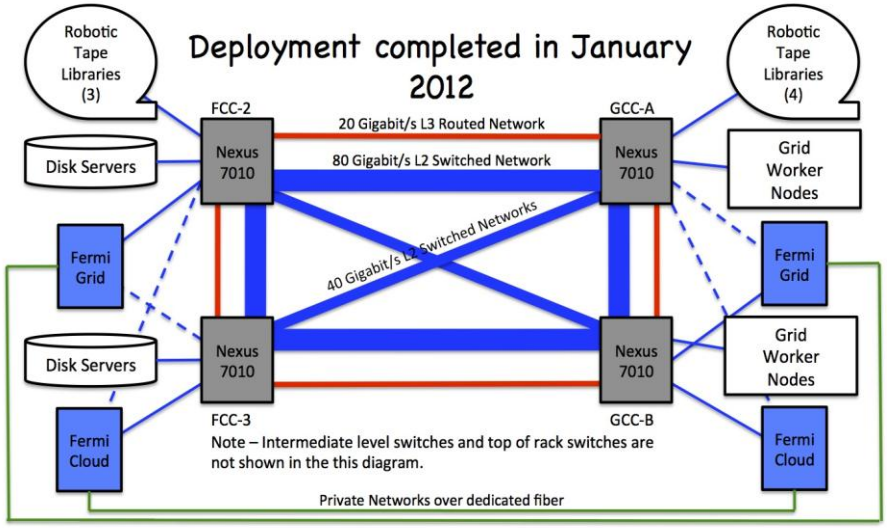
Computing Centers @ Fermilab

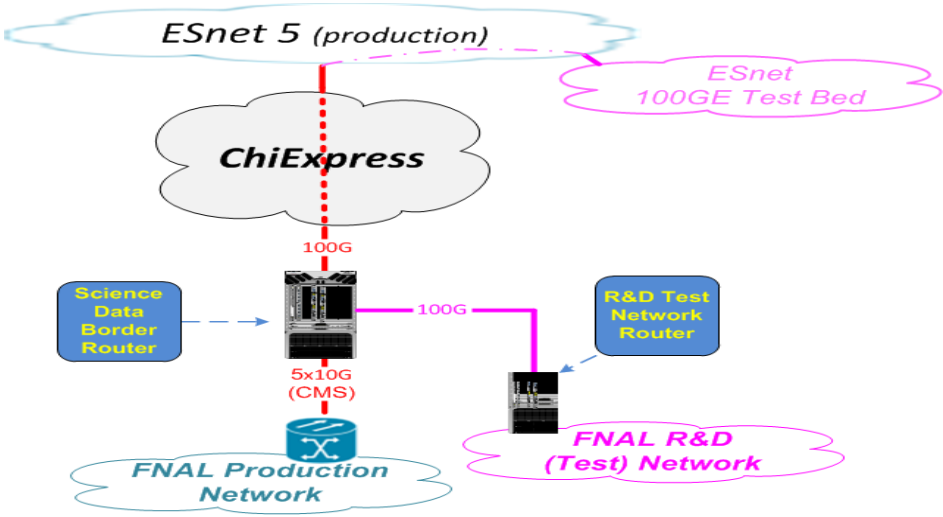


Very High Speed Networking @ Fermilab

- The offsite network links were moved from the ESnet CHIMAN 10GE network to the new ESnet ChiExpress 100GE infrastructure on Friday 9-May-2014.

- The reorganization of the IPv6 and the 100 Gb/s testbed continues,
  - Slow progress since enhancements and maintenance of the production network takes priority.





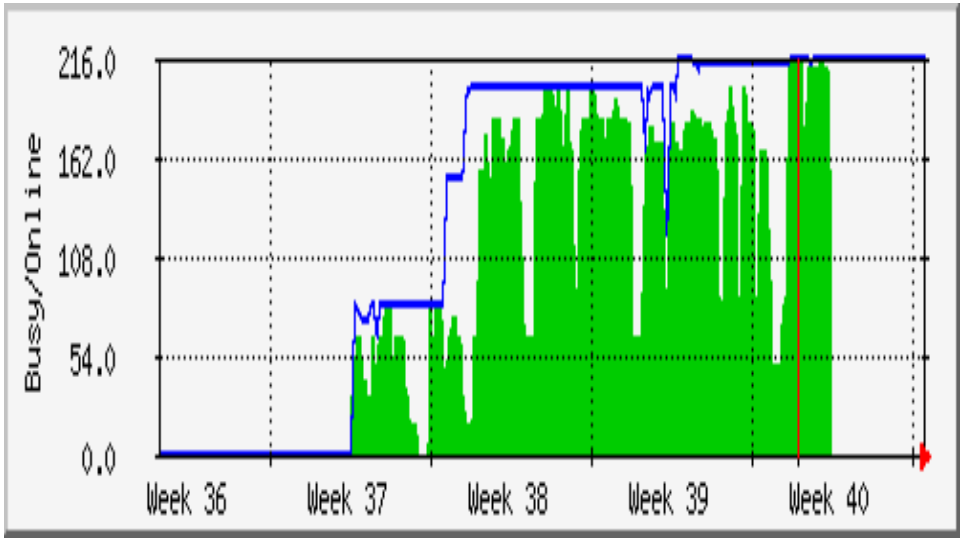
Active Compute Works @ Fermilab

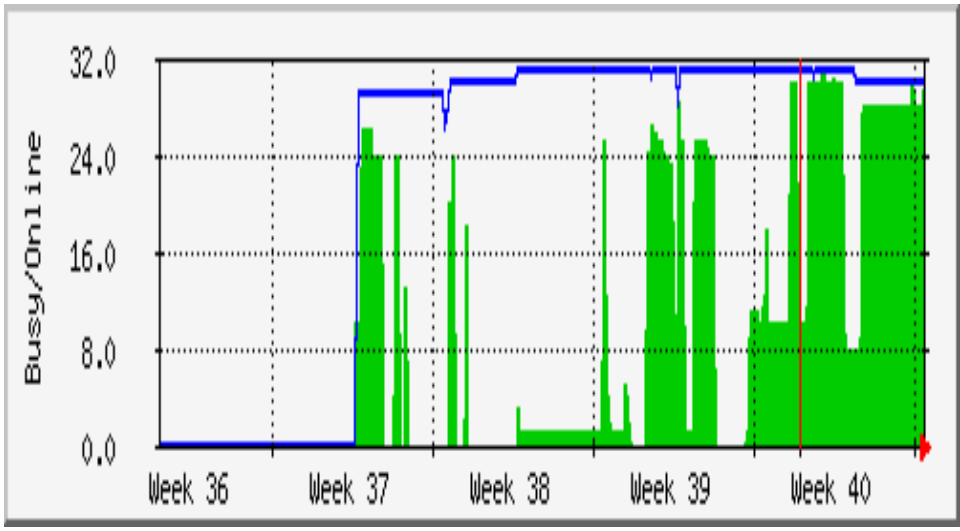
- HPC LQCD
- CMS
- Open Science Grid, OSG
- FermiCloud
- FEF, Digital Acquisition work
- Data Management and Storage
- Scientific Linux

HPC and Lattice Quantum Chromo Dynamics@ Fermilab

- Most recent “Hybrid” HPC Cluster Acquisition:
  - ❑ ≥ 10 TF sustained performance Conventional
  - ❑ ≥ 29 TF sustained performance GPU as accelerators

- Acquisition completed and hardware delivered,
  - Conventional: 212 systems
    - Dual Intel E5-2650v2 2.6GHz 8-core processors with 128 GB of system memory
  - GPU: 32 nVidia K40
  - Underwent stress testing for 1 month
  - Conventional portion released to production on 10-Oct-2014.





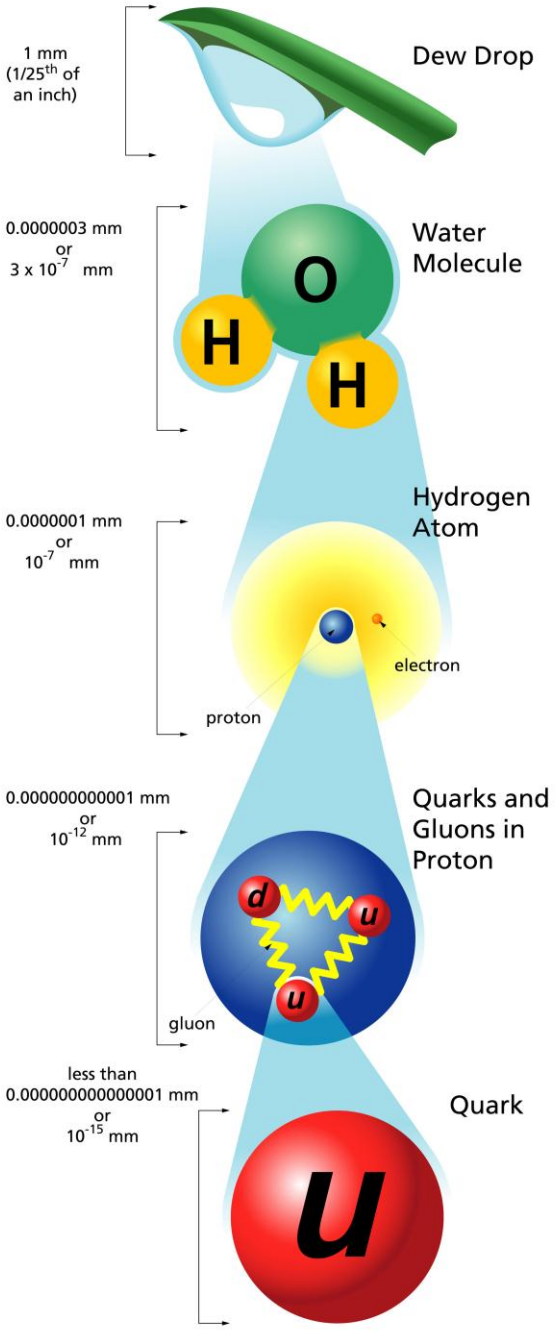
HPC and Lattice QCD @ Fermilab

A little Intro

The proton is a complicated blob. It is composed of three particles, called quarks, which are surrounded by a roiling sea of gluons that "glue" the quarks together.

Why go into this?

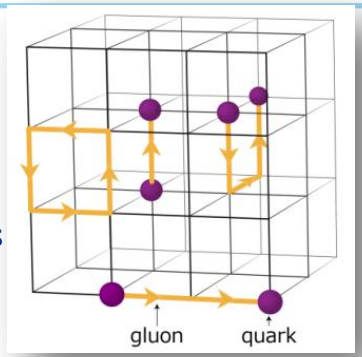
These calculations are crucial to answering important questions about the universe, such as: What is the origin of mass in the universe? Why do the elementary particles we know come in three generations? Why is there so much more matter than antimatter in the universe?



HPC and Lattice QCD @ Fermilab

What is Lattice Quantum Chromodynamics?

Lattice QCD (LQCD) is a well-established approach to solving the quantum theory of quarks (the "building" blocks of protons, neutrons, …) and how they interact with gluons that bind the quarks together. In this approach we imagine an immense 4D structure or lattice of points in space and time. When the size of the lattice is infinitely large and its sites infinitesimally close to each other, the continuum QCD is realized.



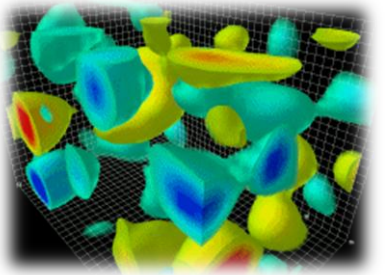
Why does HPC matter to LQCD?

LQCD calculations are computationally intensive and extremely challenging. Effective parallel machine designs need to balance floating point performance, memory, network bandwidth and latency. Even a modest problem size of $48^3 \times 144$ results in a matrix size of 47.8 million x 47.8 million elements! This may take several decades of compute time on your average desktop. HPC is the only way we can accelerate this using many technologies together.

How have people used LQCD ?

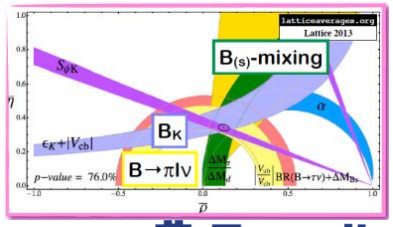
In nuclear & high energy physics, LQCD has been used by physicists to help:

- Search for new physics
- Calculate masses and decay rates of different particles
- Help interpret experimental results
- Predict possible results of new experiments
- Predict properties of QCD that cannot be obtained otherwise



Recent LQCD Successes in quark flavor physics

- Ds meson leptonic and semileptonic decay rates
- K to π semiileptonic decay rates



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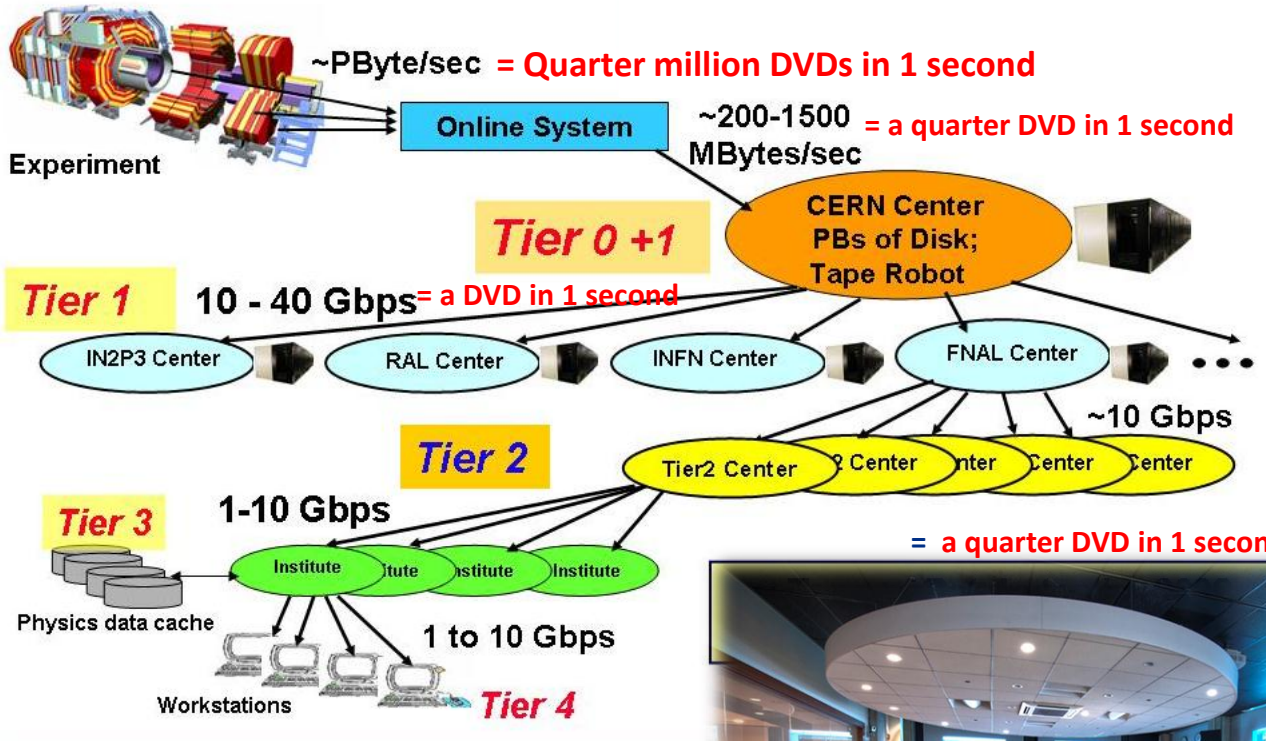
CMS experiment with LHC/CERN @ Fermilab



The distributed computing system for LHC distributes hundreds of Terabytes a day outward from CERN to the 11 distributed Tier-1 sites (one at Fermilab) & then 25 University Tier-2 and access to more than 100 smaller Tier-3 centers.

= a quarter DVD in 1 second

The CMS Remote Operations Center at Fermilab remotely supports the CMS experiment located 4,000 miles away at Cessy in France. The ROC allows US physicists to help operate the CMS

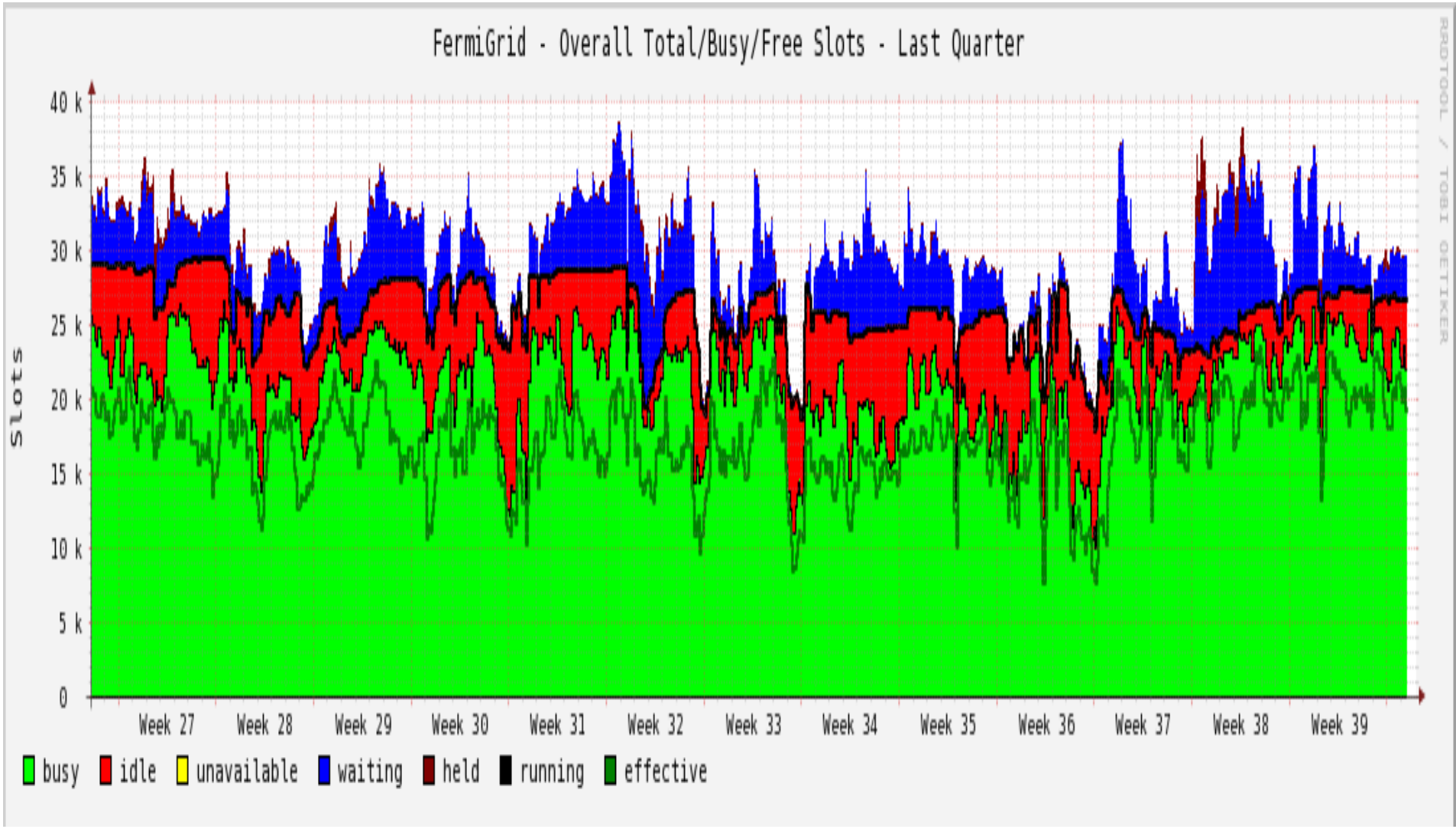
Open Science Grid @ Fermilab

- The Open Science Grid (OSG) Consortium promotes discovery and collaboration in data-intensive research by providing a computing facility and services that integrates distributed, reliable and shared resources to support computation at all scales.
- The OSG is a community alliance in which universities, national laboratories, scientific collaborations and software developers contribute computing and data storage resources, software and technologies. Initially propelled by the high energy physics community, participants from an array of sciences now benefit from our infrastructure.

- Fermilab is an active member of the OSG and the Computing Sector(CS) contributes effort in several areas:
  - FermiGrid, established by the CS, is the Fermilab campus-wide Grid providing a uniform interface to most of the Fermilab resources. FermiGrid contributes to and supports the Open Science Grid and the LHC Computing Grid
  - CS members also contribute grid software to the OSG software stack; examples include the glideinWMS project for managing job submissions and Gratia for grid accounting.

- The US CMS grid, for which Fermilab is the Tier-1 center in the US, is part of the Open Science Grid infrastructure. OSG contributes to the Worldwide LHC Computing Grid which is the basis for the Worldwide CMS computing system

Campus Grid @ Fermilab



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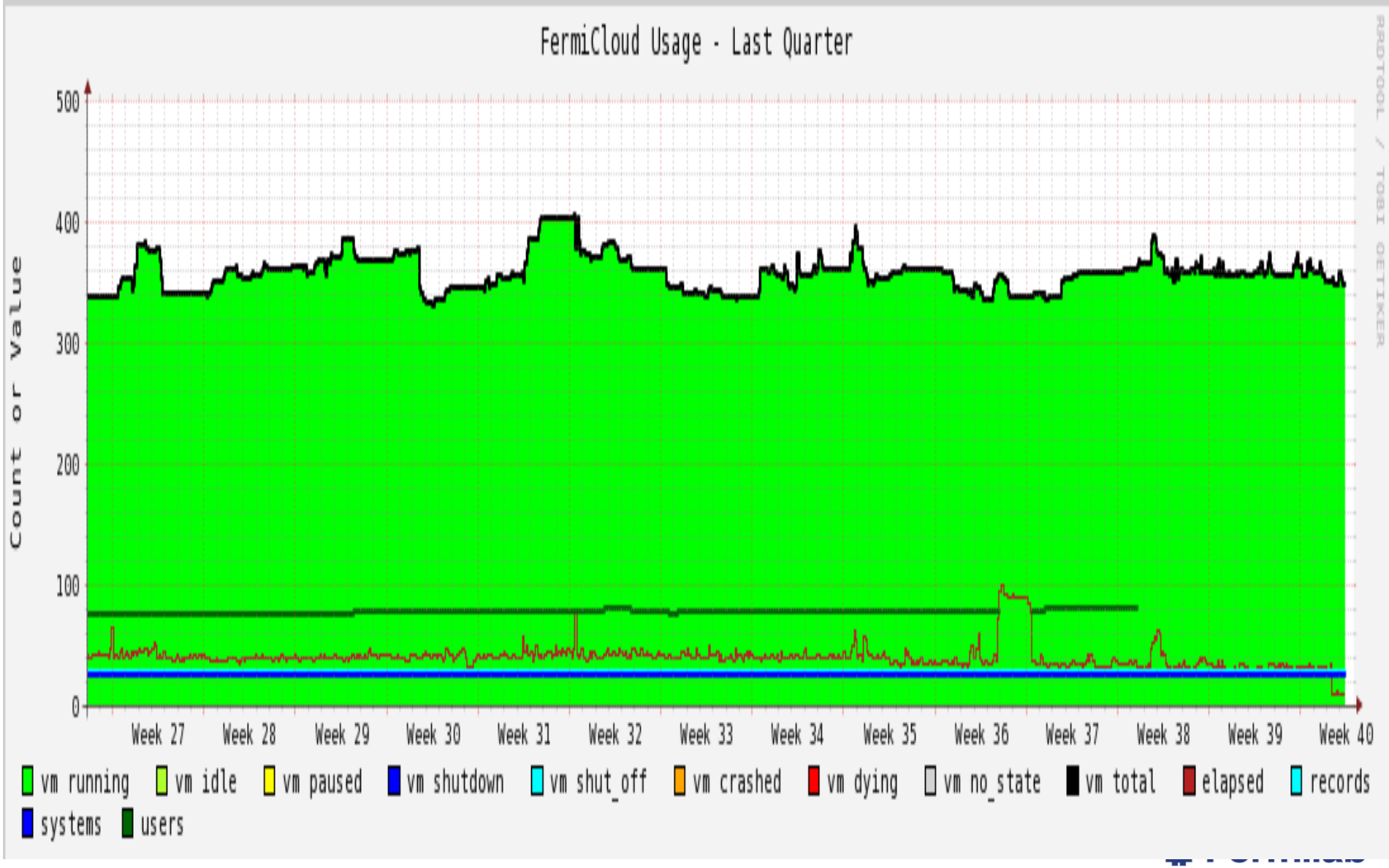
FermiCloud @ Fermilab



FermiCloud @ Fermilab

- Tested VM launching on Google Compute and Microsoft Azure Clouds,
  Have specific “recipes” for each

- Is being used to support “custom” Grid worker nodes for specific VOs,
  Typically larger memory allocations, disk partitions, or multi-core jobs

- 1000 VMs “en mass launch” test under OpenNebula 4.8,
  - 1000 VMs deployed sequentially with a sleep 1 between each launch,
  - 998 VMs successfully deployed,
  - 2 VMs went to FAIL state for a libvirt error.

- Currently setting up for a “1000 VM” hybrid cloud test with VMs deployed on FermiCloud and Amazon EC2.

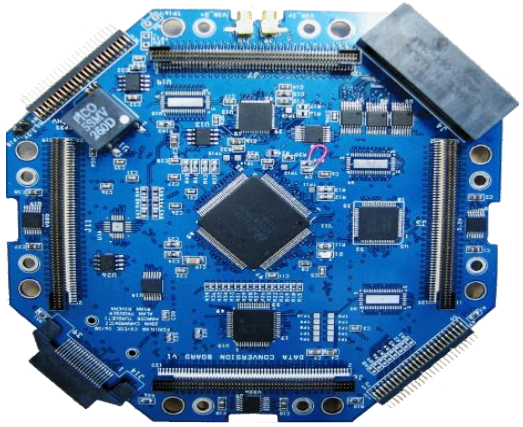
DAQ @ Fermilab

Motivation:

The Electronic Systems Engineering department of Fermilab Scientific Computing Division has developed a data acquisition system that is:

- flexible and
- powerful enough

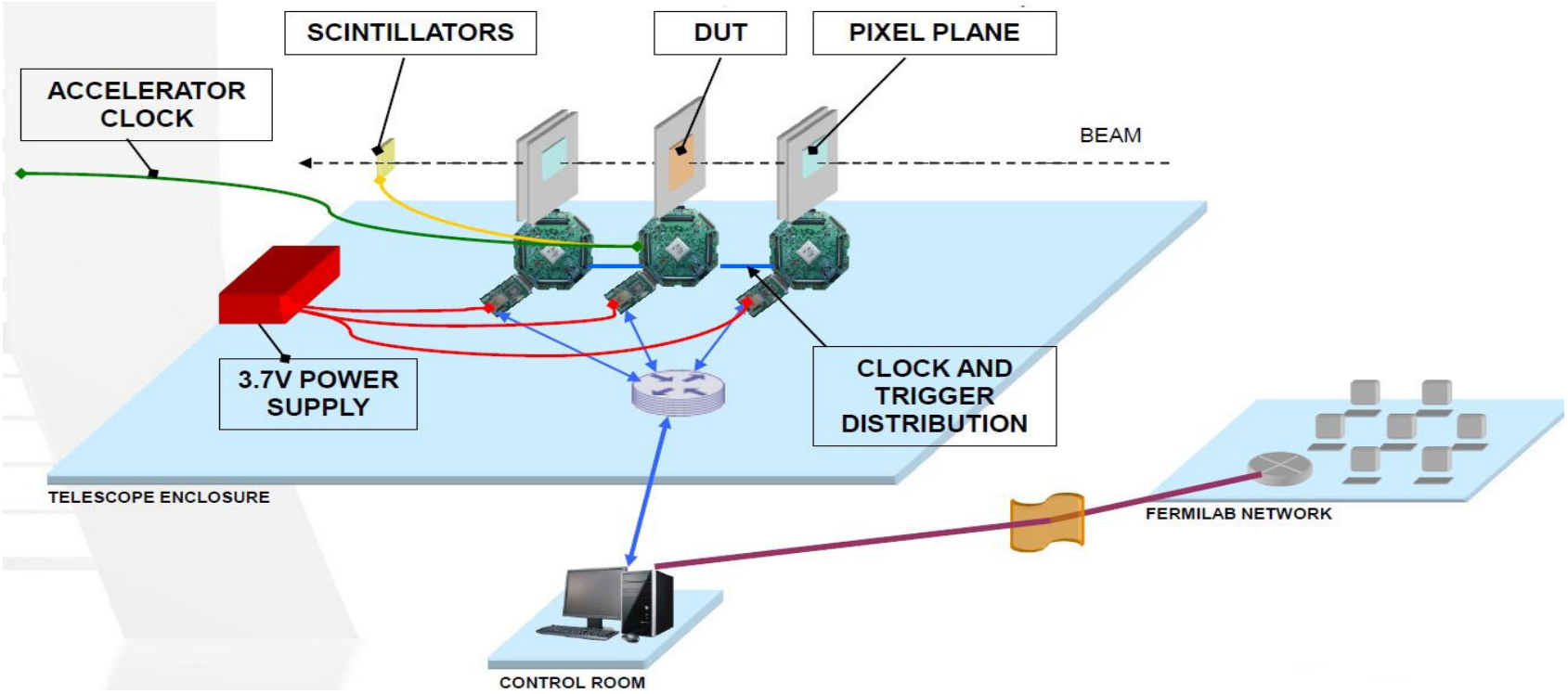
meet the demands of pixel and strip detectors for high energy physics applications, but also capable of far broader application utility. The individual unit within the system is known as a Compact And Programmable daTa Acquisition Node, or CAPTAN.



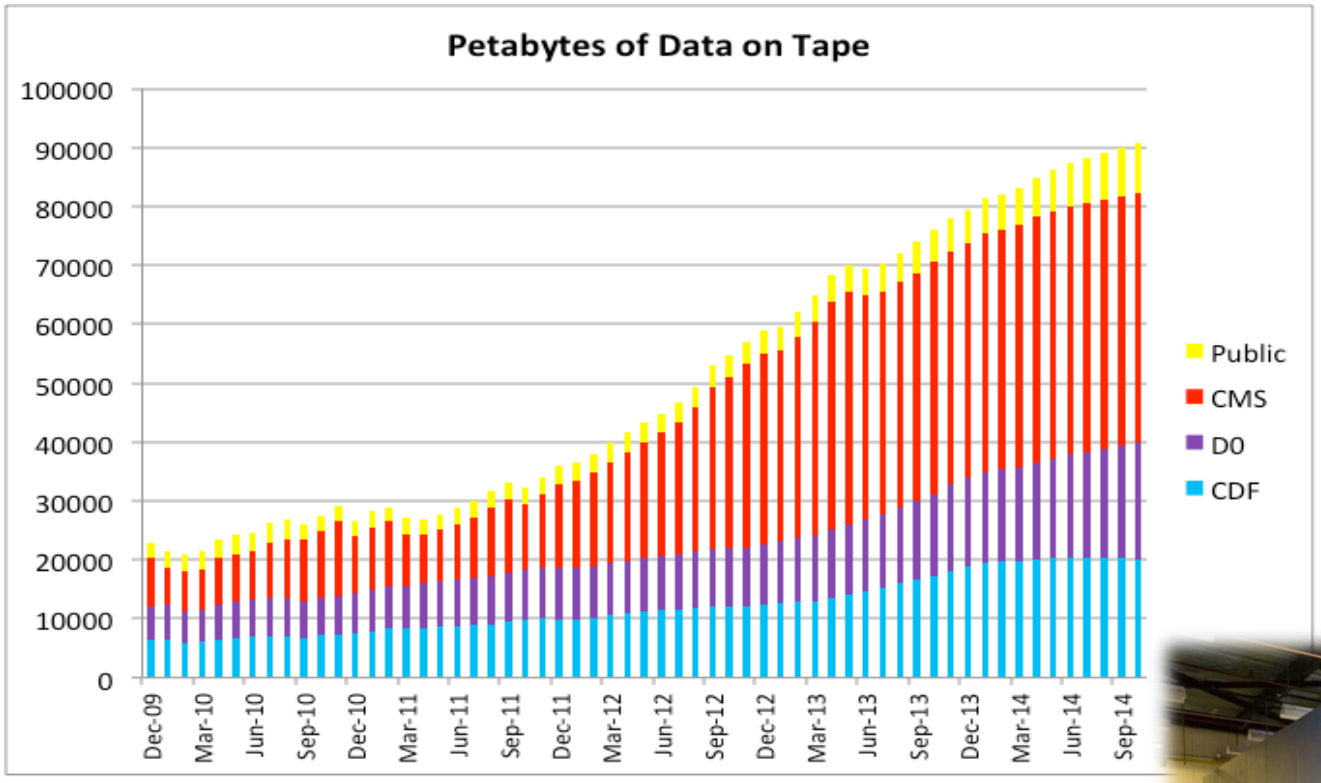
DAQ @ Fermilab

CAPTAN Pixel Telescope

The CAPTAN pixel telescope is part of the FTBF facility and has been used by many experiments as a high resolution tracking tool to characterize different Detectors Under Test (DUTs).



Data on Tape @ Fermilab



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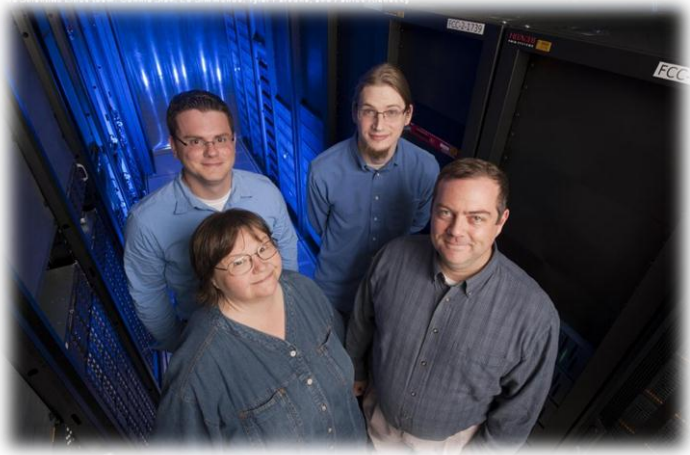
Scientific Linux @ Fermilab

- ✓ Created in 2003/2004 at Fermilab, Scientific Linux is a Linux operating system distribution assembled by Fermilab and CERN in collaboration with other HEP institutions.
- ✓ Supported by an active user community.
- ✓ Complete build from RHEL sources (not CentOS based)
- ✓ Scientific Linux is used as the computing platform for major research projects all around the globe.
- ✓ 100% open source and free
- ✓ Packaged by a dedicated and professional team

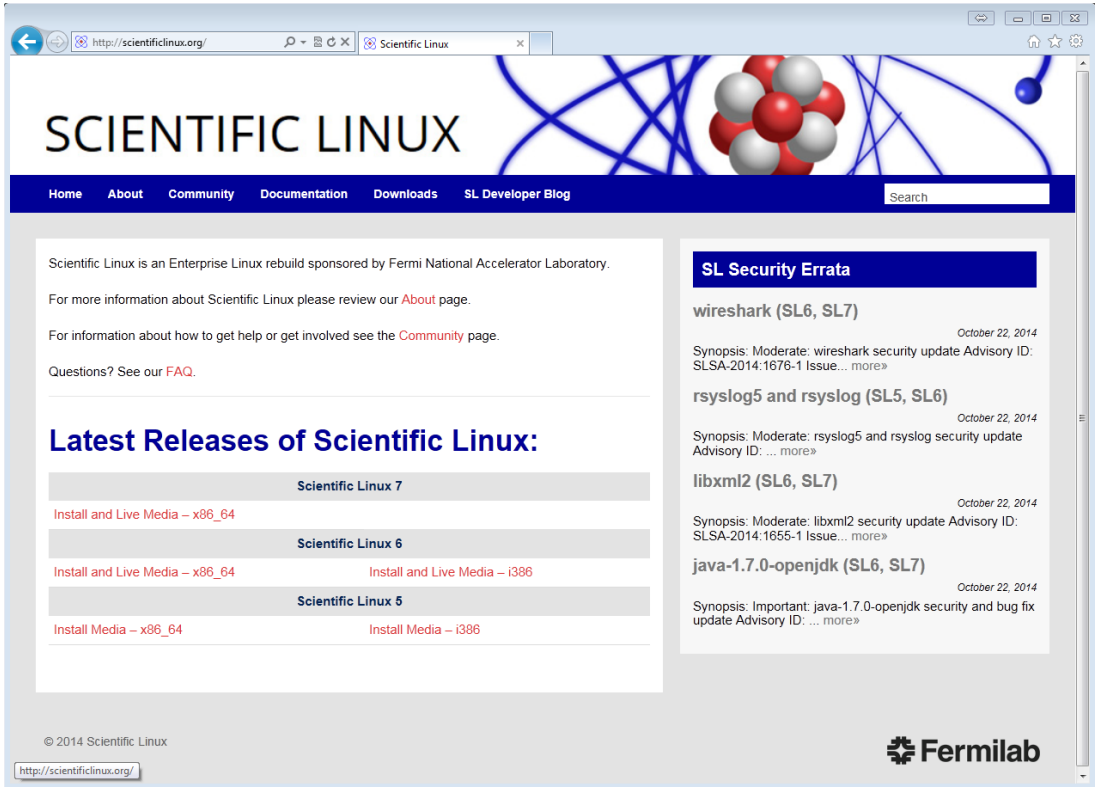


After the Red Hat/CentOS merger

In 2014, Red Hat Inc. directly embraced the rebuild community by acquiring the CentOS project. The landscape of Linux has changed a lot since 2003 and this provided an opportunity to really refocus Scientific Linux on its core competencies. We make a stable platform for scientific computing that anyone can use. We have direct access to cutting edge scientific software. Today, we focus in on putting these two things together into unified, supportable environment

Scientific Linux @ Fermilab

- ✓ SL 7 now released
- ✓ SLF is Fermi add on, for example Site Specific Kerberos stuff
- ✓ SLC is CERN add on, for CERN specific customizations, they are now trying another Linux distribution
- ✓ Fresh web site www.scientificlinux.org



Fermilab

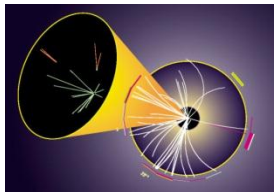
Exciting Times @ Fermilab

Science & Computing

Dzero

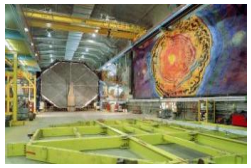
CMS

CDF

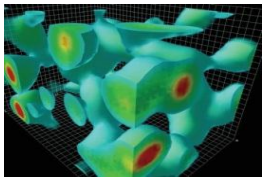


CDMS

MINOS



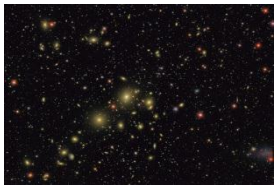
Lattice QCD



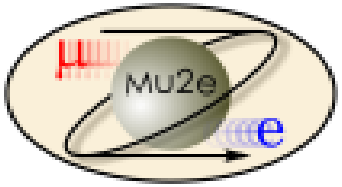
SDSS

NOvA

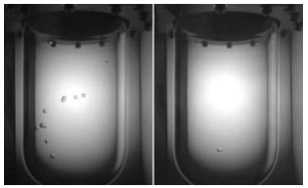
DES



Mu2e



COUPP



Pierre Auger

A major part of the Computing Sector's work is to support & improve the scientific programs at the lab. This includes computer support for experiment systems, design and implementation of the Data Acquisition and control systems, accelerator & detector simulations, research & development of the physics analysis software.

Computing *Data Handling & Storage* *Networking* *Analysis Software*

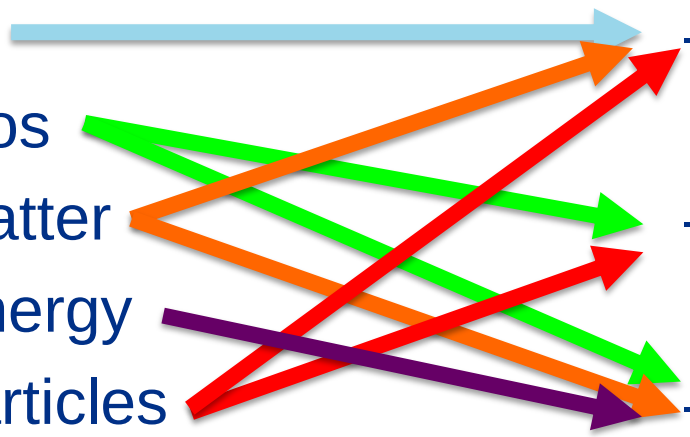
Some of the Current Questions in Physics

- Is there a theory which explains the values of all fundamental physical constants?
  - Is the theory string theory?
- Higgs Boson:
  - Is there only one type of Higgs Boson?
- What are the detailed properties of the neutrino?
  - Is mass hierarchy normal or inverted?
- Why are there three generations of quarks and leptons?
  - Is there a theory that can explain the masses of particular quarks and leptons in particular generations from first principles?
- What is Dark Matter?
  - Is it actually a particle (or particles) or is it an extension of gravity?
- What is the cause of the observed accelerated expansion of the Universe?
  - What is Dark Energy?
- Does nature have more than four spacetime dimensions?
  - Can we experimentally observe evidence of higher spatial dimensions?

http://en.wikipedia.org/wiki/List_of_unsolved_problems_in_physics

The Final Condensation…..

- Science Drivers
  - Higgs
  - Neutrinos
  - Dark Matter
  - Dark Energy
  - New Particles
- Frontiers of Science
  - Energy Frontier
  - Intensity Frontier
  - Cosmic Frontier



There is no danger of running out of work, computing, the computer systems and services that support science at Fermilab, will be around for a while……..

A picture is worth more than 1024 words……

Lunar Eclipse [October 8th 2014], photo by Matt Murphy, Accelerator Division