Scientific Computing at Fermilab

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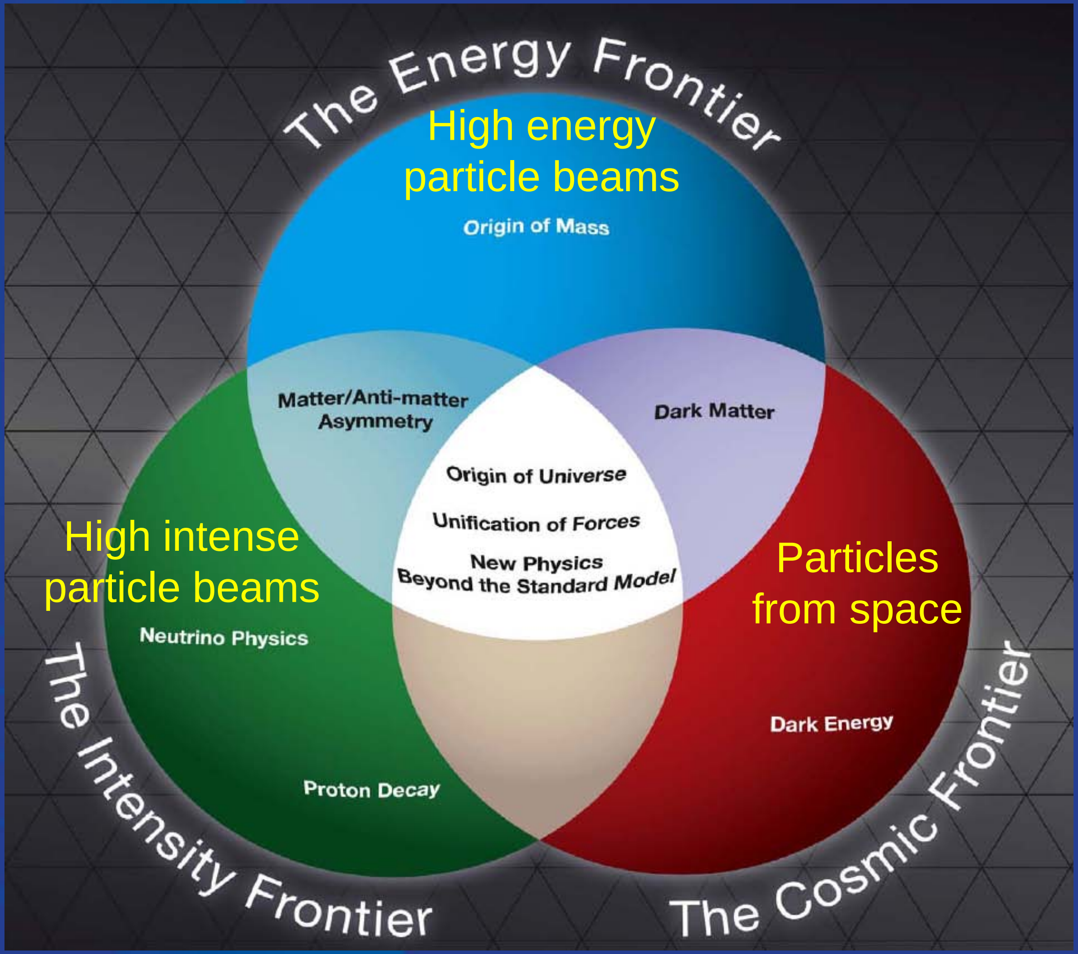
U.S. DEPARTMENT OF ENERGY

Fermilab

Three Frontiers in Particle Physics



Scientific Mission needs significant computing resources and expertise

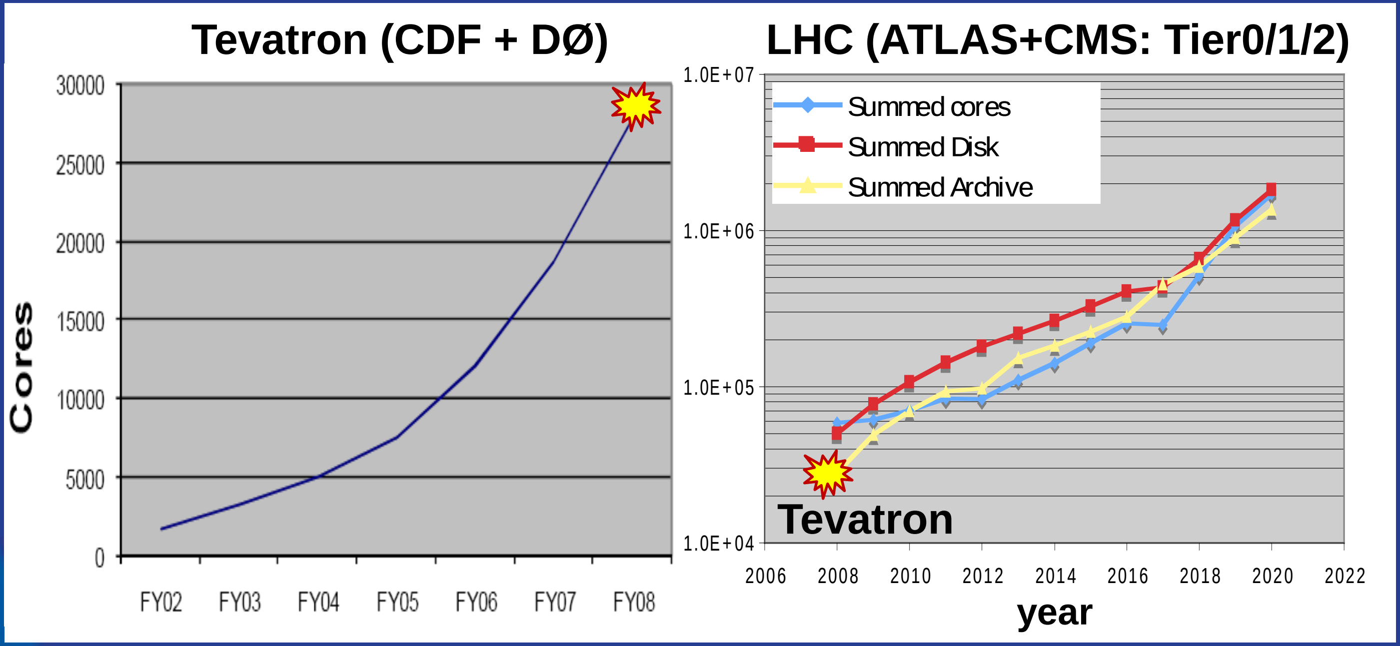
- Accelerator Simulation
- Detector Simulation
- Data Processing, Distribution, Simulation, Analysis
- QCD Numerical Calculation
- Cosmology / Astrophysics Simulation

Computing at Fermilab

- Supports experiments, theory, accelerators at three (energy, intensity, cosmic) frontiers
  - Accelerator & detector simulation for design, R&D, optimizing performance
  - Data processing, distribution, simulations, analysis
  - QCD numerical calculations, cosmology simulation
- Requires high-bandwidth US and international Wide Area Networking
  - ESNet, LHCnet, dedicated light paths, peering with research networks in US and worldwide.
- Leverages use of DOE and NSF leadership class high performance computing
  - Simulation science

Energy Frontier: Tevatron Experiments

- Scientific computing has truly enabled science
  - CDF/DØ each collect/process ~100events (30 Mbytes) / s
  - Total data in tape storage ~ 10 PB, disk cache ~ 2 PB
  - ~1500 international collaborators supported
  - Computing “Gridified”



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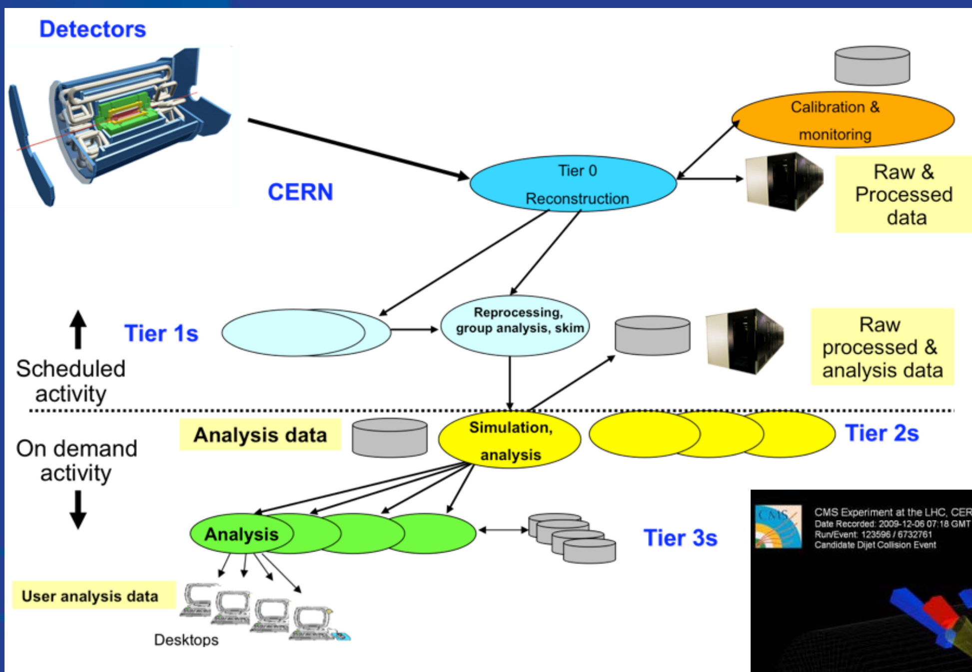
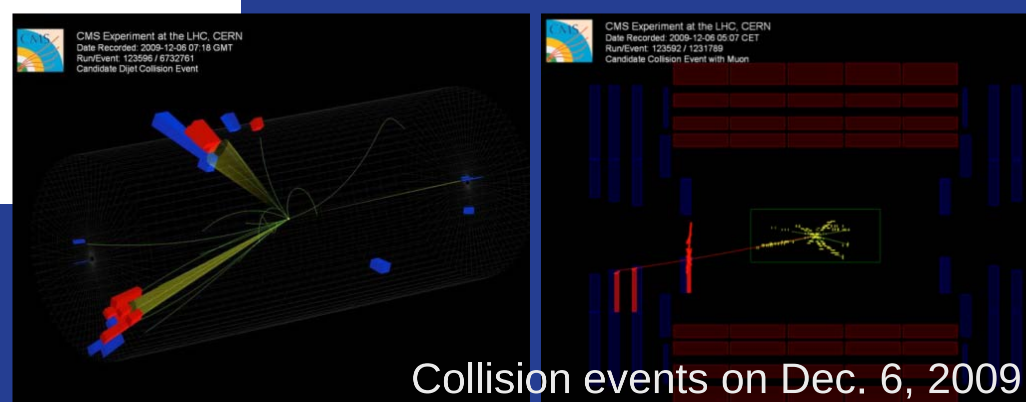
Energy Frontier: CMS at LHC

- Extraordinary computing challenge
  - ~1 Mbytes/event, 1000 events/s from 10^8 collisions/s
  - Tier-1 center at Fermilab – largest Tier-1 center



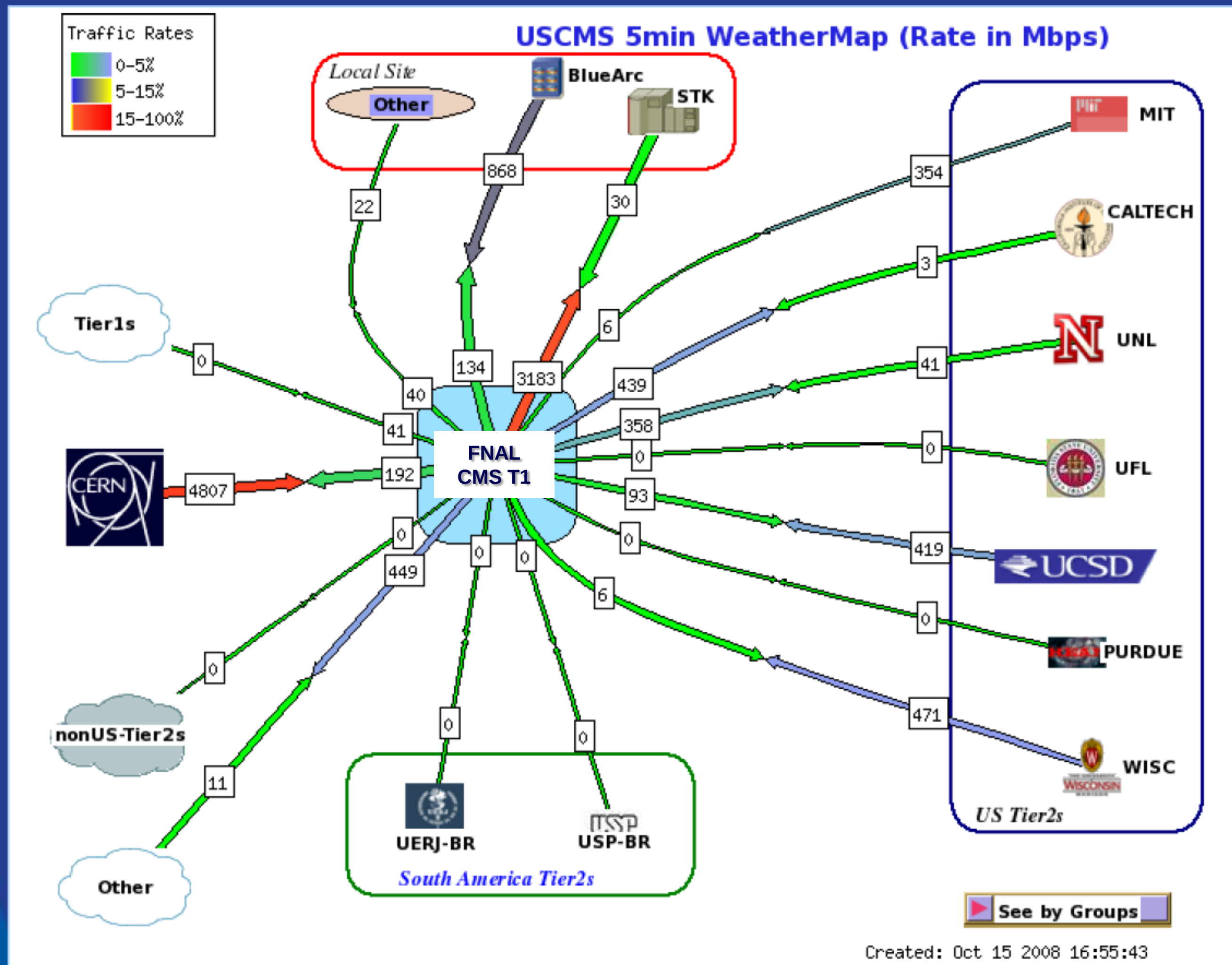
Remote Operations Center at Fermilab



Collision events on Dec. 6, 2009

Network Weather Map for CMS

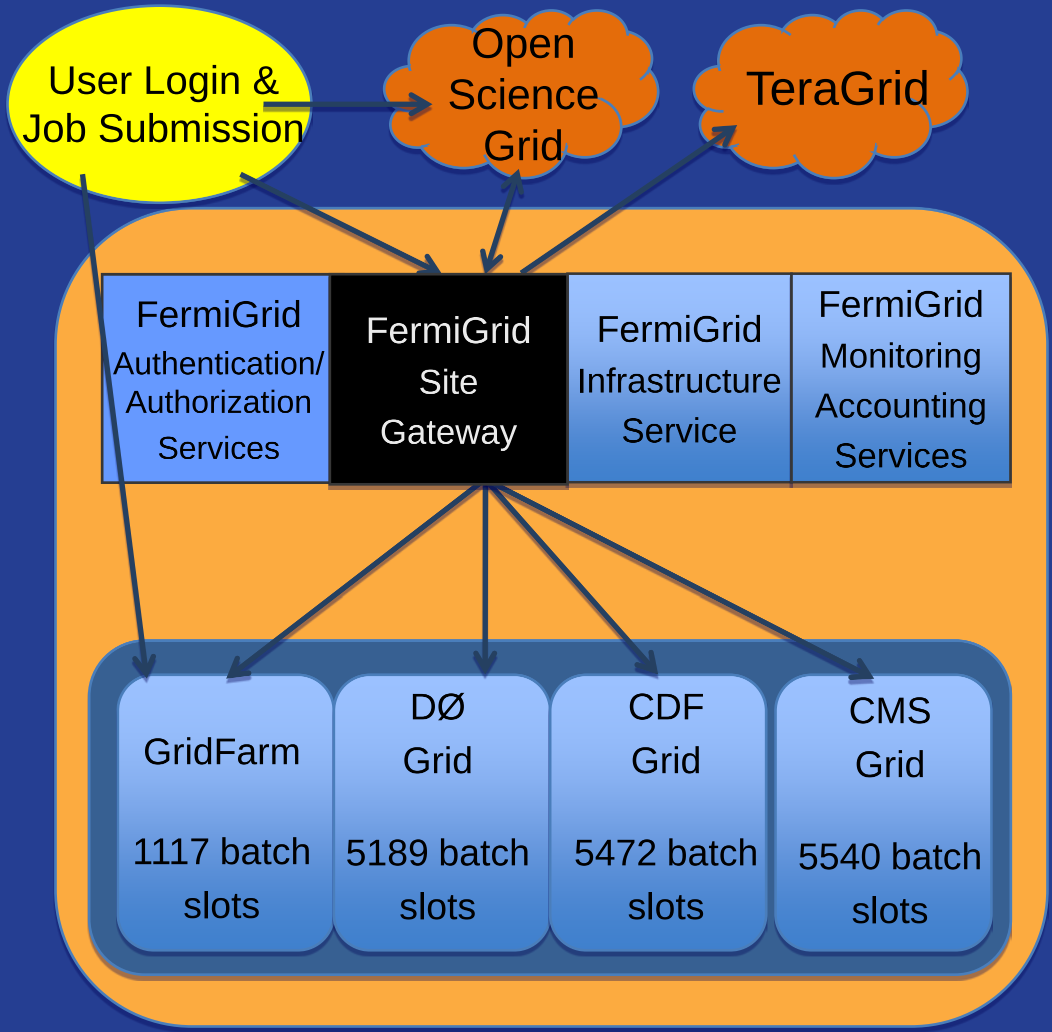
https://fngrey.fnal.gov/wm/uscms/html/uscms-dynamic-map-5min.html



FermiGrid

onsite computing resources

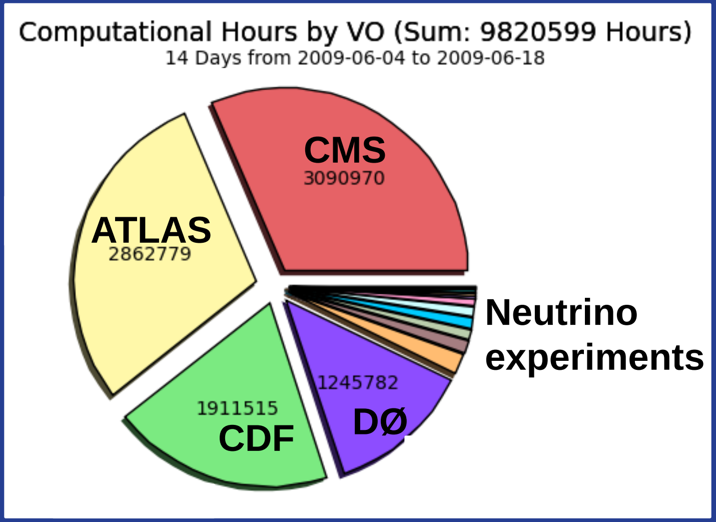
http://fermigrid.fnal.gov



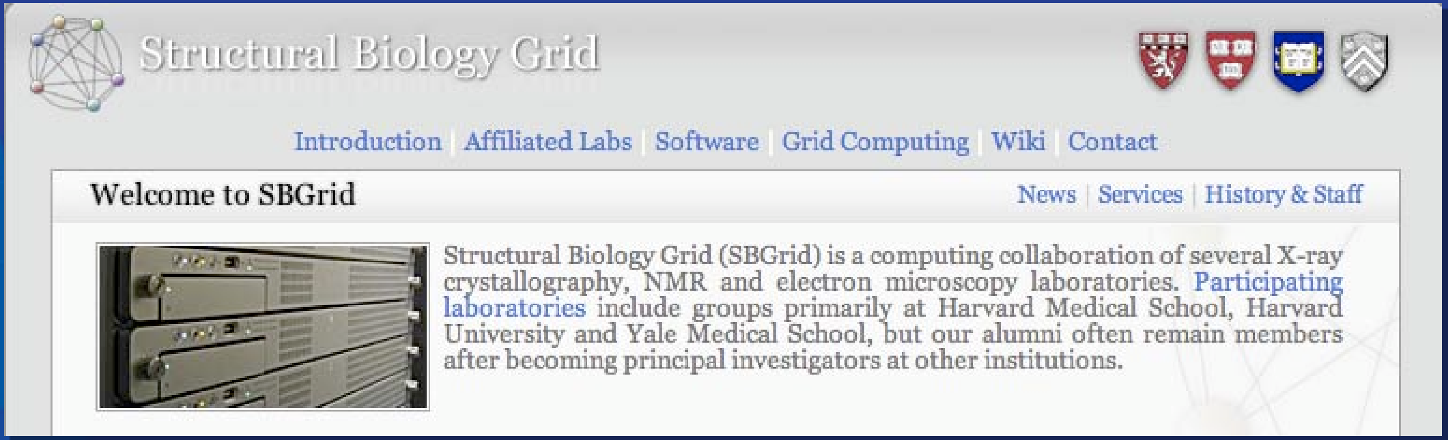
Open Science Grid – OSG

Open Science Grid

DOE/NSF collab. towards building a national computing infrastructure for science



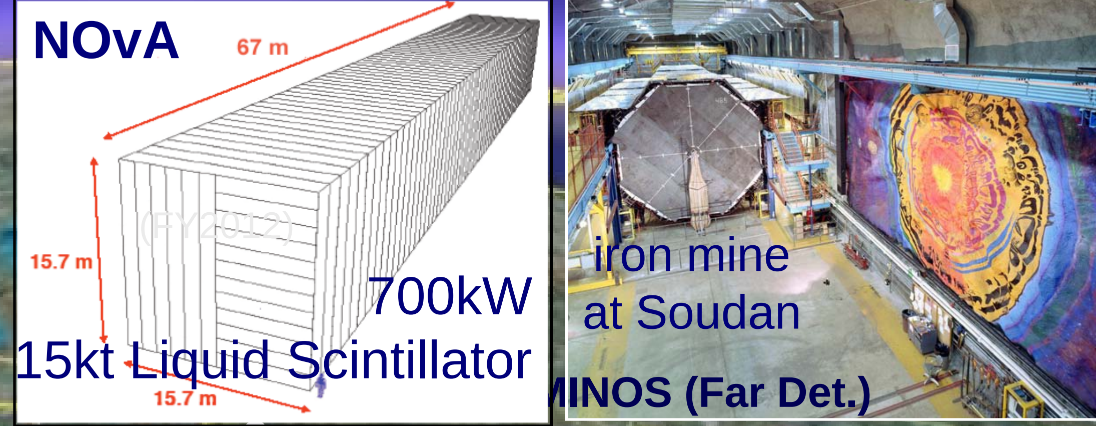
OSG has been adopted
as Infrastructure for Multi-Institutional Structural Biology Community

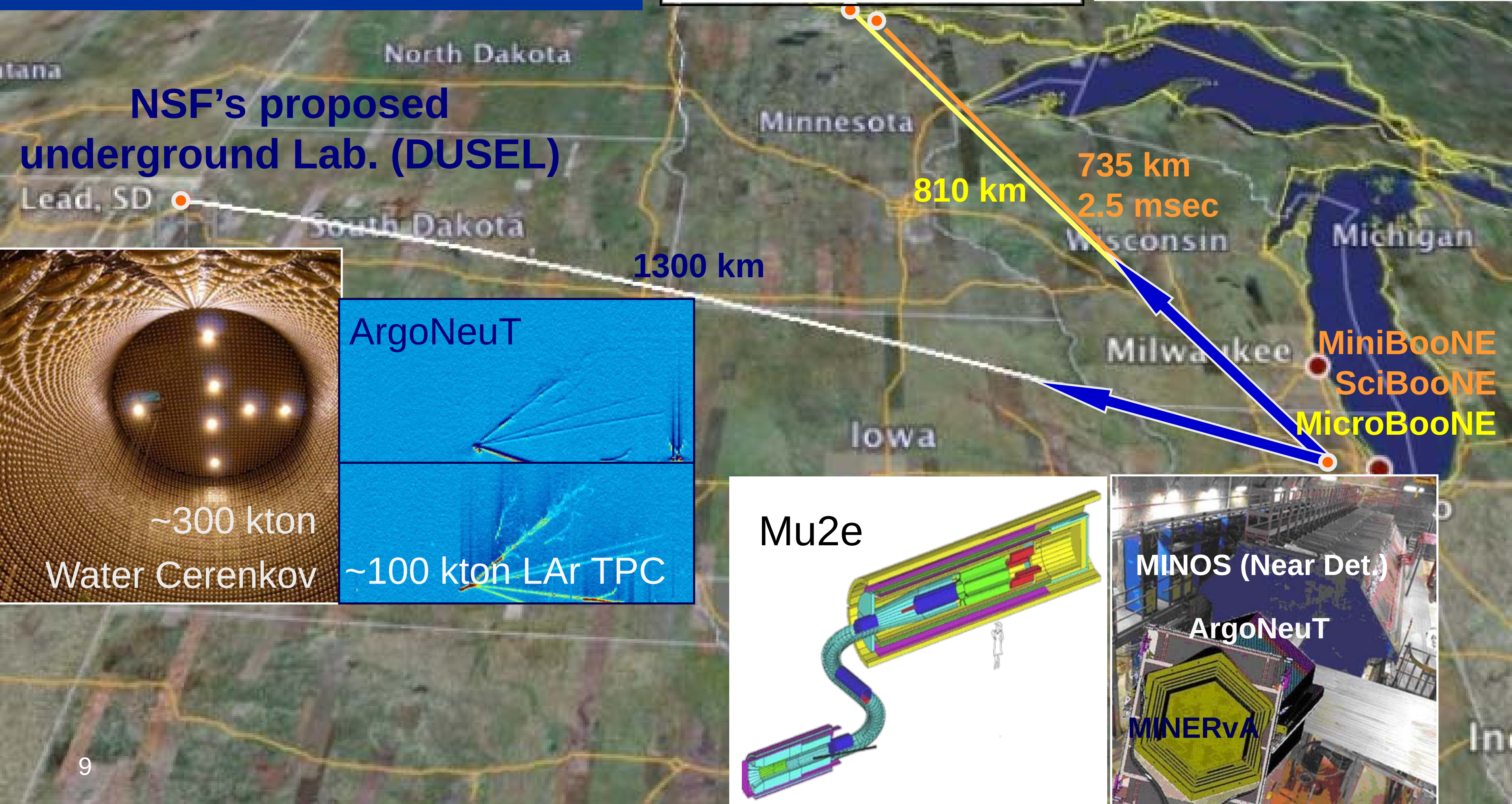


Intensity Frontier:

Neutrinos, Muons, Kaons, …

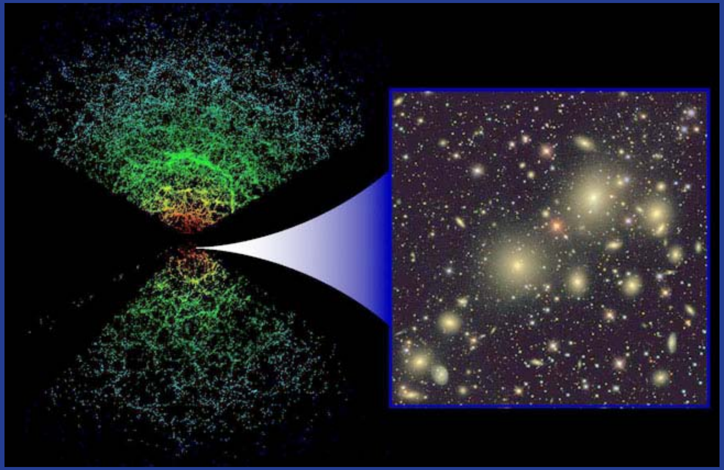
Beamline and Target (HPC)
Detector Simulation
Background Simulation





Comic Frontier

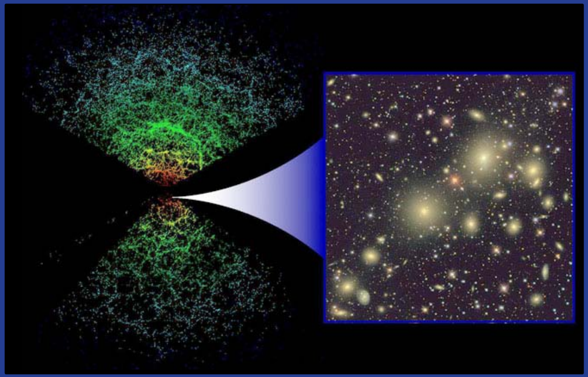
- SDSS:
  - Surveys a large fraction of observable universe
  - Science ranging from stars in the Milky Way to dark energy in universe

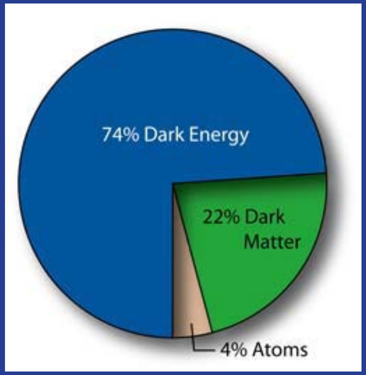


  - Astro data rates are becoming large like particle physics
    - Fermilab hosts 91 TB primary archive, 3M queries, 15 TB export per month
  - Fermilab's involvement in SDSS changed the way astronomy was done.
- Dark Energy Survey follows this example
  - Fermilab will host secondary archive

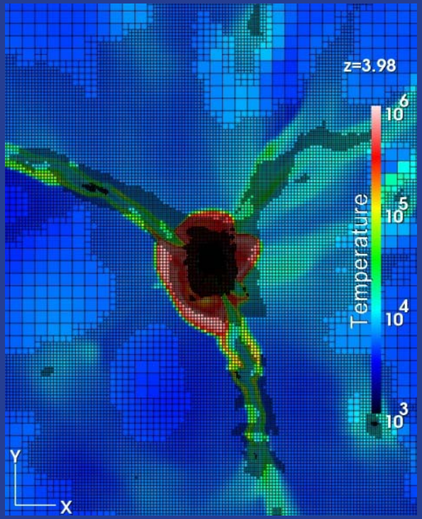
Cosmological Computing

- Observations
  - Dark Matter
  - Dark Energy
  - Neutrino Mass
  - Inflation





- Extracting science from observations requires numerical simulations.
  - Gravitational Instability is nonlinear
  - Baryons governed by hydrodynamics
  - Radiation field affects, and is effected by structure
  - Stars form, supernovae explode
  - …..



Cosmological Computing: Need for Medium Scale Computing

- Regional Initiative
  - FNAL, U.Chicago, ANL
  - 1240 core cluster at FNAL (2009)
  - Numerous small internal/external funding resources

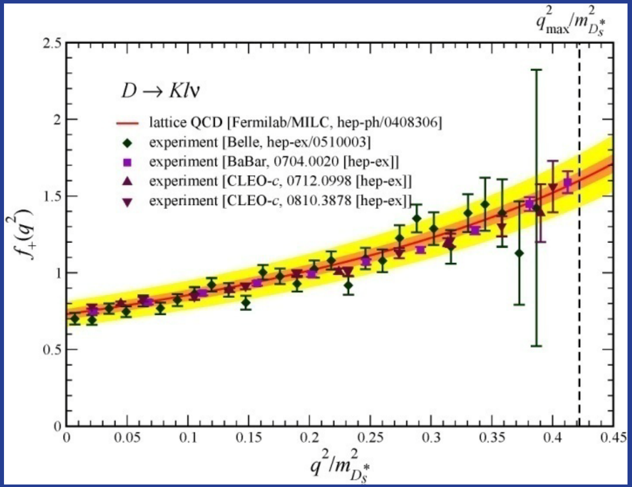
- National Initiative
  - FNAL-LBNL-SLAC submitted White Paper for medium scale computational cosmology initiative (Feb. 2009)
  - Cosmology Data Grid (DES, LSST, JDEM)
    - A user facility, wide area data repository of numerical simulations using standardized data formats
  - Diverse computing hardware
    - ranging from shared memory architectures to machines optimized for collaboration codes

High Energy Theory: Lattice QCD or LQCD

- Dominant user of computational resources within theoretical particle physics.
- QCD(non-perturbative) can not be studied using analytic methods, requires numerical simulations
- Space-time replaced by a discrete lattice of points
- Extensive overlap in methods used for particle and nuclear physics
    - USQCD Collaboration (lab.s and universities)

LQCD: Needs

- High Capacity Machines
  - Leadership Class machines (QCDOC at BNL, NERSC, INCITE, NSF centers)
  - Generate gauge configurations
  - 2~5 TF of generation (now) → PF (needs)
- High Capability Machines
  - Clusters at FNAL, JLab (FNAL: runs ~1.5M jobs /yr)
  - Physics analyses
  - 2~5TF (now) → PF(needs)



- Common software framework
  - SciDAC grants to USQCD Collaboration

LQCD → LFT (Lattice Field Theory)

- The last decade (LQCD)
  - Lattice simulations matured into a quantitative tool
  - Set the stage for a golden era of QCD calculations and the extension of simulations to new theories.
- The upcoming decade (LFT): priority directions
  - Rare processes at the intensity frontier
  - Testing QCD at the sub-percent level
  - Simulating theories of physics beyond standard model
  - QCD thermodynamics for heavy ion collisions and early universe

Accelerator Simulation

- Modeling of accelerator and simulation of beam dynamics are necessary for
  - understanding and optimizing the performance of existing accelerators
  - optimizing the design and cost effectiveness / risk reduction for future accelerators

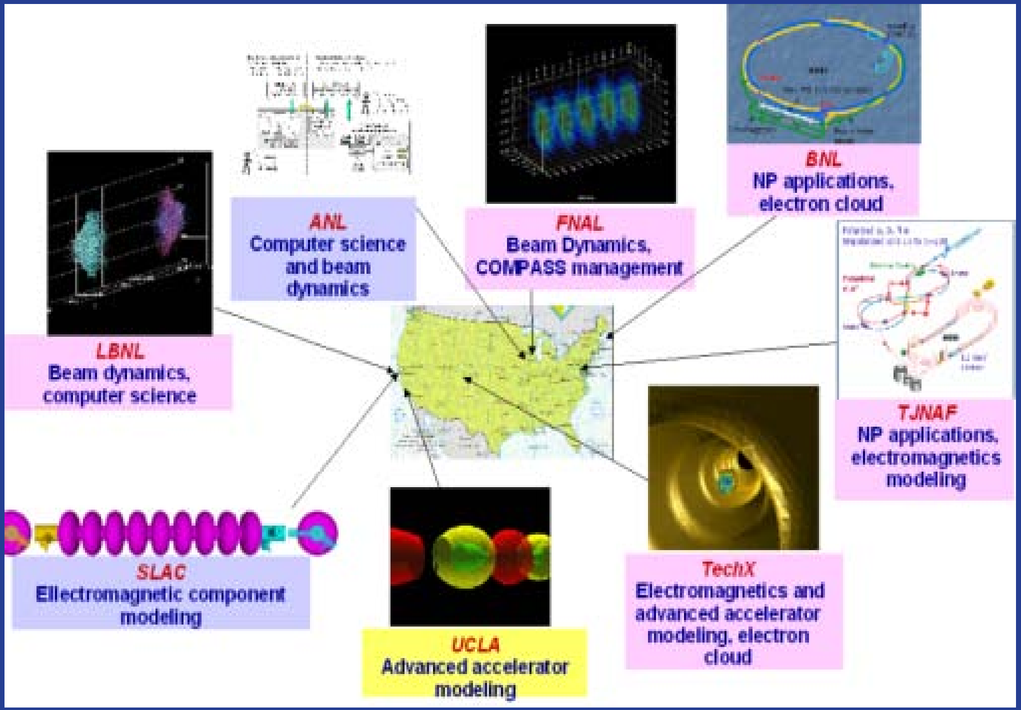
Accelerator Modeling Tools

- Leading the ComPASS Project
  - Development of High Performance Computing (HPC) accelerator modeling tools
  - SciDAC funded collaboration

https://compass.fnal.gov/

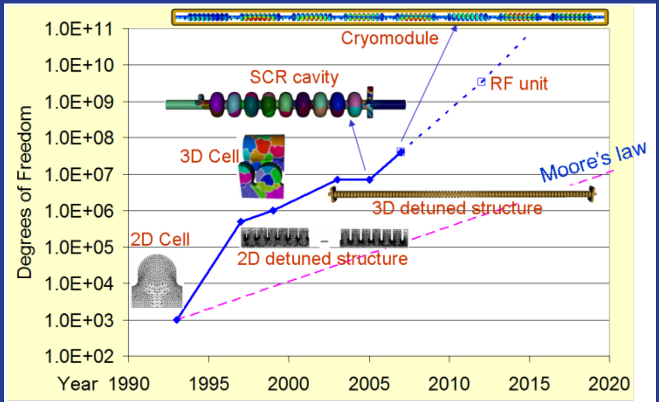
Multi-physics
multi-scale
for beam dynamics
"virtual accelerator"

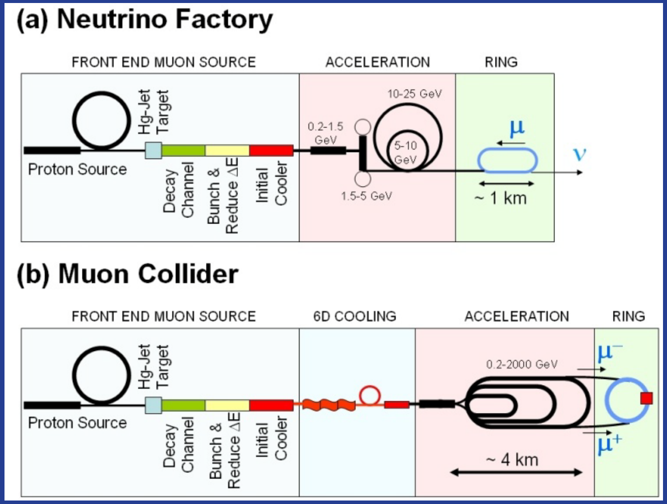
Electromagnetic
Thermal
Mechanical
"virtual prototyping"



Accelerator Simulation: Future Needs

- Enhance integrated electromagnetic, thermal and mechanical analysis, beam dynamics
- Shorten design & prototype build cycle(accel components)
- Standardize codes
- Integrated capability
  - Subsystem of system (e.g. Superconducting linac crymodule, RF unit)
  - Entire accelerator chain or end-to-end simulation (e.g. ν factory, μ collider)





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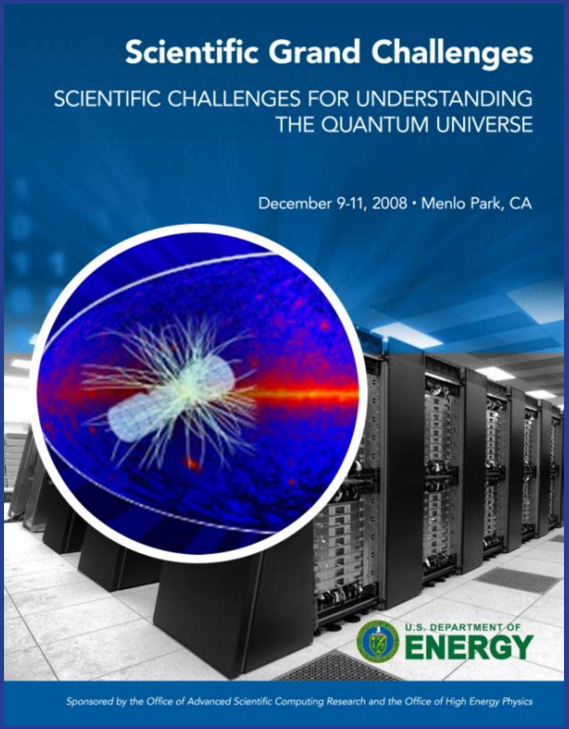
A Path Forward

- HEP research directions require extreme computing
  - Good coordination: efforts began



- Three essential ingredients to meet computing challenges
  - Computational capability: no single machine can do, but a diversity of new capabilities will be needed.
  - Software, numerical algorithms, programming tools
  - Creating the highly trained cadre of scientists who will understand the challenging science and master the computing system and software.