High Energy Physics and Computing – Perspectives from DOE

CHEP
May 21, 2012

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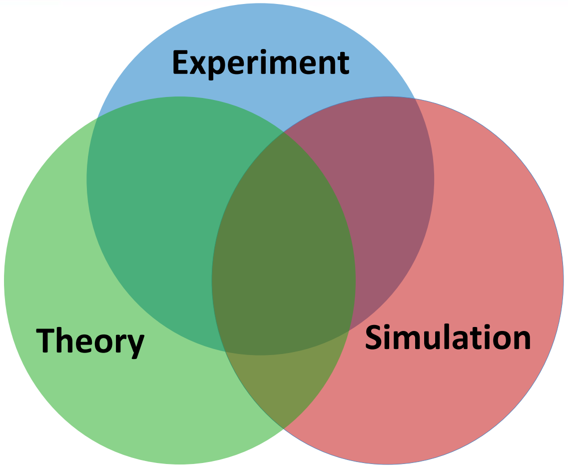
Office of High Energy Physics
Office of Science, U.S. Department of Energy

Outline

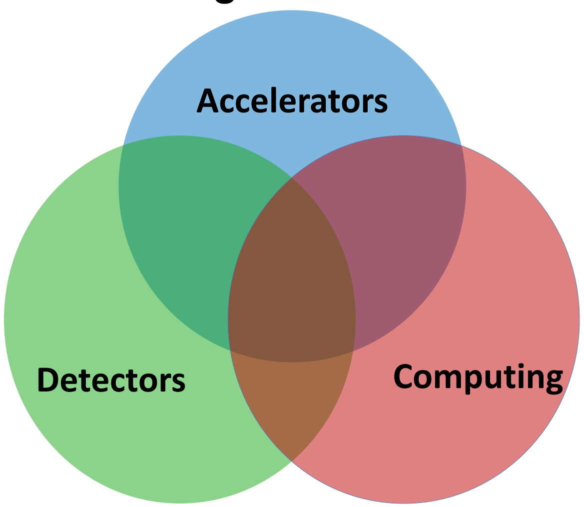
- High Energy Physics
- The Key Role of Computing
- HEP at the three frontiers
  - Related computing, technology, stewardship
- HEP Computing - Historical perspectives
- How DOE is advancing computing
- Role of Computing in HEP Strategic Planning
- What we hope to learn from this conference
- Conclusion

WE LIVE IN INTERESTING TIMES

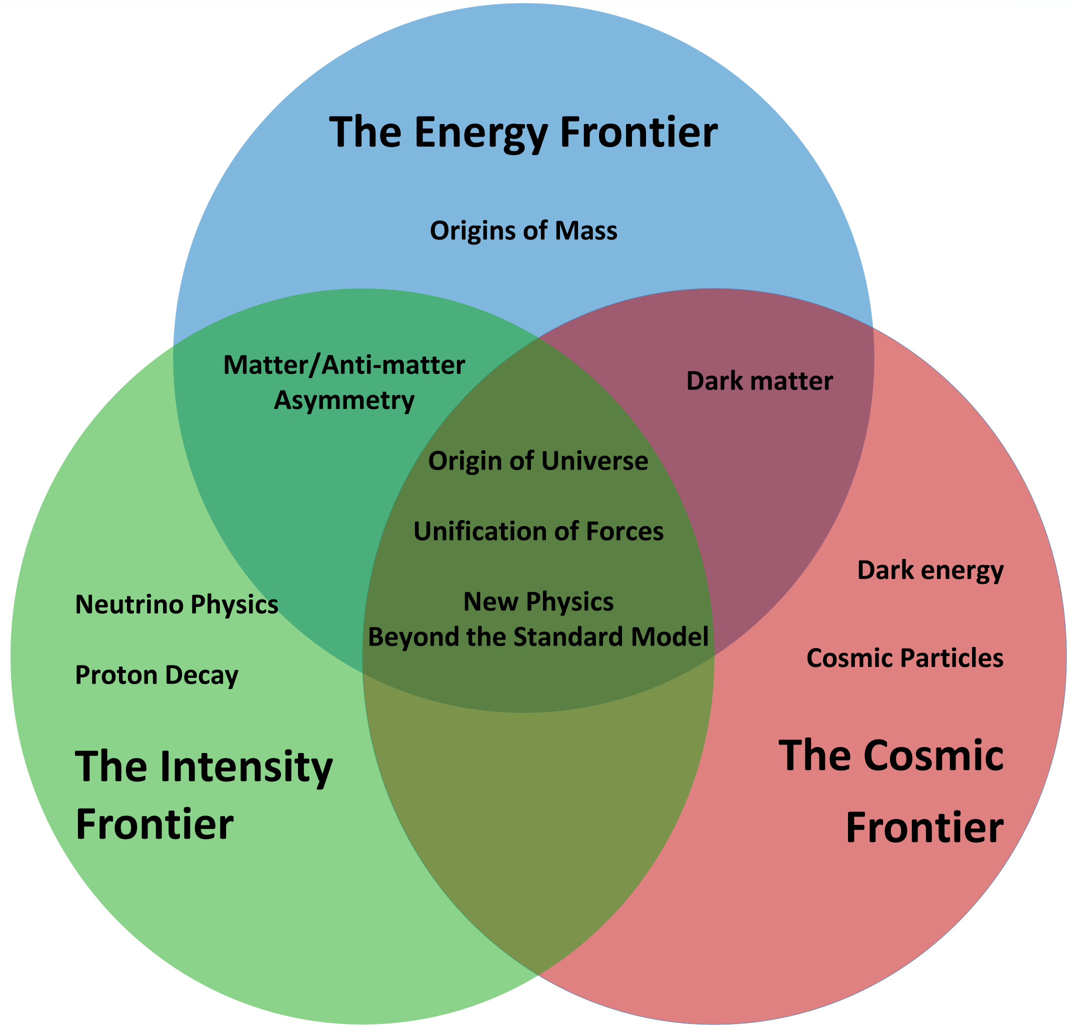
Physics and Technology



Along Three Paths

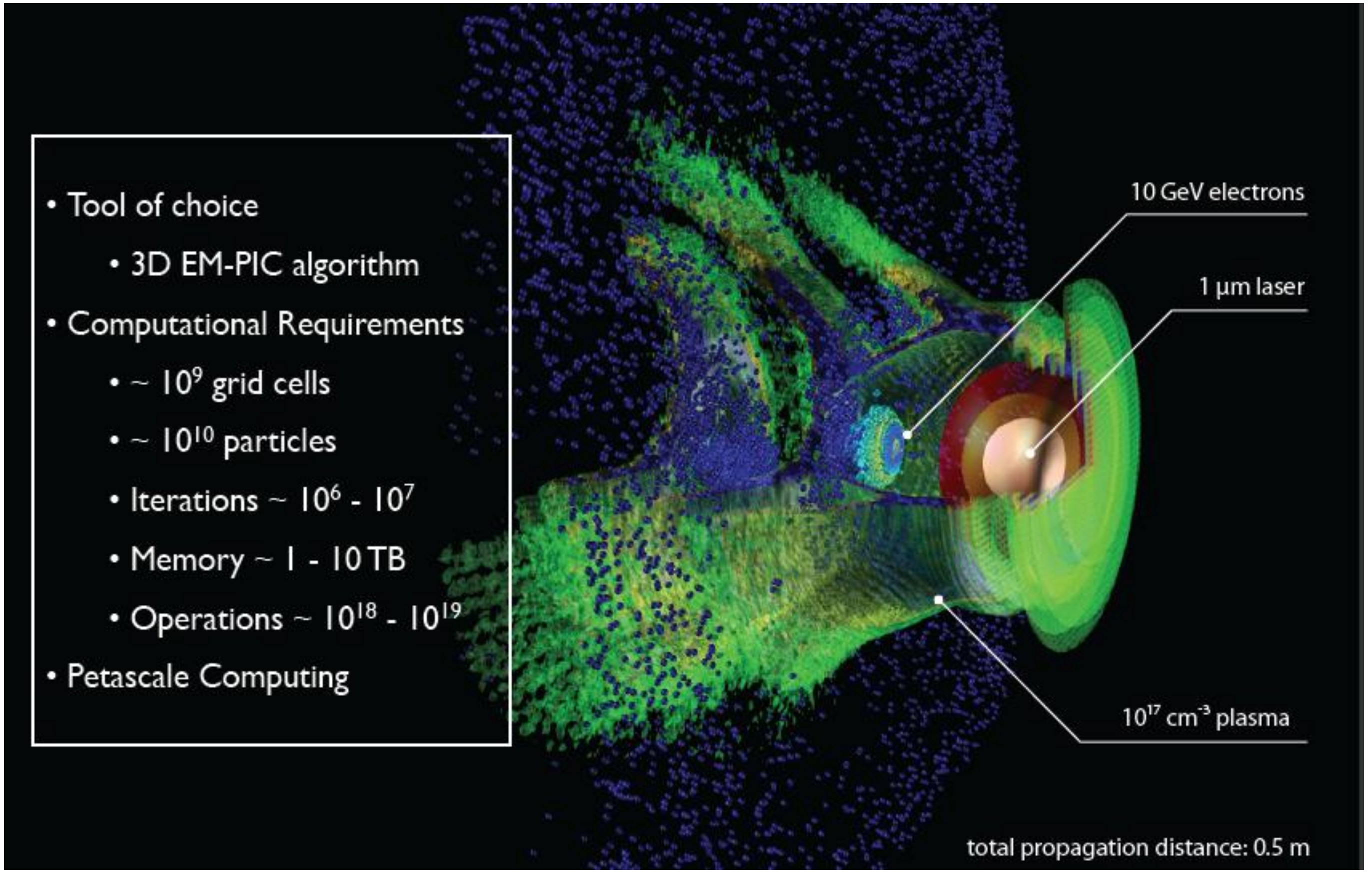


Enabled by
Advanced Technologies in:



Physics Frontiers

Simulation as the Third Way to Scientific DIscovery



Algorithms and software developed by the SciDAC project ComPASS enable analysis of the subtle 3D dynamics of particle trapping and acceleration that forms high quality bunches in a manner not accessible to experiment and allows better optimization of the worldwide experimental efforts.

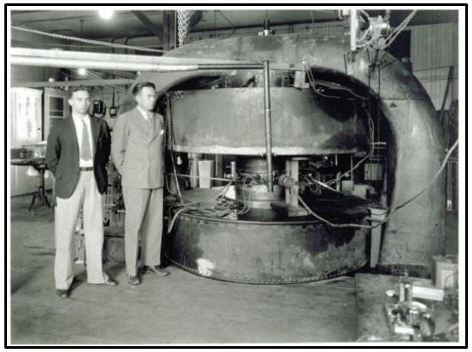
Technology is Integral to HEP

HEP is driven by fundamental scientific questions about the nature of matter and energy. But the pace of discovery has very often depended on crucial advances in technology.

The field has always utilized and driven the cutting edge of technology to enable our science

Where HEP did not invent new technology, it was often an early adopter and drove its practical implementation

- **Accelerators**

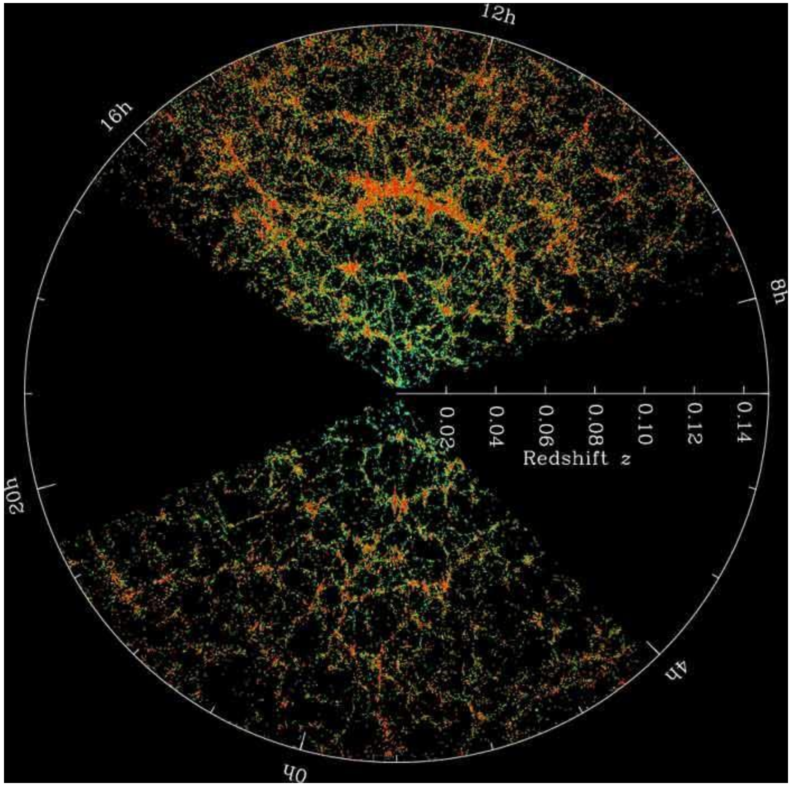


- **Detectors**

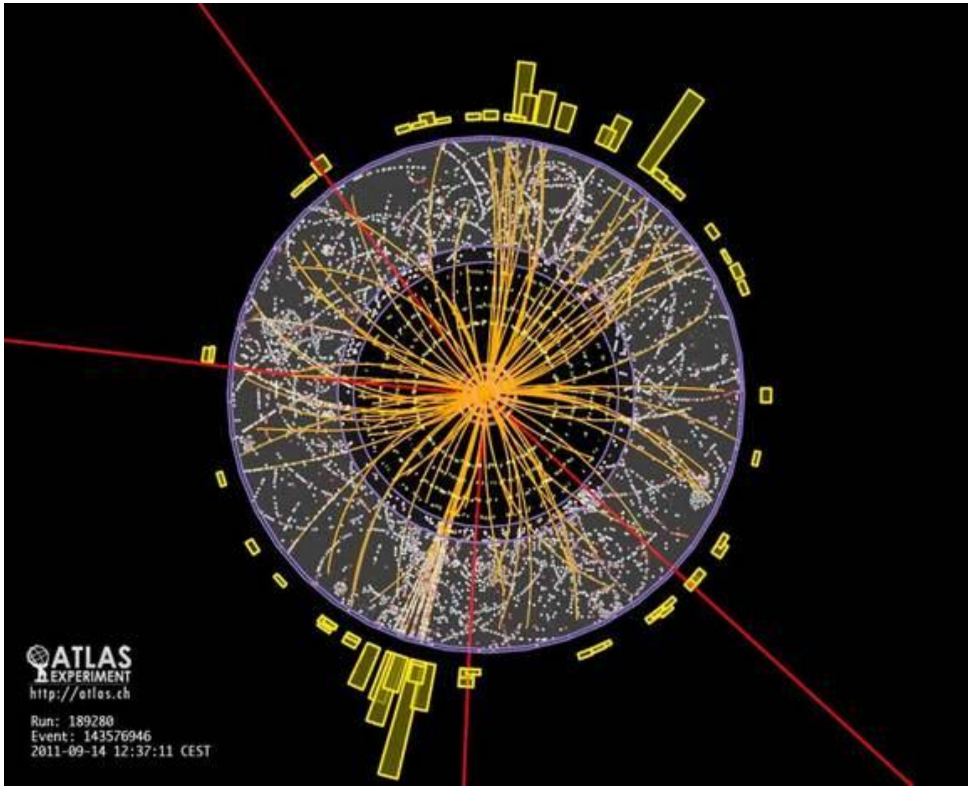
- **Computing**

Computing is Integral to HEP!

Experimental and Observational HEP relies on advanced Computing

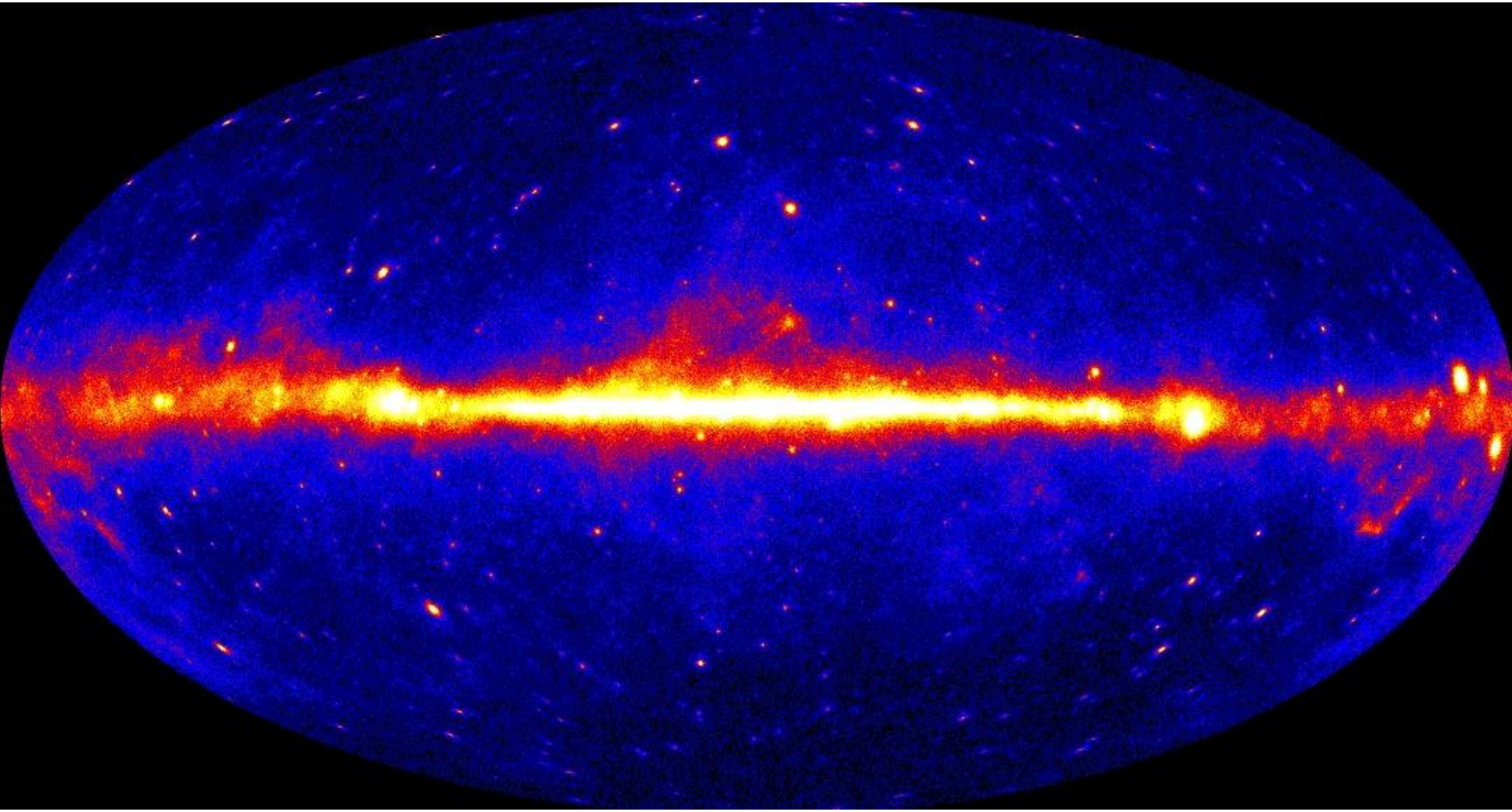


Sloan Digital Sky Survey



LHC Event

Cosmic Frontier



70% of the photons in the high-energy g-ray sky are diffuse radiation from the Milky Way; remainder are localized sources or extragalactic "diffuse" radiation

Cosmic Frontier Highlights

Saul Perlmutter
Adam Riess
Brian Schmidt

Awarded the 2011 Nobel Prize in Physics "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae" was heavily dependent on DOE Computing Resources at the National Labs

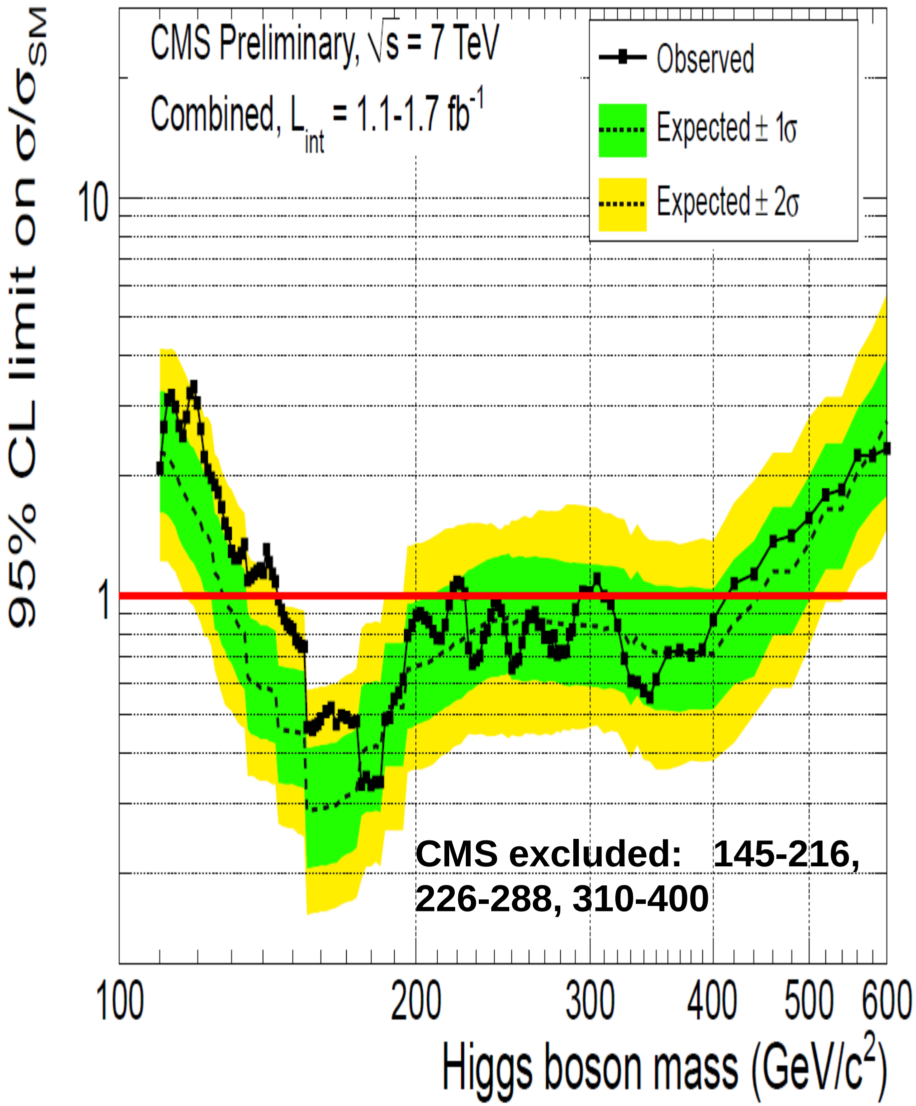
Computers were an essential part of the automated supernova search system - involving a robotic telescope equipped with a CCD detector (instead of photographic plates), producing digital images that could be compared automatically by computers using the image subtraction software they developed.

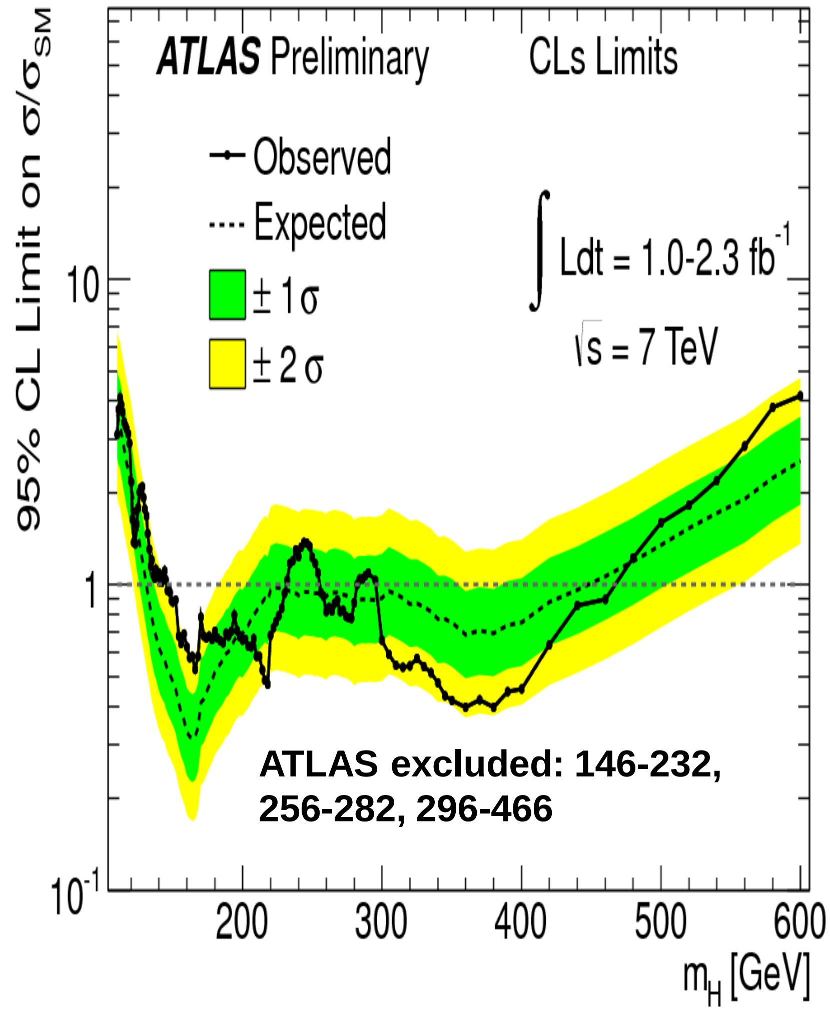
http://www.scientificcomputing.com/news-DA-Nobel-Laureate-Blazed-New-Trails-in-Computational-Cosmology-100711.aspx

Cosmic Frontier Status

- **Near-term Science goals :**
  - **Discover (or rule out) the particle(s) that make up Dark Matter**
  - **Advance understanding of Dark Energy**
- **Recent results :**
  - **Various controversial evidence for Dark Matter from both direct and indirect searches**
  - **Demonstration and prototyping of several Dark Energy measurements**
- **New facilities under construction:**
  - **Dark Energy Survey commissioning**
- **Planned program of major projects:**
  - **Large Synoptic Survey Telescope (2018-2023+) will make definitive ground-based Dark Energy measurements using "weak lensing"; 3rd-Generation (ton-scale) Dark Matter experiments (2021?) to reach ultimate background limits**

Energy Frontier Highlights



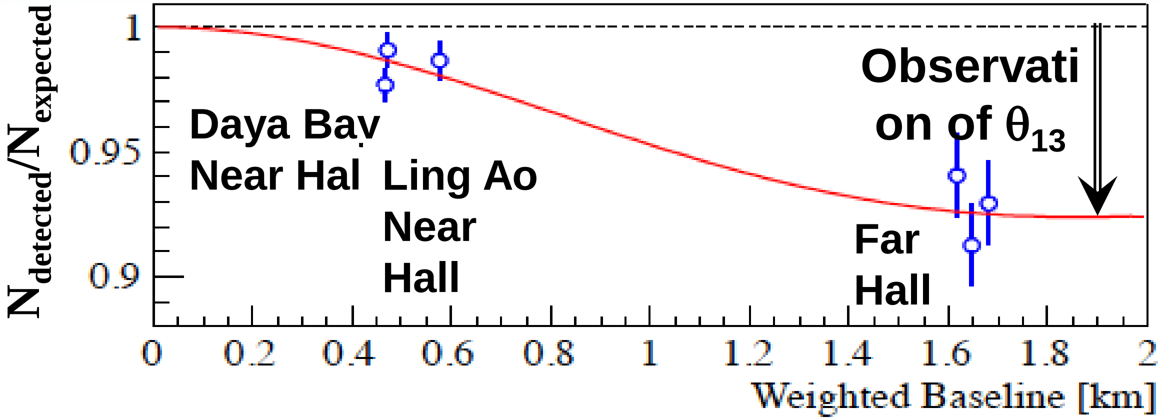


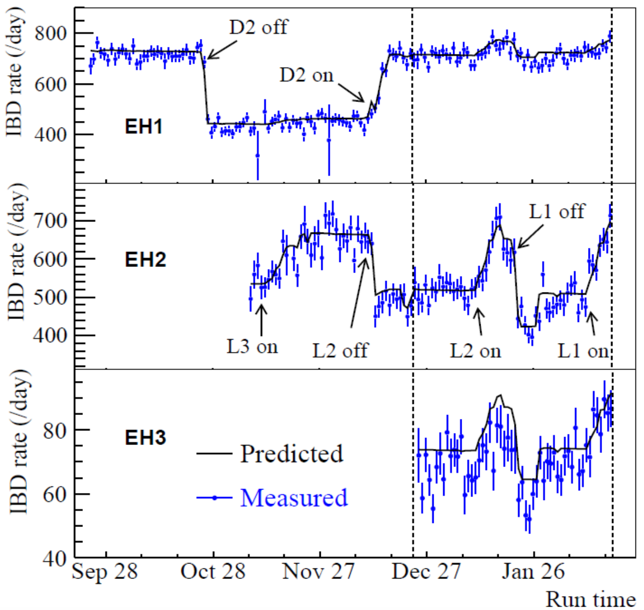
Energy Frontier Status

- **Near-term Science goal :**
  - Discover the Higgs or whatever takes its place. Is there just one?
- **Recent results**
  - LHC + Tevatron have ruled out most of the interesting Higgs mass range
  - Tevatron run is completed, final data analyses are underway
  - LHC will run thru 2012, then shutdown to achieve full energy (14 TeV)
- **No new facilities under construction at this time**
  - Program is centered in Europe (CERN) for the next 10+ years
- **Planned program of major projects:**
  - LHC Upgrades Phase I : (2017-2018) to cope with increased data rates
  - LHC Upgrades Phase II: (2021+) factor of 10 increased luminosity
  - Future evolution (>2025) will depend on results in the next few years:
    - *If New Physics can be accessed at ~TeV energy*, e+e- or mu+mu- collider (?)
    - *If not,* long program of LHC exploitation (+ LHC energy upgrade?)

Intensity Frontier

Intensity Frontier Highlight: θ_{13}

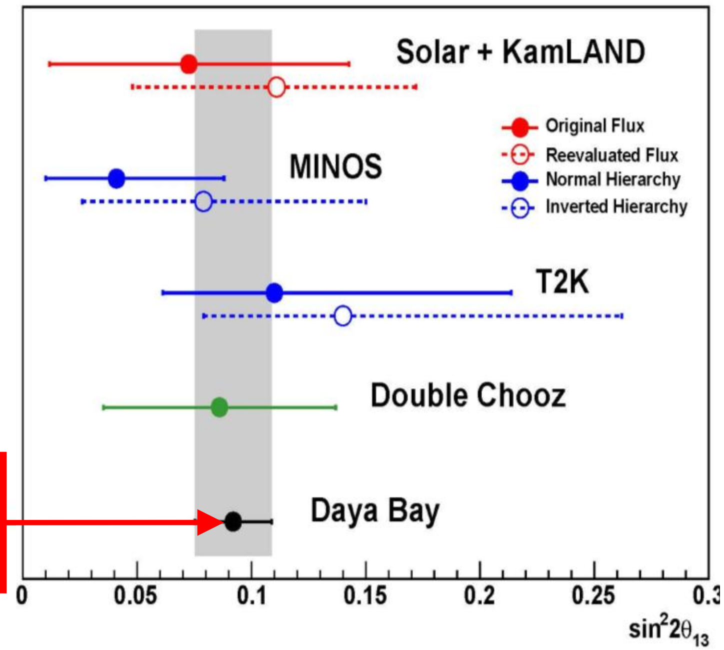




- Discovery of reactor electron antineutrino disappearance at ~2 km.
- Neutrino mixing angle θ_{13} is non-zero at 5.2σ
- Non-zero θ_{13} enables a clear path forward towards measuring leptonic CP violation.

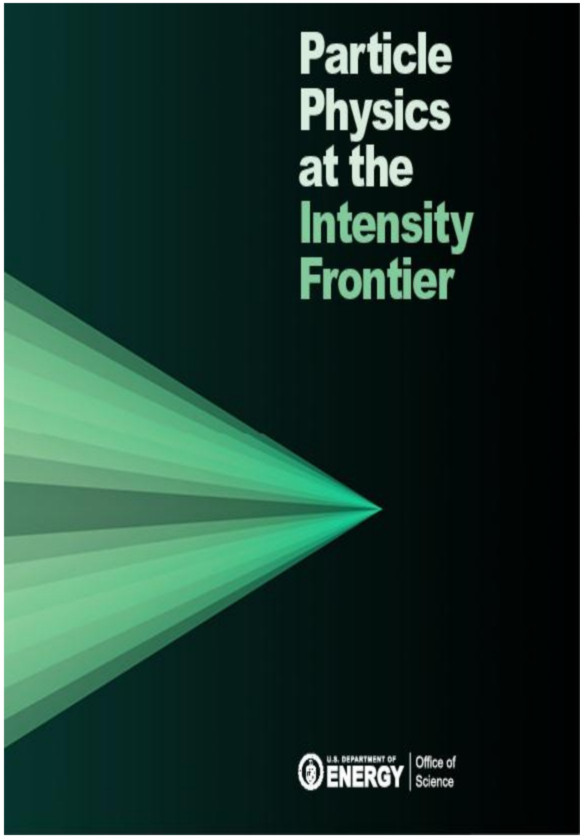
Daya Bay performs simulations of the detectors, reactors, and surrounding mountains at the DOE NERSC facility to help design and anticipate detector properties and behavior

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$$

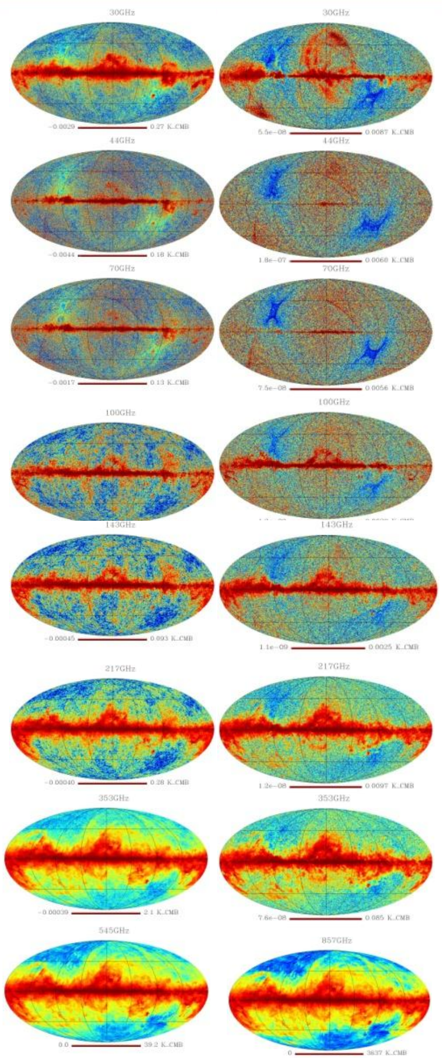


Intensity Frontier Status

- **Near-term Science goals :**
  - Implement comprehensive program to understand neutrino mixing
  - Deliver much improved limits (measurements?) of charged lepton mixing and hidden sector phenomena
- **Recent results (see following slide)**
  - Daya Bay discovers third kind of neutrino mixing (and its large!)
  - Various “hints” of additional neutrino species, anomalous interactions?
  - Faster-than-light neutrinos?!?
- **New facilities under construction:**
  - NuMI upgrade + NOvA; reactor experiments commissioning
- **Planned program of major projects:**
  - Mu2e to explore charged lepton mixing (2018-2022)
  - LBNE to make definitive measurements of neutrino properties (2021+)
- **Must upgrade domestic facilities to maintain US leadership**



Simulations for Science



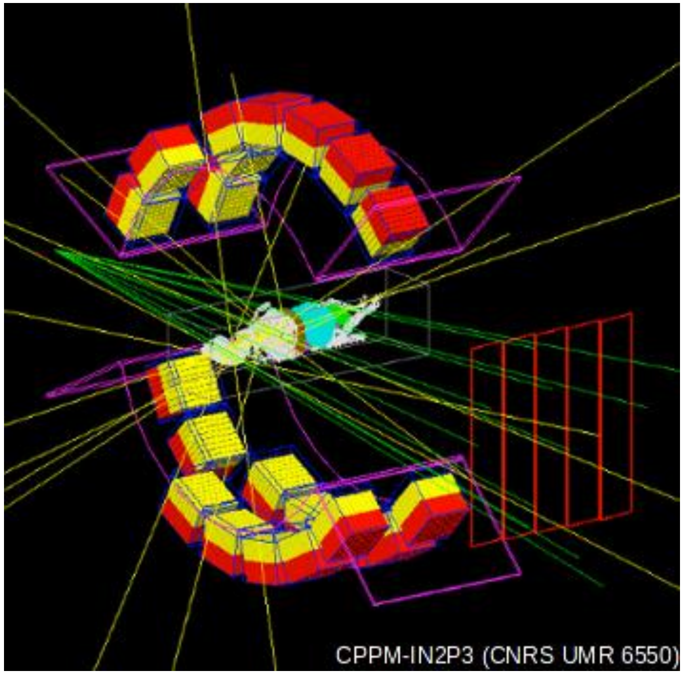
One simulated realization of the temperature and polarization of the sky as observed by Planck at each of its 9 observing frequencies (2 unpolarized).

- **The analysis of Cosmic Microwave Background data depends on computationally challenging simulations with up to 10,000 realizations of the entire experiment for Monte Carlo studies.**
- **Researchers generated the first comprehensive simulation of the ongoing ESA/NASA Planck mission, including 100 MC realizations.**
- **This ran on up to 100,000 cores of NERSC's *Hopper* supercomputer, taking 500,000 CPU-hrs and generating 35TB of data.**
- **This simulation is now being used to validate the ongoing analysis of the real Planck data in preparation for their release in January 2013.**

Julian Borrill – Computational Cosmology Center, Berkeley Lab (for the US Planck team)

Applications Beyond HEP

- **In addition to being vital for our ongoing detector simulation, GEANT4 captures the experience and knowledge of particle physics about what happens when particles pass through matter.**
- **GEANT4 is freely available to the public and has found important uses in industry.**

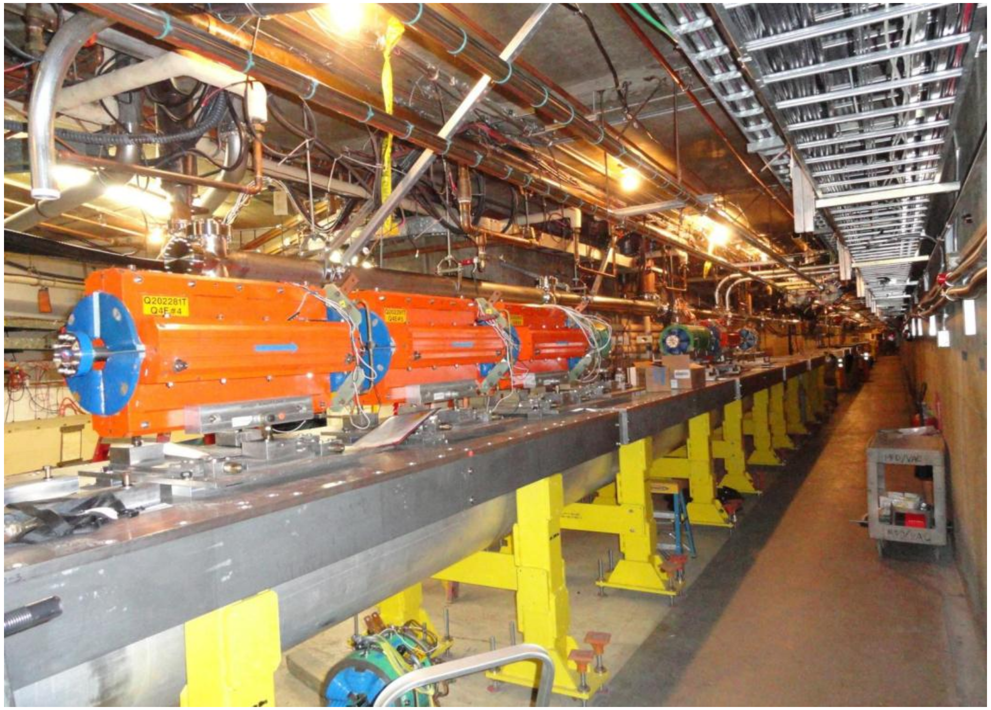


EmissionSimulation of PET scans and Radiotherapy using GEANT4 as its base.

- **Aerospace and medical devices companies use the software in their work. Boeing and Lockheed Martin use it to study the effects of cosmic rays on the electronics in satellites.**
  - Electronics have become so sensitive that a single cosmic ray can affect the proper operation.
  - Monte Carlo Radiative Energy Deposition (MRED) software uses GEANT4.
- **Geant4 Application for Tomographic scanning**

HEP and Accelerator Stewardship

- **HEP has invested in particle Accelerator R& D to access physics at the Highest energies and this continues.**
- HEP is developing a new projected role in accelerator Stewardship per the FY2012 Senate report



HEP is supporting Facility for Advanced aCcelerator Experimental Tests (FACET) at SLAC **as part of its accelerator R&D stewardship initiative.**

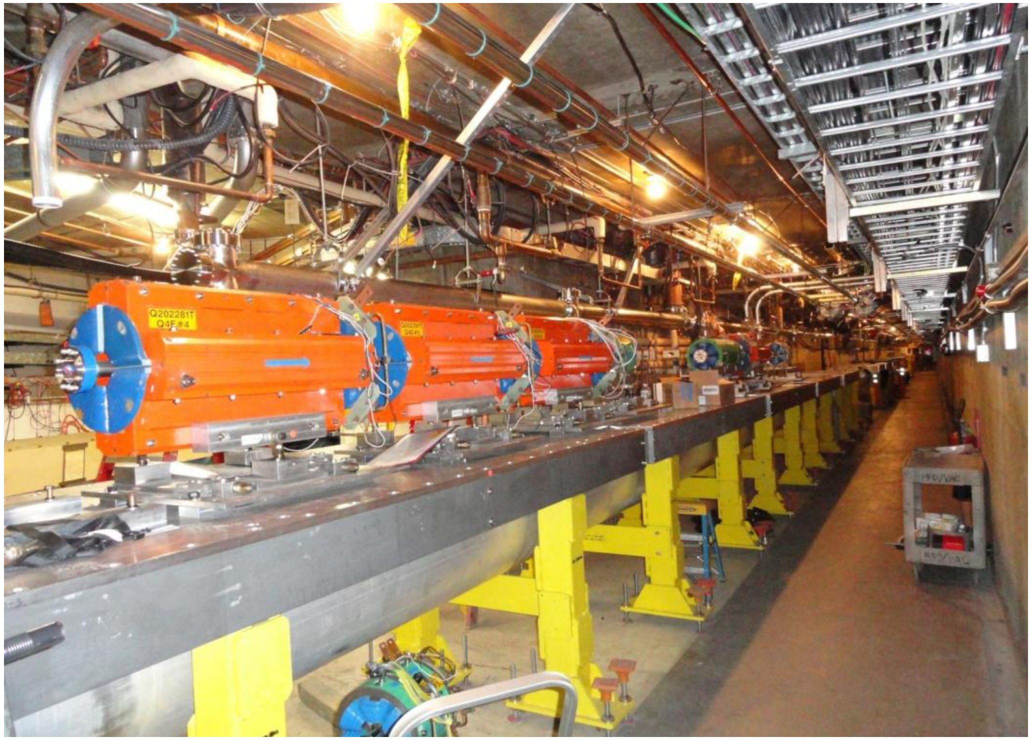
HEP and Accelerator Stewardship

- **HEP requested by Senate to take on a broader role in accelerator stewardship for the Nation and planning for this is in Progress**

Workshop Report: Accelerators for America's Future

http://www.acceleratorsamerica.org/files/Report.pdf

10-yr strategic plan in preparation



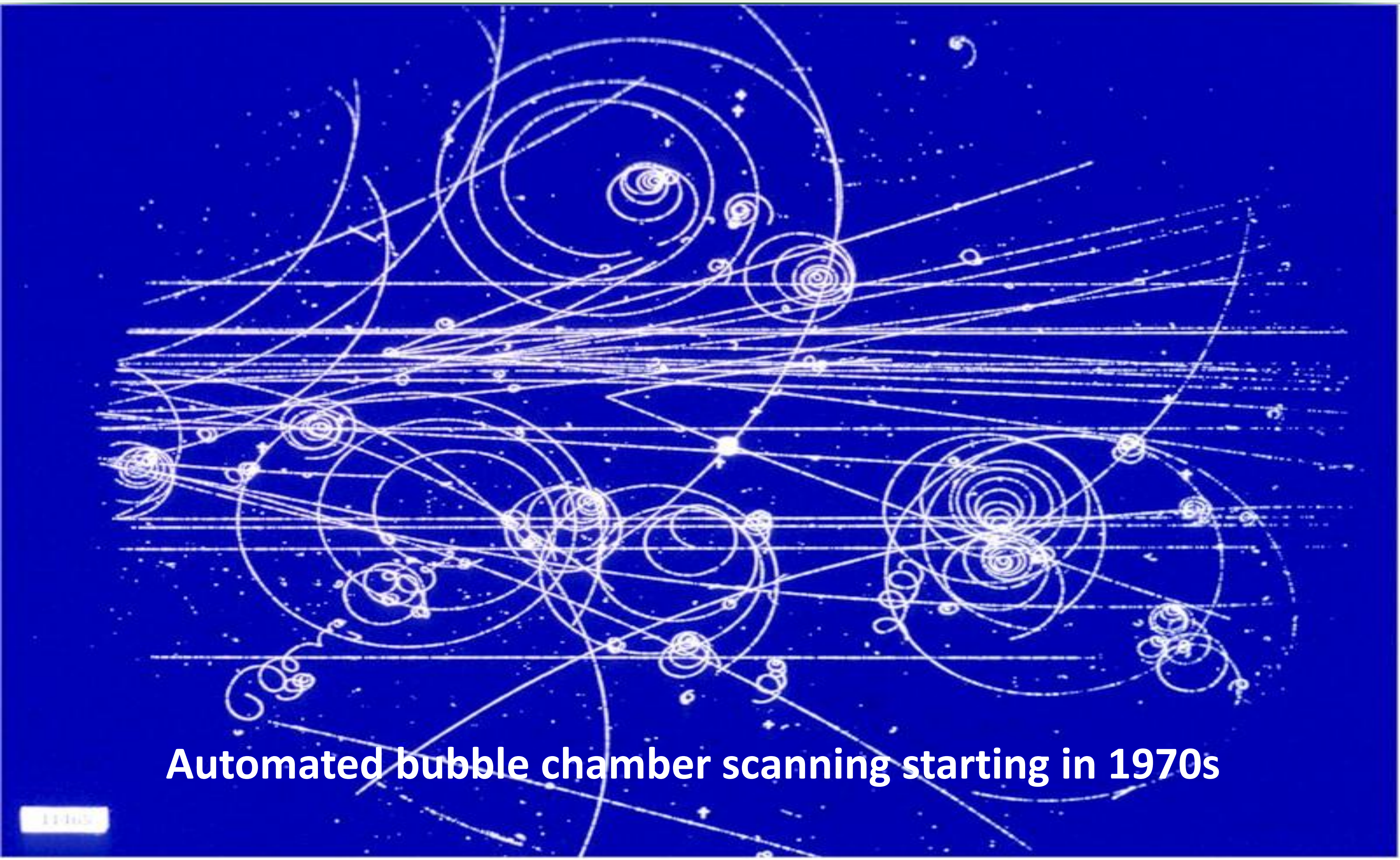
Facility for Advanced aCcelerator Experimental Tests (FACET) at SLAC

Community Participation in Program Development

- **Recent developments require us to revisit the HEP Strategic plan to explore adaptations that would enable us to respond to evolving scenarios.**
- **We need to continue to develop the science case and planned program on all 3 frontiers.**
  - HEP office plans to work on this with participation from the HEP community.
  - Plan for ‘Snowmass’ in summer 2013 to assess our program (neutrino and LHC results available for guidance)
- **We need active participation of our community in the development of the science case, with lab leadership in the background. DOE and NSF agree on this approach.**
  - This is an inversion of the “traditional” HEP modus operandi
  - The HEP community needs to own the science case, and sell the science case
- ***Our goal includes increasing connections to other SC programs by***
  - Interacting with material science, computing, nano scale, etc.
  - Developing new technologies for use by HEP and transferring HEP expertise to other fields.

BILL AND DAVE'S EXCELLENT ADVENTURE

HEP as an Early Adopter of Computing



Automated bubble chamber scanning starting in 1970s

HEP as a Leader in Development

- First research discipline-wide computer network (HEPnet 1980s)
- Precursor of modern research networks, including Esnet

HEP DECnet in 1985

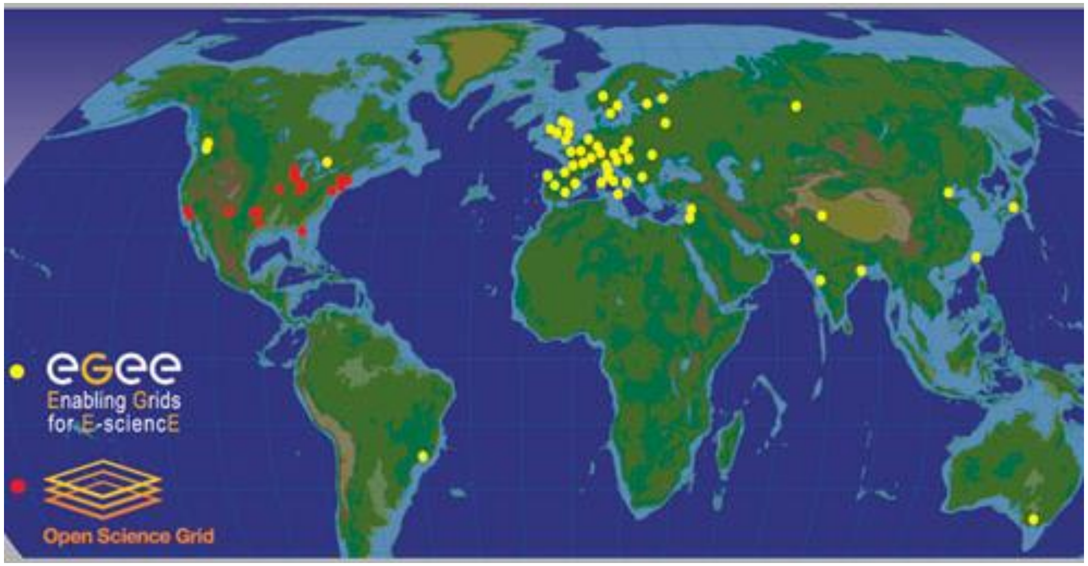
Dialup lines for terminals in 1985

HEP as a Leader in Implementation

Large Collaborations (and QCD) drove rapid development of large cost-effective computing

- Highly parallel computing "farms" (1990s)
  - Note Lattice QCD farms => IBM Blue Gene
- Large scale implementation of distributed (grid) computing (2000s)

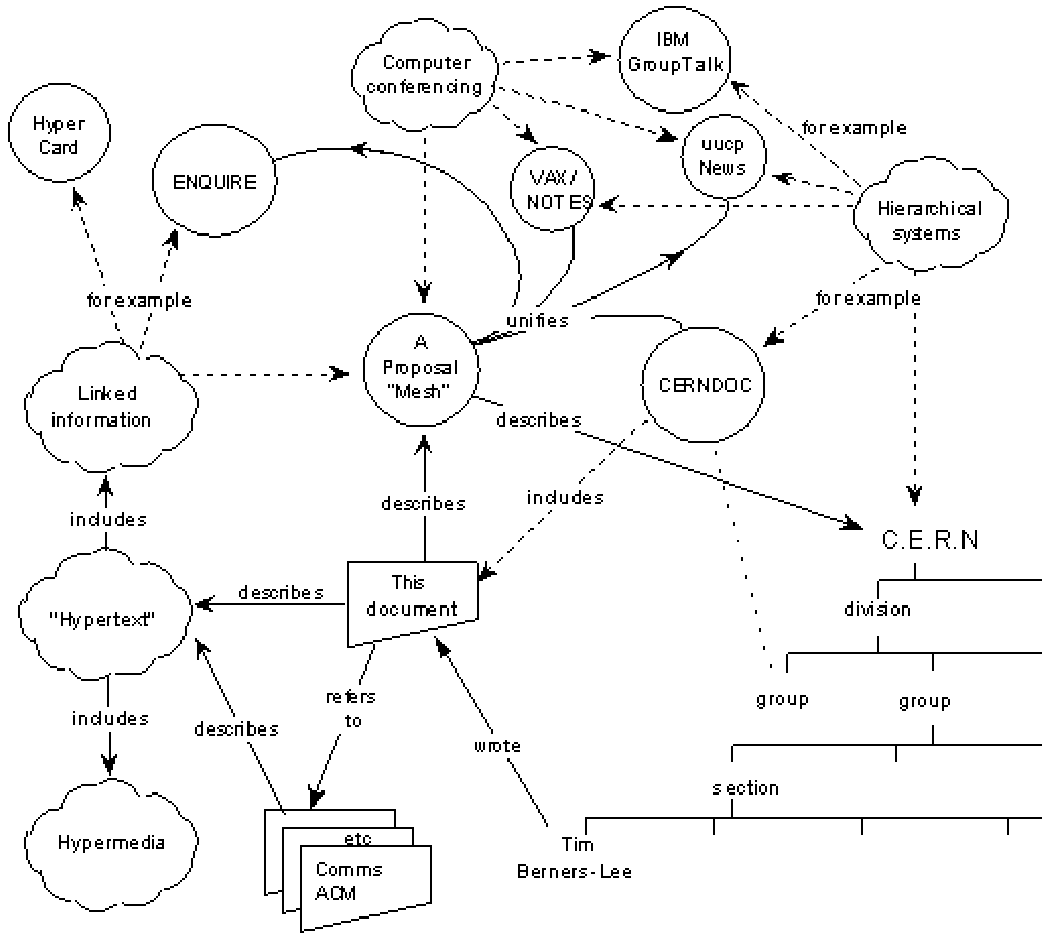
FNAL Computing Farm



Worldwide Grid for LHC

HEP as a Visionary Force

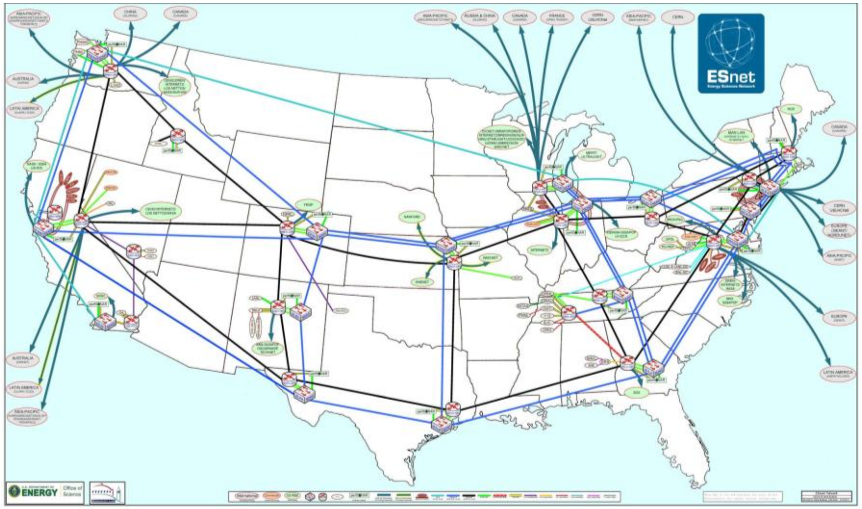
World wide Web 1989



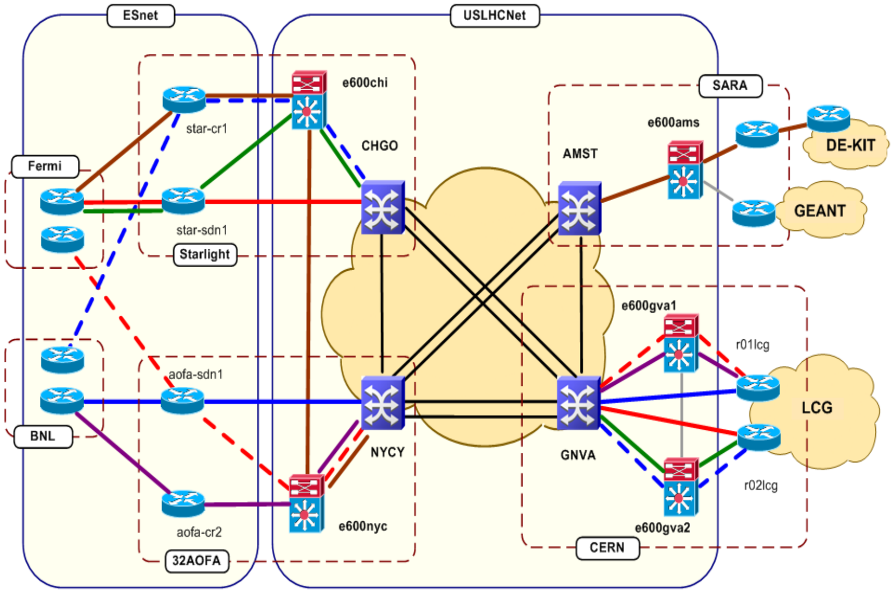
Graphic from 1989 WWW Proposal

HEP Computing and DOE

- **Department of Energy Office of Science**
  - **Provides important national and international networks for HEP and other science**

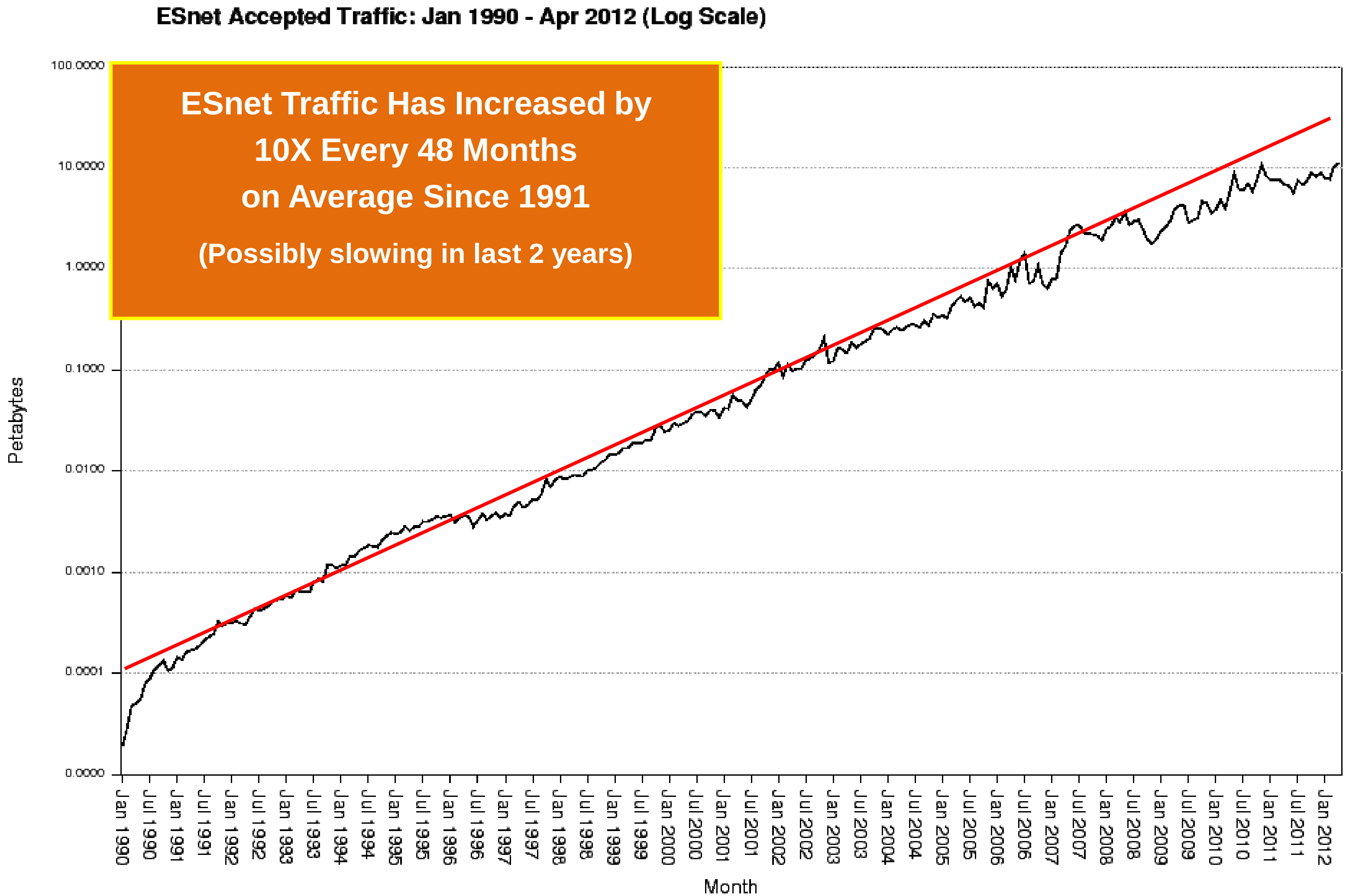


ESnet Backbone and Science Data Network



US LHCNet

Science Relies on Networks



Open Science Grid (OSG) & Big Data

OSG enables distributed computing for US LHC and the Energy Frontier

- **US Sites:**

- Access to over hundred thousand processing cores & over petabytes of data storage at sites across the world
- US LHC: “(OSG) is vital to the LHC program..”

Other Available Resources

- The National Energy Research Scientific Computing Center (NERSC) see example for PLANCK Mission
- The Innovative & Novel Computational Impact on Theory and Experiment (INCITE) program
- The ASCR Leadership Computing Challenge (ALCC) program
- DOE Office of Science Scientific Discovery through Advanced Computing (SciDAC) program (Research)
- DOE HEP research is done in large part in partnership with NSF and NSF Computing resources are available to DOE researchers and vice versa.

Computational High Energy Physics at HEP

- **Scientific Discovery through Advanced Computing (SciDAC) is an Office of Science (SC) program.**
  - HEP led four projects – in partnership with other Offices in SC and NNSA in the last round of SciDAC.
  - New proposals submitted under SciDAC 3 solicitation are under considerations for ‘Research to advance the HEP mission by fully exploiting leadership class computing resources in the areas: Cosmic Frontier Scientific Simulations, Lattice Gauge Theory Research, and Accelerator Science Modeling and Simulation

- **General HEP Computing – addresses current needs current community needs for Event Generators, Data Tools, Distributed Computing, Networks, Software**
  - Also looks to the Future: joint HEP-ASCR workshop for GEANT 4 held in May 2012 to explore re-engineering to many core platforms.

Role of Computing in HEP Strategic Planning

- **Active Planning for Future Computing Capabilities**
  - Computing at the Cosmic Frontier Workshop September 2011
  - Transforming GEANT4 for the Future Workshop May 2012
  - Working to include focus on computing requirements within the HEP program in the Snowmass 2013 summer study
  - New focus in HEP program office on future computing requirements

- **Part of the overall HEP strategic planning for Science**
  - At the three frontiers, in the related enabling technologies, and any stewardship and interfacing roles for HEP
  - Computing (and those involved in it) can play an important role

WHAT WE HOPE TO LEARN FROM THIS CONFERENCE

What We Hope to Learn From CHEP

- **What have we learned from 2 years of real LHC data?**
  - About the hierarchical distributed computing model?
  - About access to data?
  - About frameworks and event storage?
  - About the need for agility to react to experience?

- **What is the Future of Distributed Computing?**
  - Has the Distributed Computing Model Worked Fully for LHC?
  - Where else should it be used?
  - Will it be replaced by the Cloud?
  - More centralization?
  - Less centralization?

What We Hope to Learn From CHEP

- **Are computing and data needs different for other Frontiers?**
  - For the Intensity Frontier?
  - For the Cosmic Frontier?

- **How long must data be preserved and what are the technical challenges?**

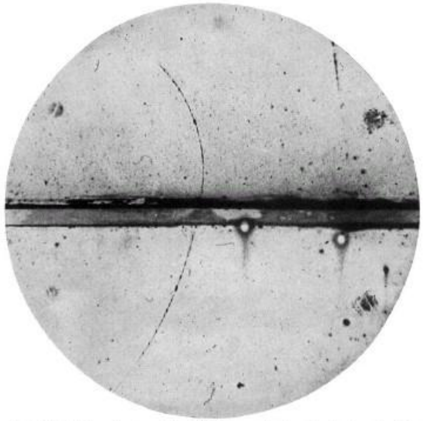


Fig. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

What We Hope to Learn From CHEP

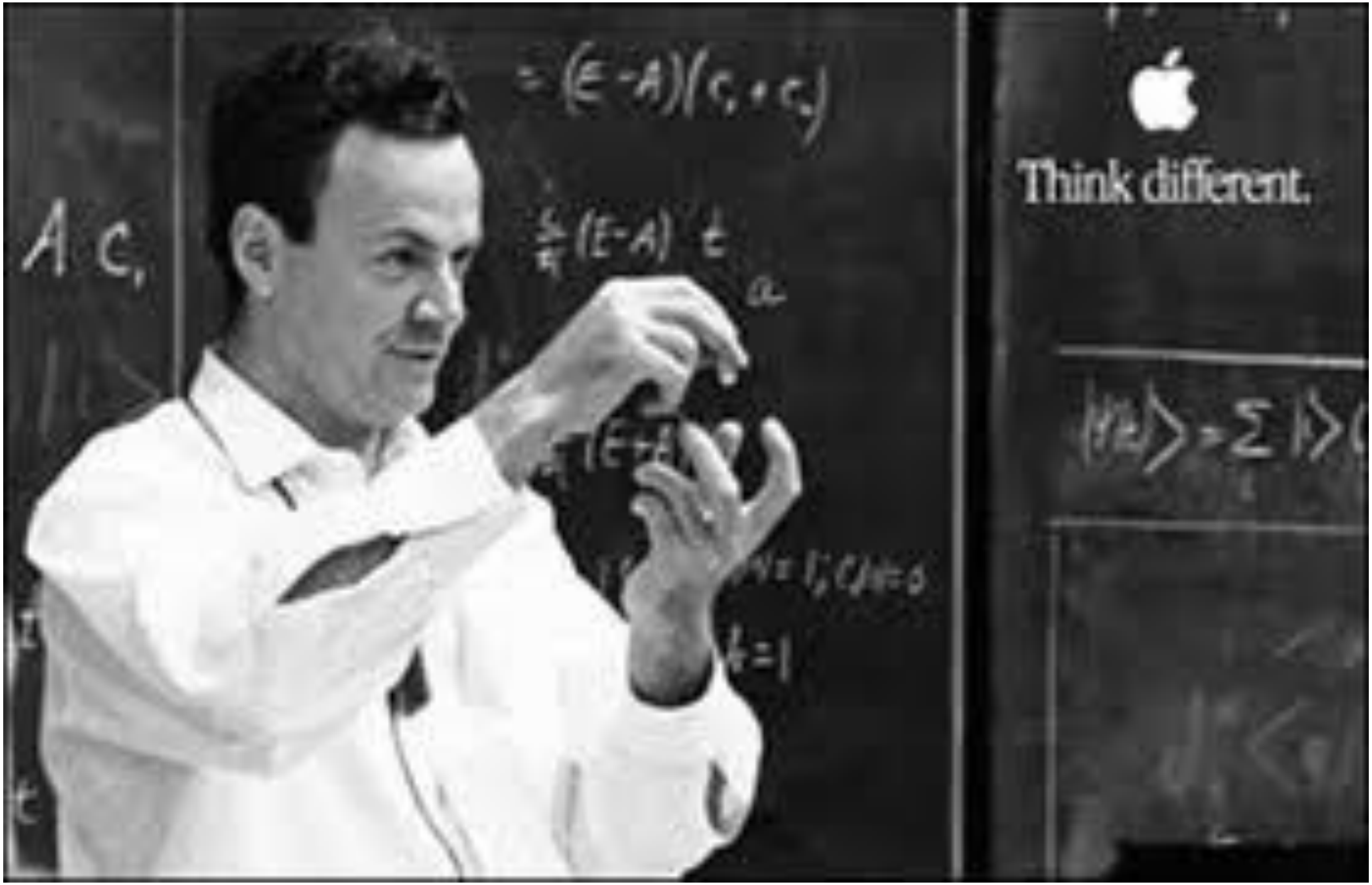
- **How do we best make use of "new" technology (and what happens if we don't)?**
  - Highly parallel supercomputers
  - Highly parallel processor chips (multicore)
  - GPUs
  - Cloud computing
    - Public or private?
    - Standards?
- **Is there a software strategy to handle any (likely) computing architecture of the next several years.**
  - Cannot rewrite software for each hardware change.

What We Hope to Learn From CHEP

- **Experiments usually develop their own computing systems (software and hardware)**
  - Often seems the shortest path to meeting their special needs
  - But does this lead to duplication or "reinventing the wheel"?
  - Is there an argument for more common development of software in HEP? And/Or use of shared processing and storage systems?
  - If so, what is the best path toward this goal?
  - A common software base is an important goal for the field.

Conclusion

- **HEP is an exciting program pushing ahead all three scientific frontiers**
- **Our success has always been tied to advances in computing and other technology**
  - E.g., LHC Computing, enabled by networks and the Grid
- **The external world of computing is changing now as fast as it ever has and should open paths to knowledge in physics**
- **HEP needs to be ready for new technical challenges posed both by our research demands and by external developments**
- **More commonality and community planning is needed for future computing systems in HEP**
  - Risk-taking and results are not mutually exclusive
  - The next chapter is yours to write


Think different.