# Status of the U.S. LHC Research Program

A Presentation to HEPAP

by

Homer A. Neal, Sr.

March 6, 2003

# Outline of Talk

Introduction

Physics goals

Progress of the US LHC Collaborations

Education and Outreach Activities

Plans and Challenges for the Research Program

Impact of Potential LHC Upgrades

Conclusions

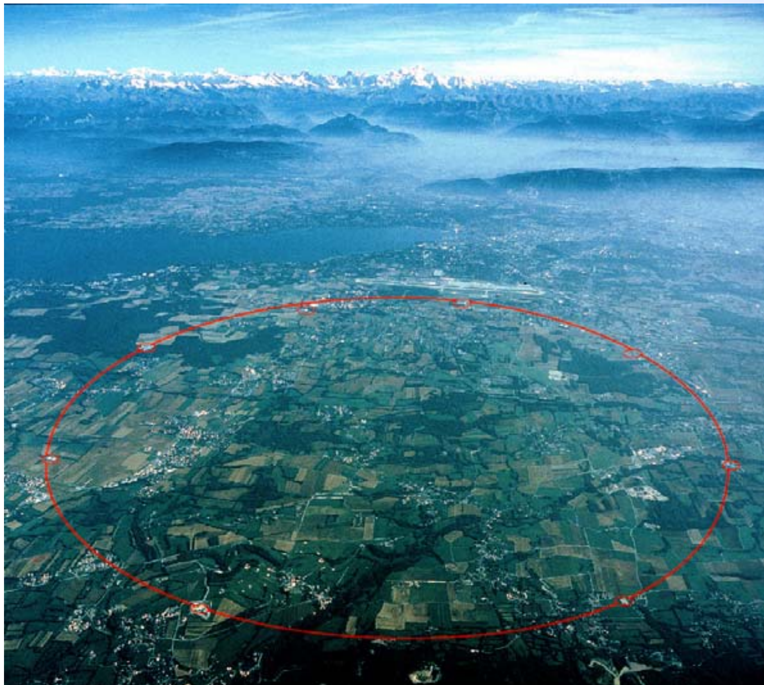
# Presentation Made on Behalf of the U.S. LHC Collaboration

*Steering Committee Appointed by US CMS, US ATLAS, and US LHC Accelerator Groups:*

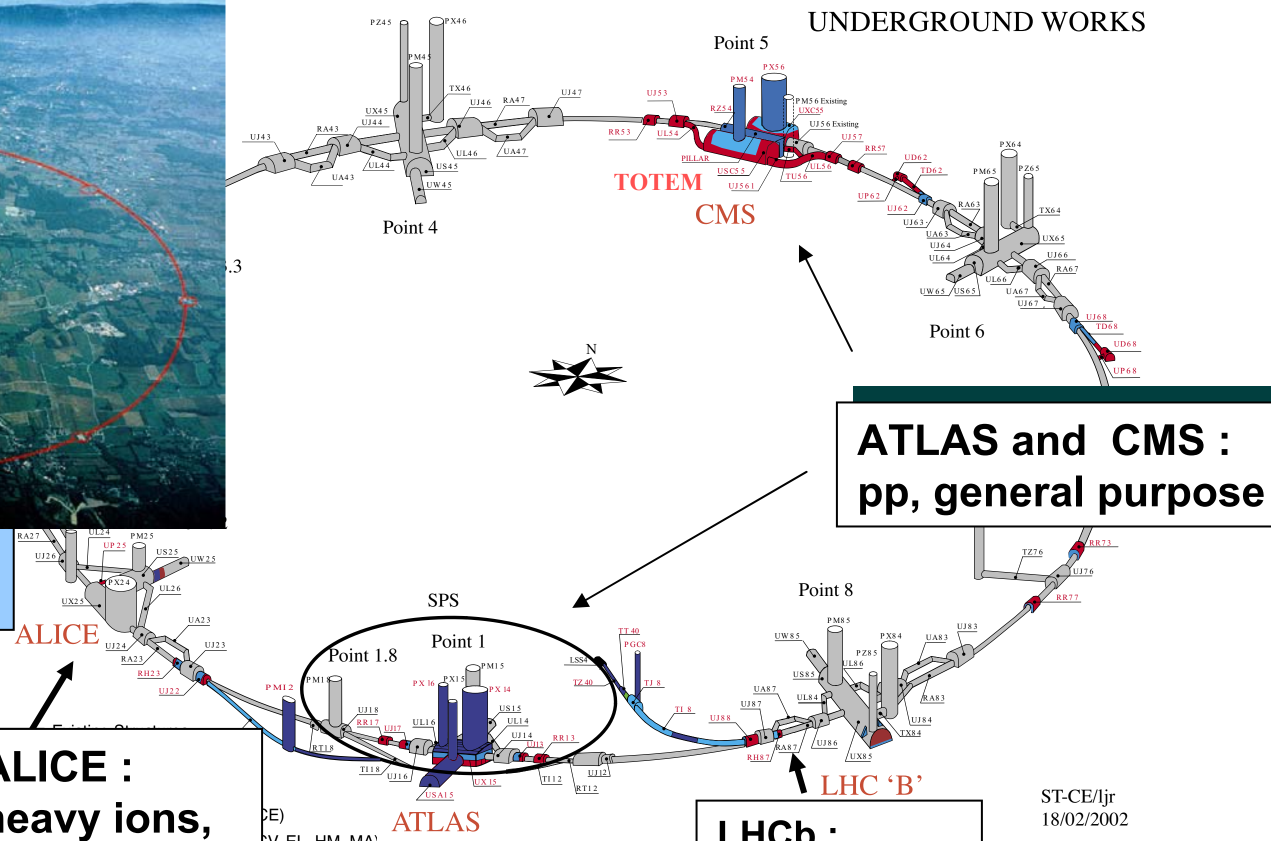
**Steve Gourlay**
**Dan Green**
**Homer Neal, Sr.**
**Harvey Newman**
**Steve Peggs**
**James Siegrist**
**Wesley Smith**
**James Strait**
**George Trilling**
**Bill Willis**

# LHC

- pp $\sqrt{s}$ = **14 TeV** $L_{design} = 10^{34}$ cm$^{-2}$ s$^{-1}$
- **Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)**



27 Km ring
1232 dipoles B=8.3 T
(NbTi at 1.9 K)




**ATLAS and CMS : pp, general purpose**

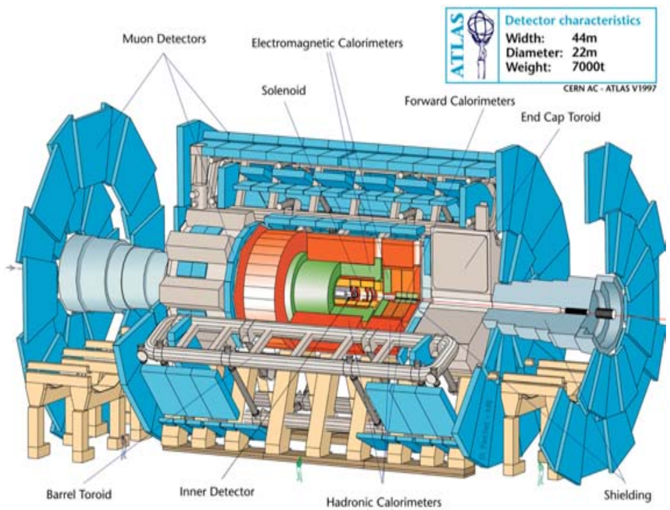
**ALICE : heavy ions, p-ions**

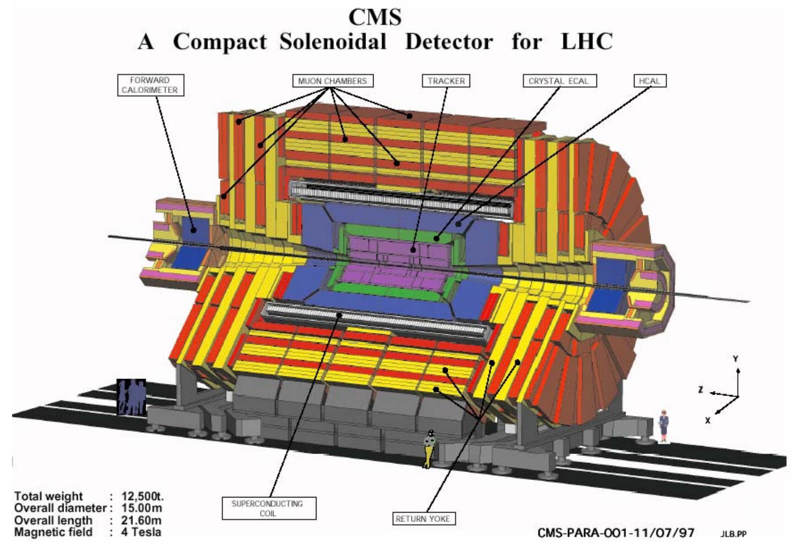
**LHCb : pp, B-physics**

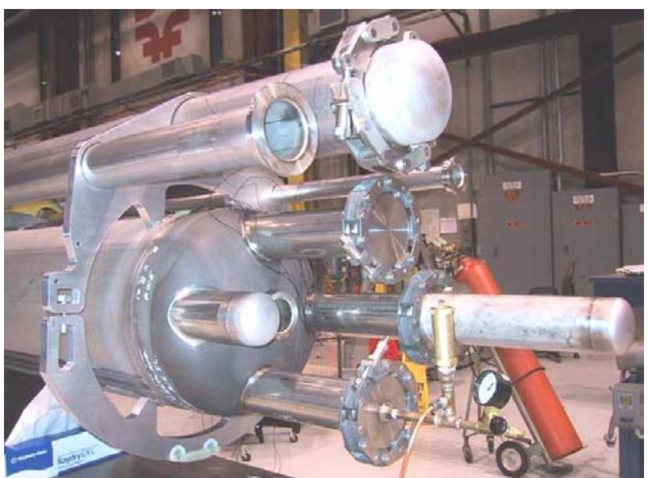
**First Beams : April 2007**

**Physics Runs: July 2007**

# Enormous Progress: State of the Art Massive Detectors Being Constructed, Frontier Accelerator R/D Underway, Impressive Civil Construction In Process



# The LHC Physics Program

- Search for Standard Model Higgs boson over ~ $120 < m_H < 1000$ GeV.

- Search for Supersymmetry and other physics beyond the SM (q/ℓ compositness, leptoquarks, W'/Z', heavy q/ℓ, unexpected ? ….)

- Precision measurements, including:
  -- Higgs mass, couplings (if Higgs found)
  -- WWγ, WWZ Triple Gauge Couplings
  -- top mass, couplings and decay properties
  -- B-physics: CP violation, rare decays, $B^0$ oscillations (ATLAS, CMS, LHCb)
  -- Detailed measurements of the new physics

Adapted from talk by F. Gianotti

# Example LHC Event Rates

| Process | Events/year | Other machines (total statistics) |
|---|---|---|
| $W \rightarrow e\nu$ | $10^8$ | $10^4$ LEP / $10^7$ Tev. |
| $Z \rightarrow ee$ | $10^7$ | $10^7$ LEP |
| $t\bar{t}$ | $10^7$ | $10^4$ Tevatron |
| $\tilde{g}\,\tilde{g}$ (m=1 TeV) | $10^4$ | — |
| H (m=0.8 TeV) | $10^4$ | — |
| QCD jets $p_T > 200$ GeV | $10^9$ | $10^7$ |

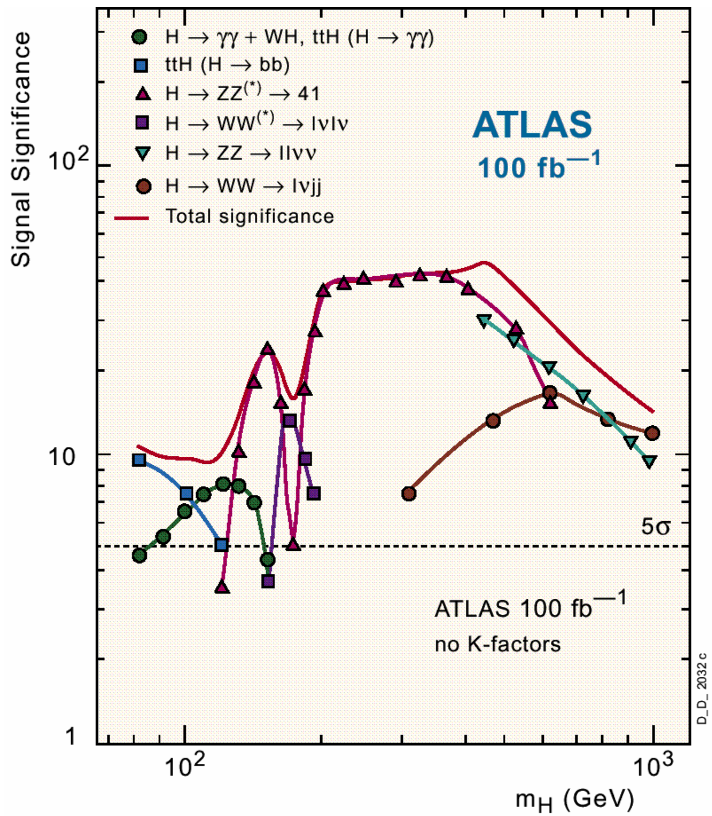
High L : statistics **10 times** larger

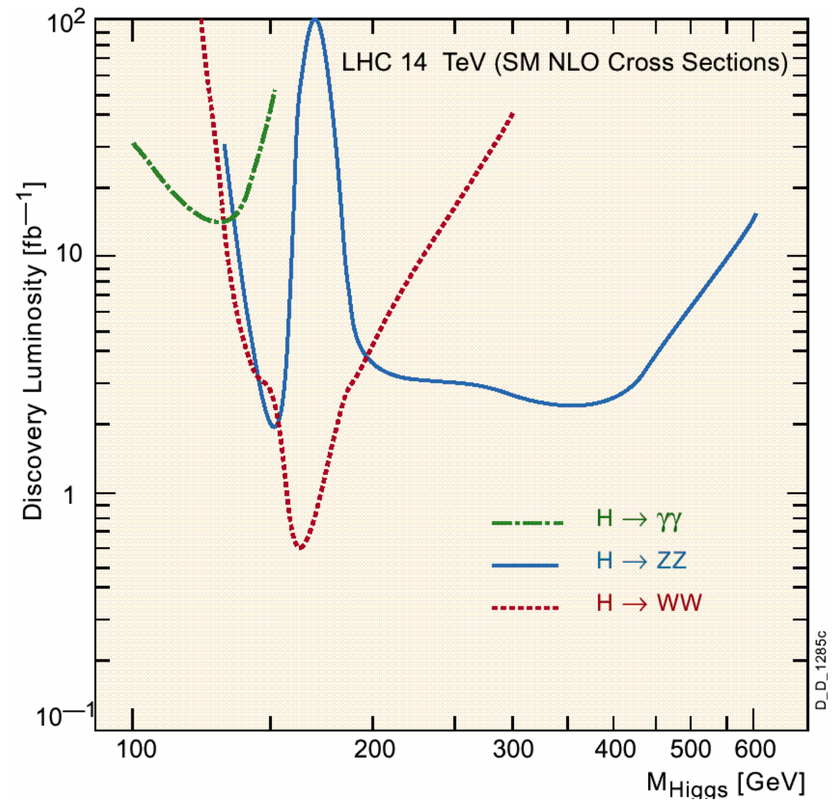
Event Rates at the LHC representative of (known and new) physics processes at low luminosity ($L=10^{33}$ $cm^{-2}$ $s^{-1}$)

Adapted from F. Gianotti Presentation

**→ LHC is a B-factory, top factory, W/Z factory, low-mass Higgs factory, and SUSY factory**

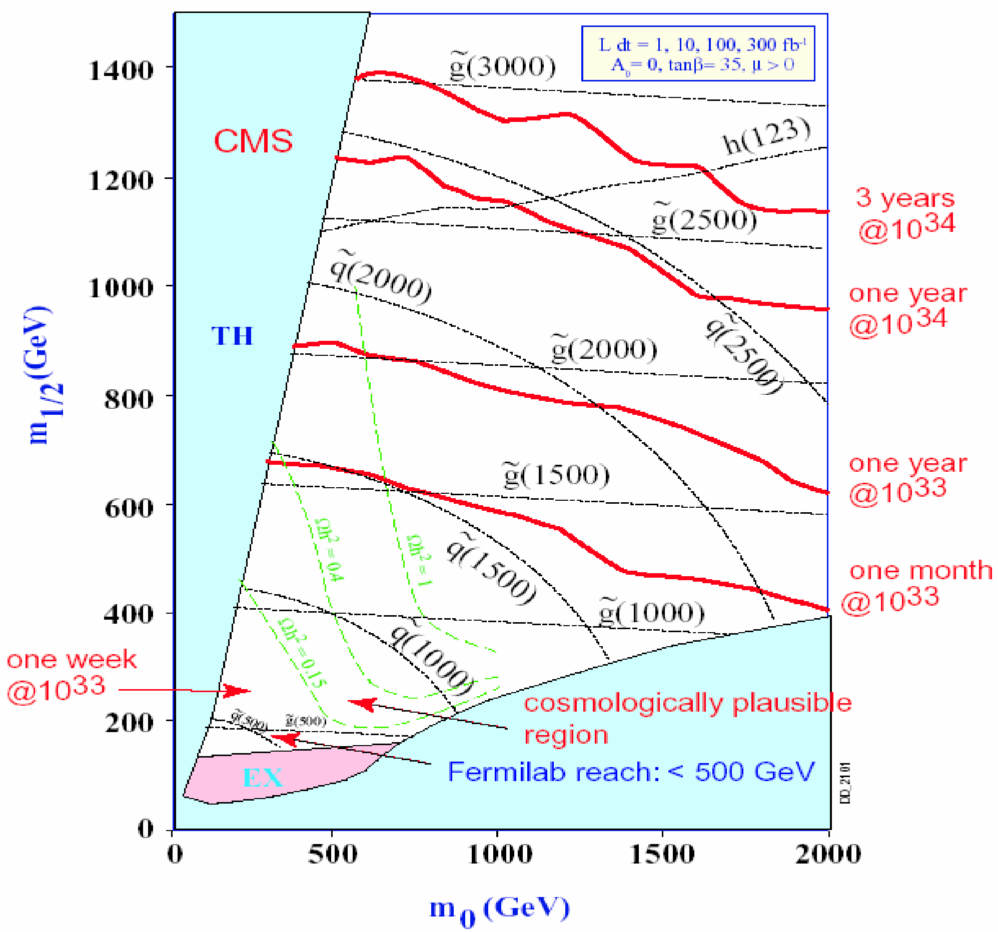
# U.S. Groups need to be ready to search for Higgs on Day 1




There are indications the Higgs is light, and groups wishing to pursue this exciting quest must be ready at LHC turn-on. We will discover the Higgs or something equally exciting. We will probably discover it quickly – during year #1

# SUSY Reach




The cosmologically interesting region of the SUSY search will be covered in the first weeks of LHC running, and the 1.5 to 2 TeV mass range for squarks and gluons will be covered within one year at low luminosity.

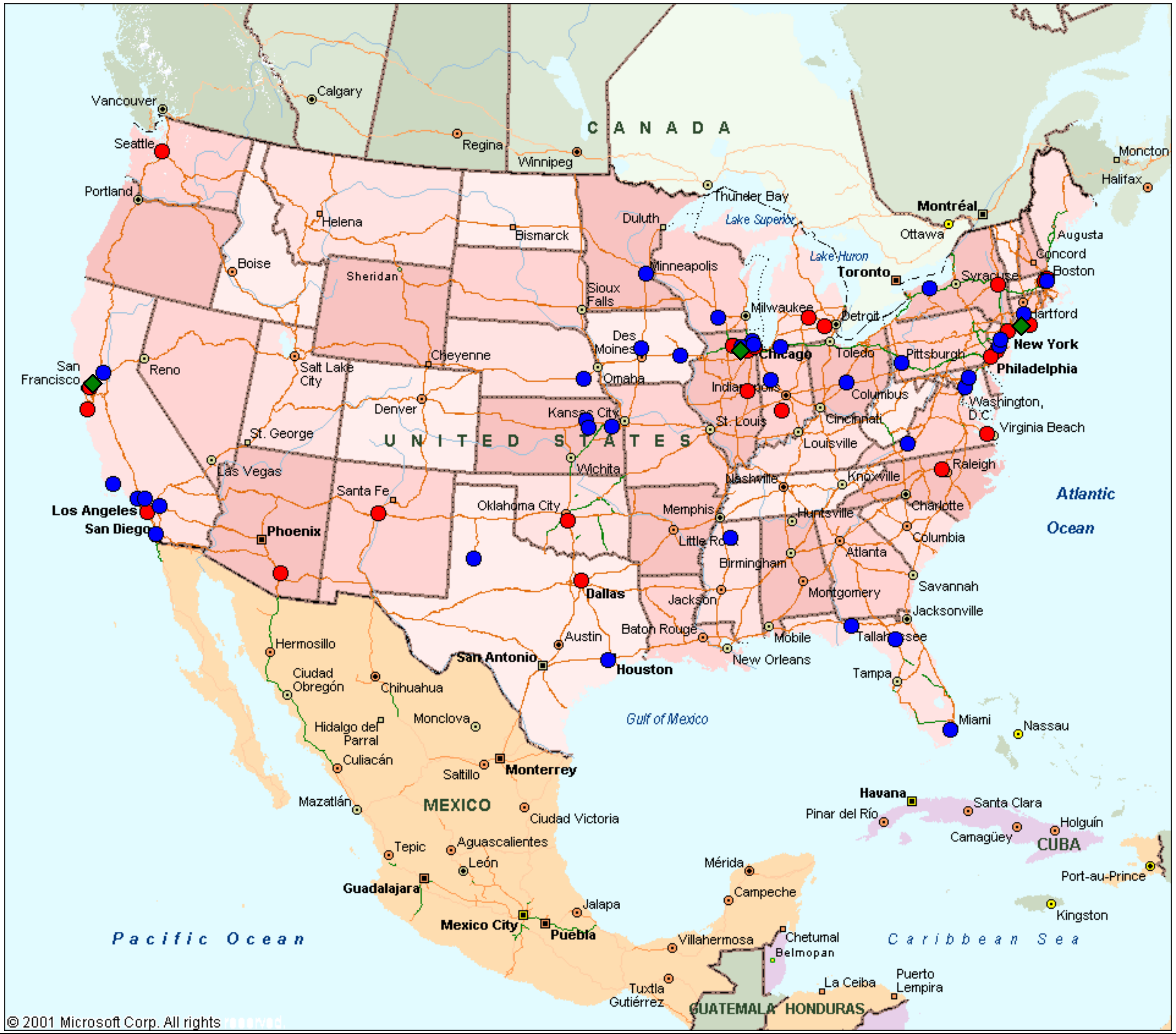
The LHC should be able to establish the existence of SUSY and open many avenues to study masses and decays of SUSY particles, if m(SUSY) is less than a few TeV.

# US LHC INSTITUTIONS

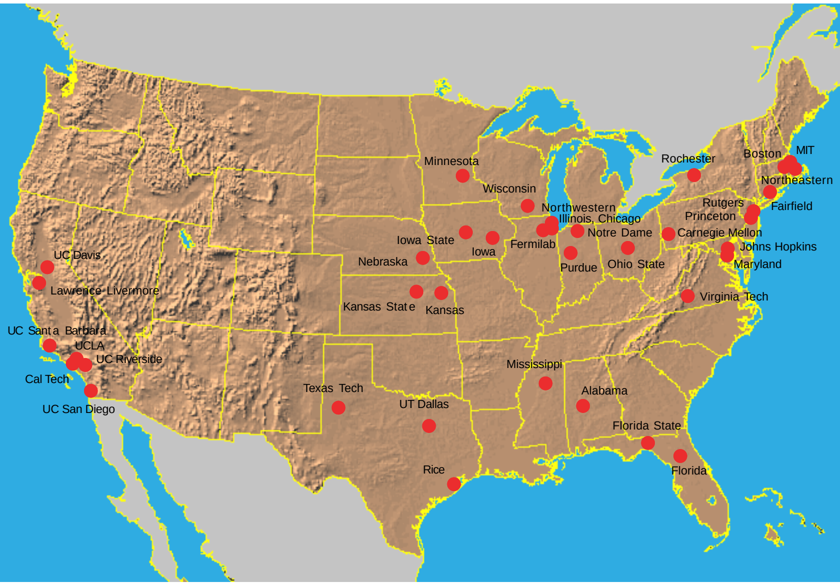
US CMS

Accelerator

US ATLAS



# The U.S. CMS Collaboration

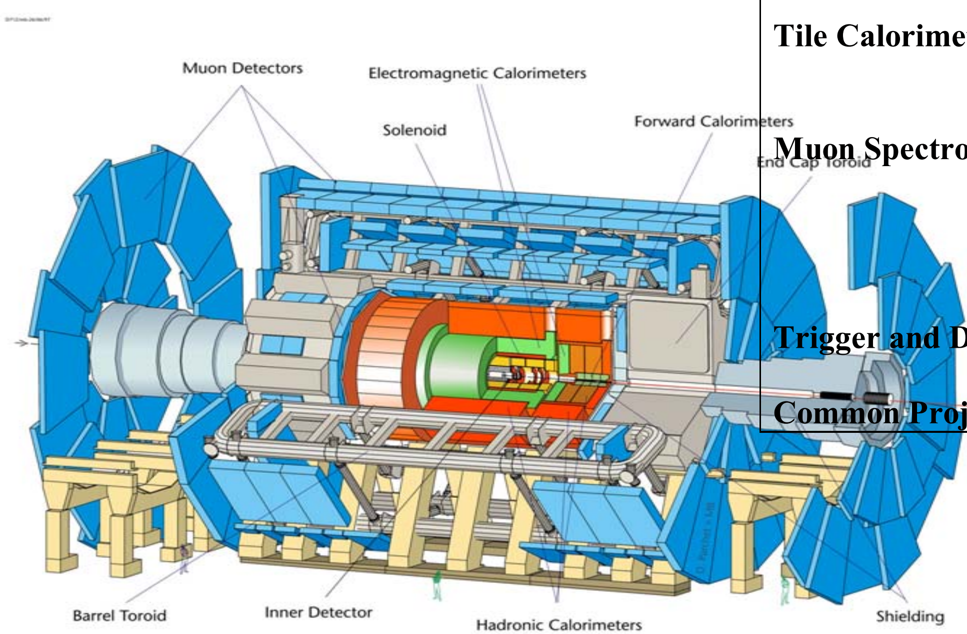



November 10, 2000

| Subsystem | Institutions |
|---|---|
| Endcap Muon | UC-Davis, UC-Los Angeles, UC-Riverside, Carnegie Mellon, FNAL, Florida, Northeastern, Ohio State, Purdue, Rice, Wisconsin |
| Hadron Calorimeter | Boston, Fairfield, FNAL, Florida State, Illinois-Chicago, Iowa, Iowa State, Maryland, Minnesota, Mississippi, Nebraska, Northeastern, Notre Dame, Purdue, Rochester |
| Trigger | UC-Los Angeles, Florida, Rice, Wisconsin |
| Data Aquisition | UC-San Diego, FNAL, MIT |
| EM Calorimeter | Caltech, Minnesota, Northeastern, Princeton |
| Forward Pixels | UC-Davis, FNAL, Johns Hopkins, Mississippi, Northwestern, Purdue, Rutgers |
| Silicon Tracker | UC-Santa Barbara, FNAL, Kansas, Kansas State, Northwestern, Rochester, Illinois-Chicago |

# The U.S. ATLAS Collaboration

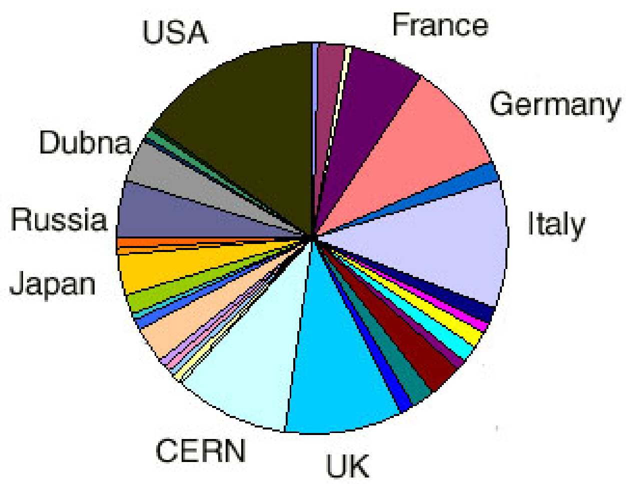
| Subsystem | Institutions |
|---|---|
| Silicon | UC-Berkeley/LBNL, UC-Santa Cruz, Iowa State, New Mexico, Ohio State, Oklahoma, SUNY-Albany, Wisconsin |
| TRT | Duke, Hampton, Indiana, Michigan, Pennsylvania |
| Liquid-Argon Calorimeter | Arizona, BNL, Columbia, Pittsburgh, Rochester, Southern Methodist U., SUNY-Stony Brook |
| Tile Calorimeter | ANL, Chicago, Illinois-Champaign/Urbana, Michigan State, UT-Arlington |
| Muon Spectrometer | Boston, BNL, Brandeis, Harvard, MIT, Michigan<br>Northern Illinois, SUNY-Stony Brook, Tufts, UC-Irvine, Washington |
| Trigger and DAQ | ANL, UC-Irvine, Michigan State, Wisconsin |
| Common Projects | All institutions |



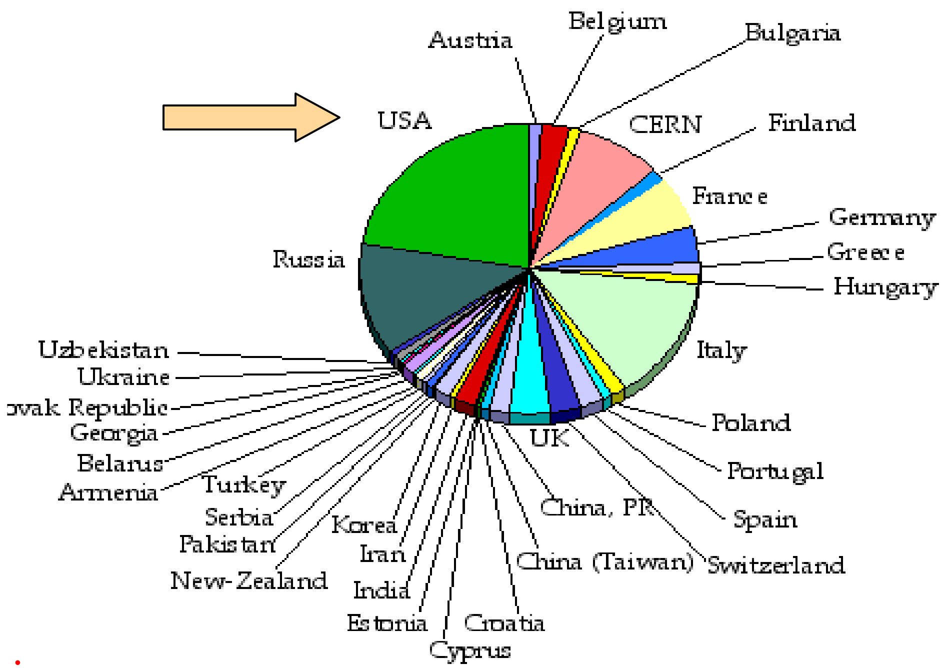
# LHC Collaborations

## ATLAS

US




## CMS

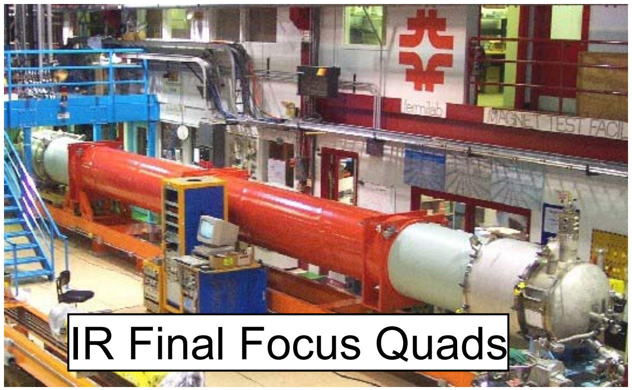



**1849 Physicists and Engineers**
**34 Countries**
**147 Institutions**

The US provides about 20% of the author list in both experiments

…and about 5% of the machine construction

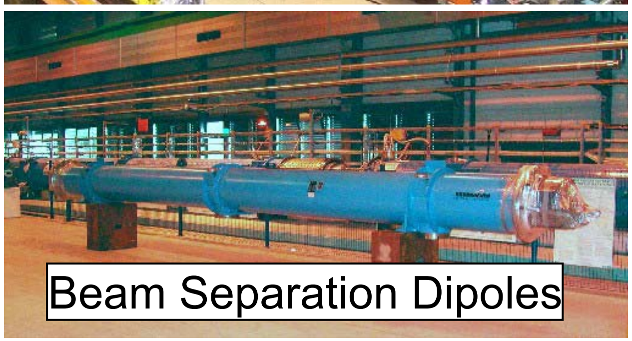
# US LHC Accelerator Groups


IR Final Focus Quads

## Fermilab

Technical Division
Beams Division

*IR quads, accelerator physics, project management*


Beam Separation Dipoles

## Brookhaven

Superconducting Magnet Division
Collider-Accelerator Department

*IR dipoles, SC cable testing, accelerator physics*


IR Absorbers

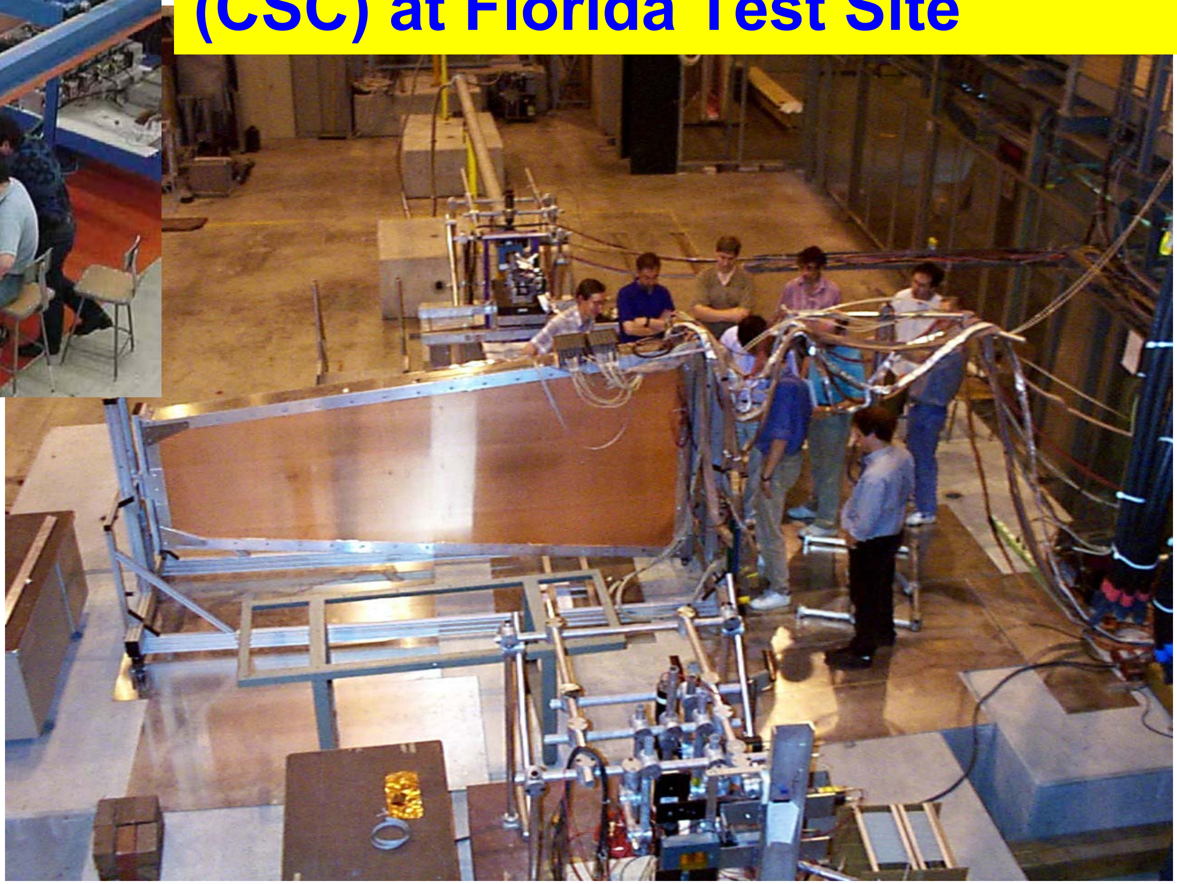
## Berkeley Lab

Accelerator and Fusion Research Division

*IR feedboxes and absorbers, accelerator physics, SC cable production support*

# US CMS Endcap Muon work

**Florida, & UCLA Personnel work with Cathode strip Chamber (CSC) at Florida Test Site**



**Fermilab, Florida, Ohio State, Rice & UCLA Personnel work with CSC at CERN Test Beam**

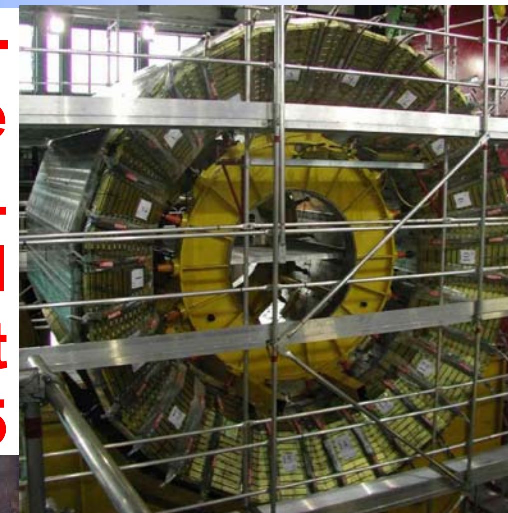
# U. Michigan ATLAS Muon Chamber Construction Team


# Hampton University: ATLAS Transition Radiation Tracker

# U.S. CMS HCAL Work

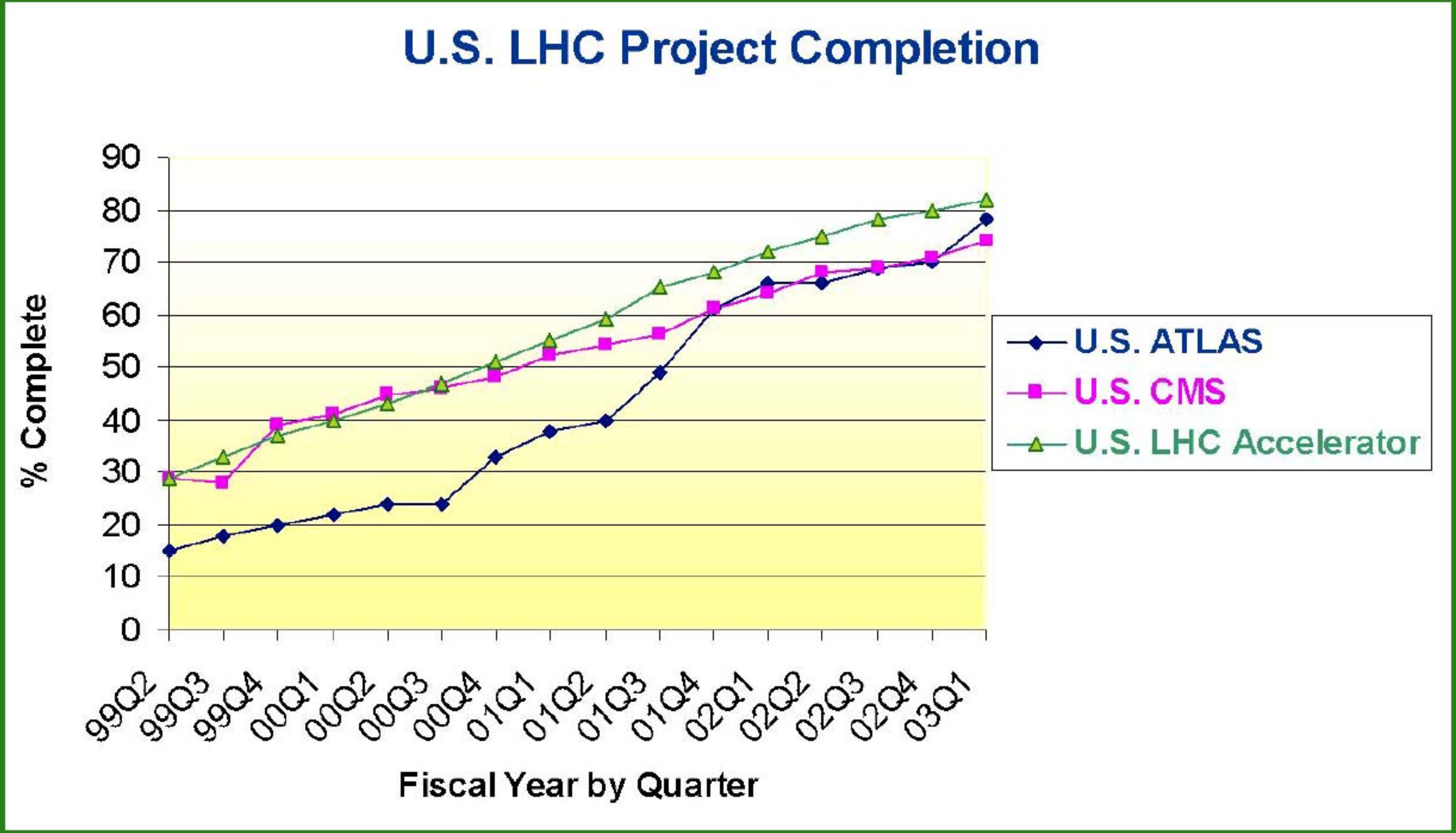
**Student works on Optical Unit at Notre Dame**

**Com-plete HCAL Barrel at Point 5**



**HCAL Barrel Wedges & Outer Modules in Test Beam at CERN with ECAL module**

# US LHC Construction Projects



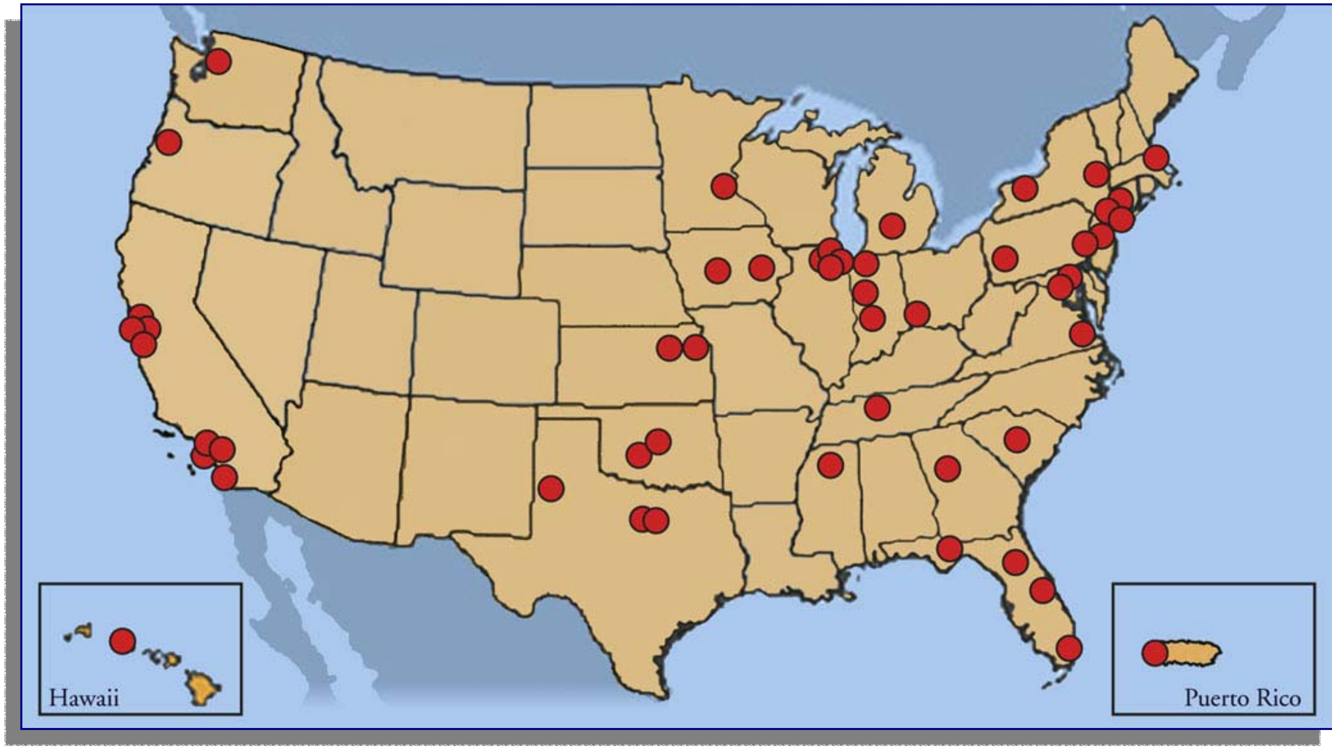

**The 531 M$ investment has been wisely used. The Projects are on schedule (for 2005 ~ completion) and on budget. The US LHC Projects are progressing steadily toward completion.**

# Education and Outreach

**QuarkNet has 50 centers nationwide (60 planned).**

Each center has:
2-6 physicist mentors
2-12 teachers*

* Depending on year of the program and local variations.



# Education and Outreach

**The focus of this program is and was to involve in our experiments:**

**Teachers: do research with us and bring that excitement and experience to their classrooms;**

**Students: analyze web-data in their classrooms.**

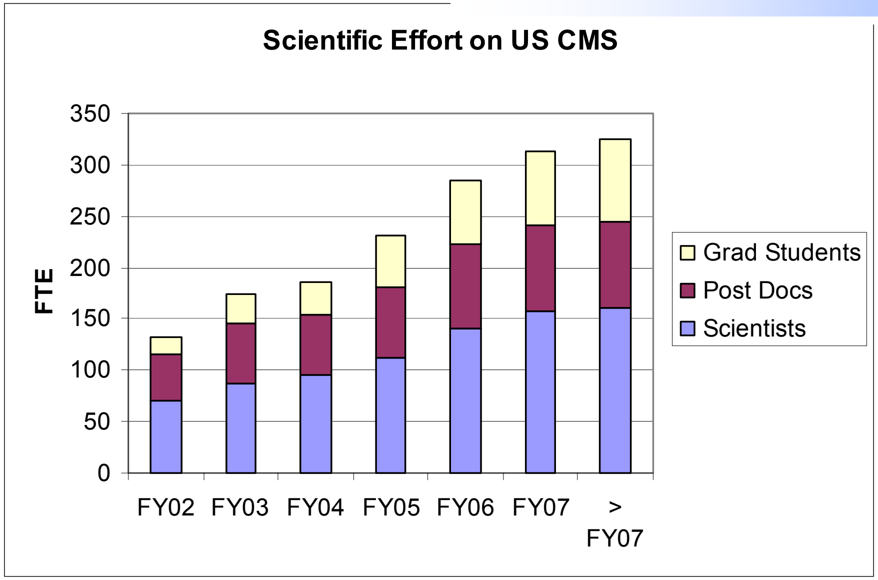
Average teacher has 5 classes with 28 students. For 60 centers with 12 teachers each:

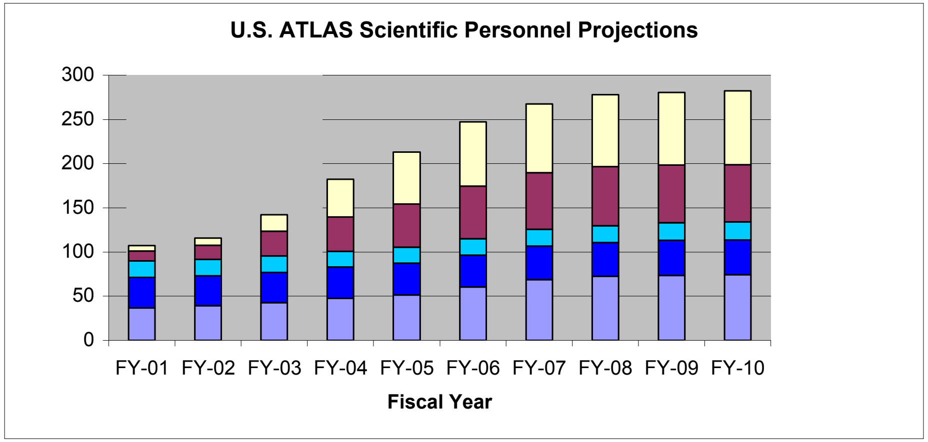
**$60 \times 12 \times 5 \times 28 = 108{,}000$ students each year**

After ten years, over one million students!

# University of Michigan REU Students Departing for a Summer of Research and Training at CERN

# LHC a growing part of the U.S. HEP Program; More users on the way




<u>Projections of Scientific Effort:</u>

It is expected that the scientific effort will grow by a factor of two and will be a critical part of the overall U.S. experimental particle physics effort.

# Computing Infrastructure

It won’t be a matter of just turning on the beam and discovering a new particle.  The high luminosity, large data samples, and theoretical uncertainties on the background will make understanding what we are seeing a tremendous challenge.

As part of meeting this challenge, we will achieve a cultural generation change at the leading edge of the transition to the Information Age:

•We will enable continual collaboration from home universities

•We will reach out to younger students and involve them in the process of search and discovery

•Make our field, and its advances in technology, as well as science, “closer” and more relevant to everyday university life

# LHC Computing Challenge

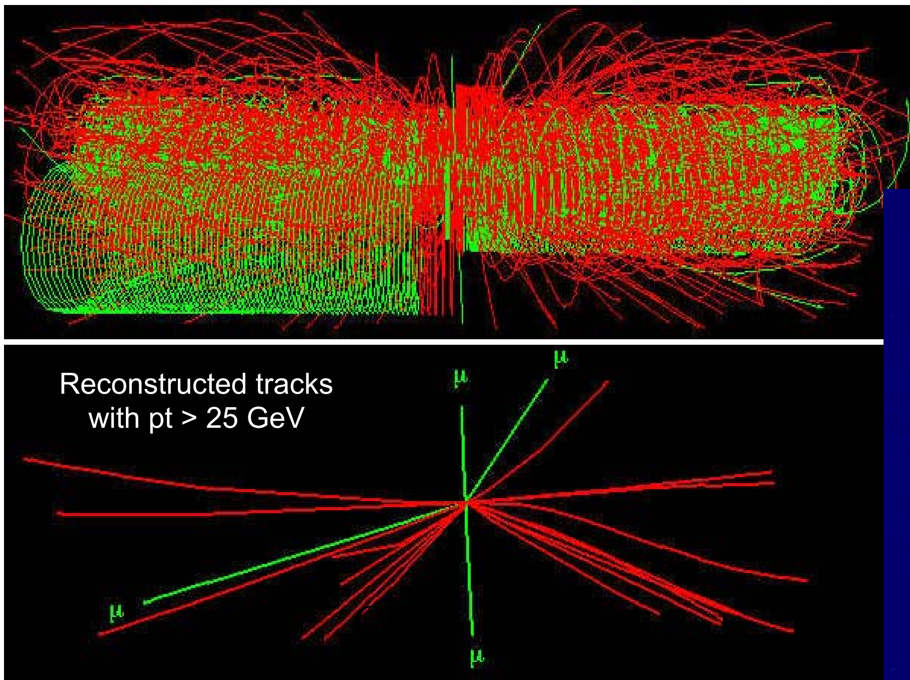
- Tens of Petabytes/year of stored and processed data distributed worldwide in the early days of LHC running, rising to the Exabyte range in the following decade
- Processing power required will progress from the equivalent of hundreds of thousands to millions of today's PCs.
- Emergence of the first truly global systems for data-intensive processing and analysis

# LHC – Computing Grids

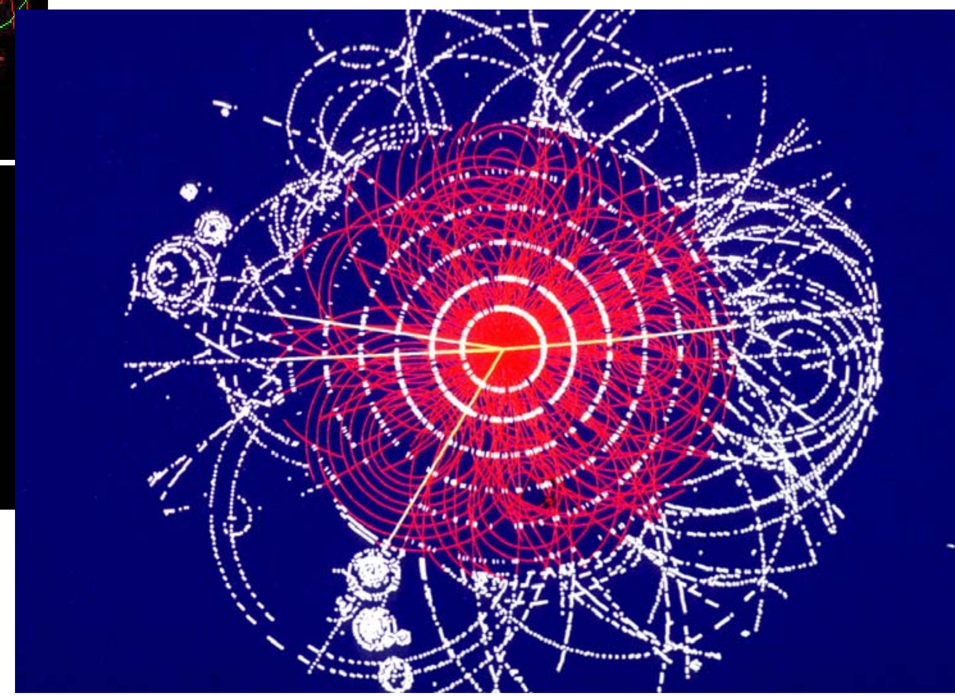
**The IT tools developed for LHC physics analysis are and will be vital to the advancement of global science. Grid computing will make a major impact in many areas of business and commerce. The leading role of LHC was recognized in the HEPAP Subpanel Report.**

> The inherent advantages of coherently operating geographically distributed and disparate resources is becoming an important issue for many scientific disciplines as well as industry, where the Grid is seen as a strategic framework for business operations and commerce. As a result, research groups and industry in the United States, Europe and Asia are undertaking a broad array of Grid research and technology development efforts. Particle physicists in these regions have taken a leading role in defining a unifying architectural framework and in deploying a common multi-continent Grid laboratory, including a multi-Gigabit/second link between the United States and Europe, in partnership with other disciplines. The scale of this laboratory, which has a large focus on LHC computing, is expected to greatly advance progress in Data Grid technologies.

# Higgs Simulations:
## The Analysis Challenges

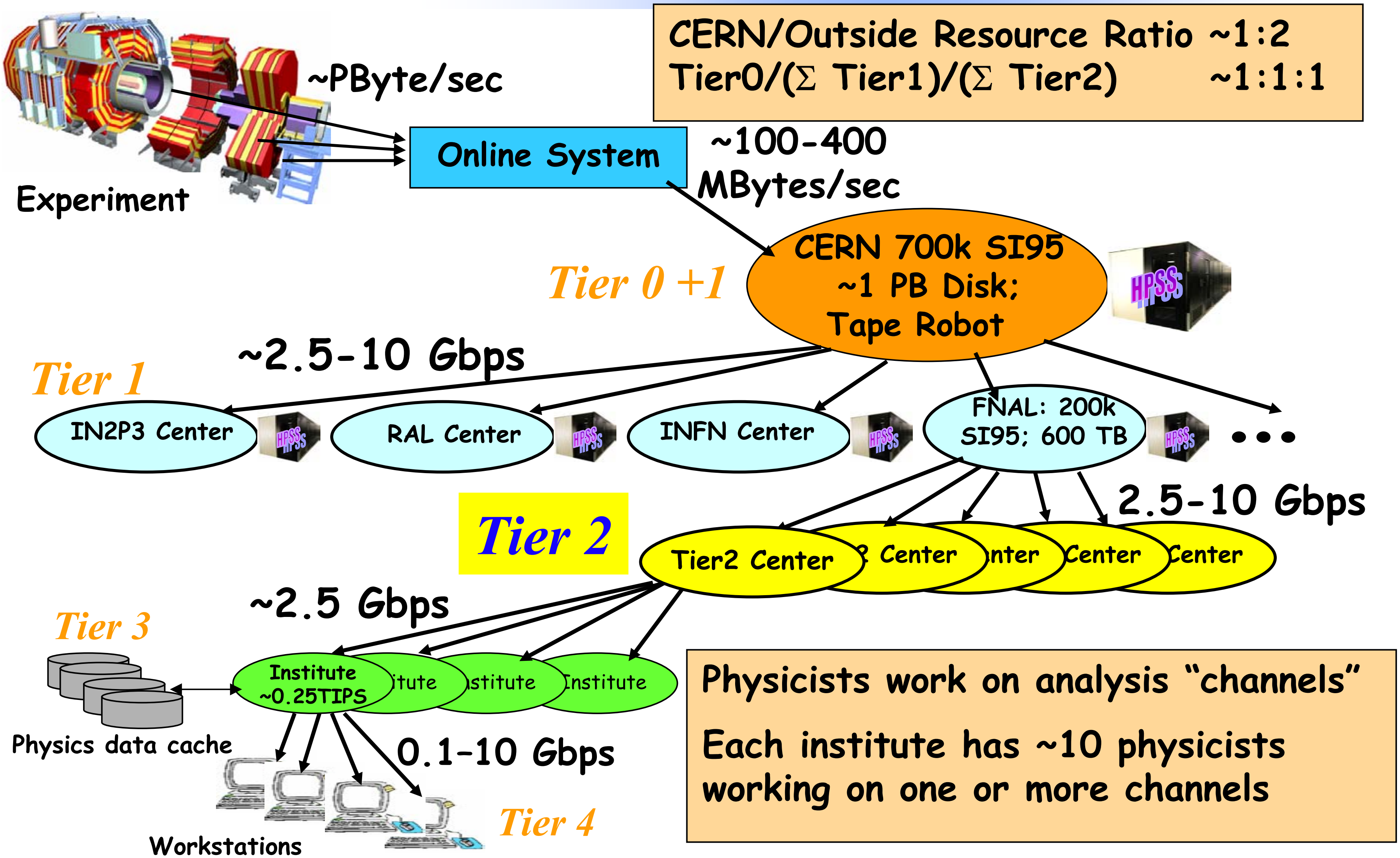



CMS



ATLAS

# LHC Data Grid Hierarchy



# LHC Computing Initiatives

Large ITR Proposal is in the process of being prepared by U.S. ATLAS/ U.S. CMS to address special computing issues associated with physics analysis in a Grid-enabled environment

Medium ITR proposal submitted to develop, prototype and deploy the first Grid-Enabled Collaboratory for Scientific Research on a global scale

Note:

- Many other countries are strengthening their computer infrastructure to address LHC computing issues
- European groups will have the advantage of proximity to CERN

# Needs of the Experimental Program

In order for the US to lead in LHC physics discoveries following the machine turn-on:

- Support of postdocs, students and travel
- Support of computing infrastructure

In order to operate & realize the full capability of the detector equipment built by the US:

- Support of maintenance and operations
- Support of technical personnel to maintain the detectors
- Support of US work on machine commissioning and studies

Needs to ramp up now to be ready for 2007

# Accelerator Research with LHC

## The LHC offers unique opportunities to work at the forefront of accelerator physics and technology.

### Beam Physics Research

- *LHC beam conditions will be the most extreme yet encountered.*
- *Forefront research at LHC can feed back to the US accelerator program.*

### The LHC will be a hard machine to operate.

- *US work on machine commissioning will speed LHC turn on.*
- *US accelerator physicists' calculations and experiments to*
  - *understand performance limitations of current configuration*
  - *develop advanced instruments and controls*
  - *develop solutions to performance limitations*

  *will help maximize the delivered luminosity to ATLAS and CMS.*

# LHC Schedule & Upgrades

- ***Luminosity upgrade x10 – SLHC : $L = 10^{35}$ cm$^{-2}$ s$^{-1}$***
  - ***--extends LHC mass reach by ~ 20-30%***
  - ***--modest changes to machine***
  - ***--detector upgrades needed***
  - ***--time scale ~ 2014***

- ***Energy Doubled LHC - EDLHC: $\sqrt{s}$ ~ 25 TeV***
  ***$L = 10^{34}$-$10^{35}$ cm$^{-2}$ s$^{-1}$***
  - ***--extends LHC mass reach by ~ 1.5-2 for $L=10^{34}$-$10^{35}$***
  - ***--requires new machine (e.g. 15 T magnets …)***
  - ***-- mostly uses detector upgrades for SLHC***
  - ***--time scale > 2020***

# SLHC Detector R&D - I

## Inner Tracker: rebuild

- **r < 20 cm: new approach, 20 < r < 60 cm: extend pixel technology, 60 cm < r: extend strip technology**
- **New approaches: defect-engineered Si, 3D detectors, new sensor materials, cryogenic Si, monolithic pixels**

## Calorimetry: usable with caveats

- **ATLAS (Liquid Argon):** Front end board should be redesigned either by making components more radiation resistant, and/or use analog optical links to bring the signals out.
- **CMS (xtal ECAL, scint. HCAL): Endcap scint. Damage**
  - Investigate more radiation tolerant scintillator
- **Modify readout & trigger electronics for crossing ID**

## Muon Systems: usable up to high $\eta$

- **Replace front end readout & trigger electronics**
- **Additional Shielding needed**

# SLHC Detector R&D - II

## Trigger: rebuild for 12.5 ns

- **Double operational frequency from 40 MHz to 80 MHz**
  - Processing & data transfer
- **Design for much higher rejection power for pileup to retain output rate of 100 kHz**
  - Exploit newer generation programmable devices

## DAQ: evolve to higher performance

- **Increase in bandwidth due to increase in event size.**
  - Use new commercial network technologies
  - Issue: Control & management of 10K CPU farms.

# LHC Accelerator Upgrades

- ***SLHC Luminosity upgrade to $10^{35}$:***
  -- *increase bunch intensity to beam–beam limit → L ~ 2.5 x $10^{34}$*
  -- *halve bunch spacing to 12.5 ns (electron cloud limitation?)*
  -- *Reduce β* by x2-3 ($Nb_3Sn$ insertion magnets)*
  -- *Increase crossing angle.*
  -- *Reduce bunch length. (new RF)*
  -- *Super Bunch option being investigated.*

**moderate hardware changes time scale ≥ 2014**

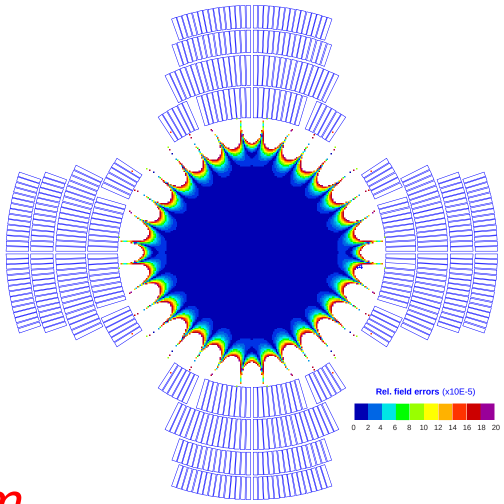
- ***EDLHC √s upgrade to 25 TeV :***
  -- *ultimate LHC dipole field : B= 9 T → √s = 15 TeV*
  *→ any energy upgrade requires new machine & Injector*
  -- *present magnet technology up to B ~ 10.5 T*
  *small prototype at LBL with B= 14.7 T*
  -- *magnets with B~17 T may be reasonable target for operation in >2020 provided intense R& D on new superconductors (e.g. $Nb_3Sn$)*

**major hardware changes time scale ≥ 2020**

# U.S. Role in Machine R&D

LHC R&D by the U.S. Labs will focus on increasing the luminosity.

- *Understand the limitations of the current machine configuration, particularly the IRs, and develop modifications.*
- *Low $\beta^*$ insertion sections: (separation dipoles, triplet quads)*
- *Develop high-field $Nb_3Sn$ magnets for new low $\beta^*$ insertion, for example: quad aperture 70 -> 110 mm => $\beta^*$ 50 -> ~17 cm.*




Other luminosity upgrade R&D to be addressed by CERN, e.g.

- *r.f. upgrades – for halving bunch length or handling superbunches*
- *collaborate with U.S. labs on R&D on luminosity upgrade magnets*

# U.S. Role in Machine R&D

$Nb_3Sn$ has never been used before in an accelerator.

- *Intensive R&D program required, starting soon.*
- *"Small-scale" application in luminosity upgrade is a stepping stone towards large scale use as main magnets of a future machine.*
- *Success of LHC program depends on continued vigorous base program R&D at all three labs.*

We will concentrate on the most challenging magnets for new IR.

- *Could be either dipole or quadrupole.*
- *Greatest opportunity to advance our capabilities for the future.*
- *Best chance for earliest possible upgrade … we can start sooner than CERN.*

Collaboration with CERN and other non-U.S. labs.

- *We do not have the resources to develop all the required IR magnets.*
- *Expect $Nb_3Sn$ R&D to start at CERN ~2006-2007.*

R&D relevant to a possible EDLHC is covered by the base R&D program.

- *Key questions of maximum field and cost minimization aren't LHC specific.*
- *High-field dipole programs at FNAL, LBNL, and BNL are addressing these now.*

# Summary of US LHC Program Needs

**In order for the US to lead in LHC physics discoveries following the machine turn-on:**

- Support of postdocs, students and travel
- Support of computing infrastructure

**In order to operate & realize the full capability of the detector equipment built by the US:**

- Support of maintenance and operations
- Support of technical personnel to maintain the detectors
- Support of US work on machine commissioning and studies

**In order to fully exploit the LHC and sustain U.S. leadership in HEP detectors and accelerators:**

- Support of detector & accelerator upgrade R&D

**Needs to ramp up now to be ready for 2007**

# LHC & Future of U.S. HEP

## Large Investment Yields a Great Opportunity for Fundamental Discoveries

## Steady Stream of Frontier Physics for 2 Decades, starts immediately at LHC turn-on

- Enormous energy leap

## US must not just participate, must lead

- Highly competitive physics environment requires strongly supported postdocs and students with state-of-the-art tools

## Physics Analysis Challenges will advance Computational & Networking Technology

- Bring the physics “home” to the U.S.
- Direct application to other areas of science

## LHC Detector & Machine Upgrade R&D will drive US HEP & Accelerator Technology

- Preparations start soon

## Demonstrates a Successful International Partnership

- Important precedent for other science projects