The Fermilab Program

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URA visiting committee

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Principal Problems of Particle Physics

A. Unification of forces
B. Electroweak symmetry breaking
C. Three generations
D. Particles and the cosmos

The Great Questions

A. Unification of forces

Why is gravity so weak?

How do we integrate gravity with quantum mechanics?

The key to this is probably new physics at the TeV scale.

B. Electroweak Symmetry Breaking

What causes the Higgs field?

Why is there only one scalar particle?

Is it an elementary particle or a composite?

Are there multiple scalar bosons, as in supersymmetry?

The Great Questions

C. Three generations

Why do the neutrinos have such small masses?

Why are there 3 generations?

What physics determines the masses?

Is the CKM matrix the only source of CP violation?

What is the origin of the matter-antimatter asymmetry in the universe?

D. Particles and the Cosmos

What is Dark Matter?

What is Dark Energy?

The Fermilab program

A. The Unification of Forces

B. Electroweak Symmetry Breaking
- **Run II of the Tevatron: CDF and D0**
- US-LHC and US-CMS
- Linear collider R&D

C. Three Generations of Quarks and Leptons

Neutrino and Lepton Flavor Physics
- The US accelerator-based neutrino program: MiniBooNE and NuMI/MINOS

Quark Flavor Physics and CP violation
- Quark flavor physics experiments to operate in 2009: BTeV

D. Particles and the Cosmos
- Sloan Digital Sky Survey
- The Auger Cosmic Ray Observatory
- The Cryogenic Dark Matter Search

The Great Questions

A. Unification of forces

Why is gravity so weak?

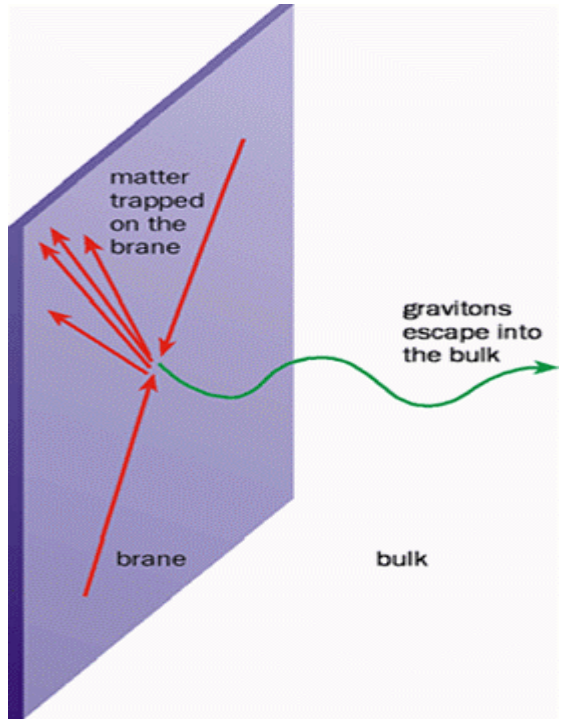
Why is $F_{grav} \approx 10^{-42} \times F_{elec}$?

Why is $M_W << M_{Pl}$?

Why is $M_H << M_{Pl}$?

Ed Witten at Lepton-Photon 2004:

"We want from accelerators not just a Higgs boson, but a mechanism that will 'stabilize' the scale of electroweak symmetry breaking and explain why the Higgs boson, and the rest of the particles, are not much heavier."



Three of the possible answers

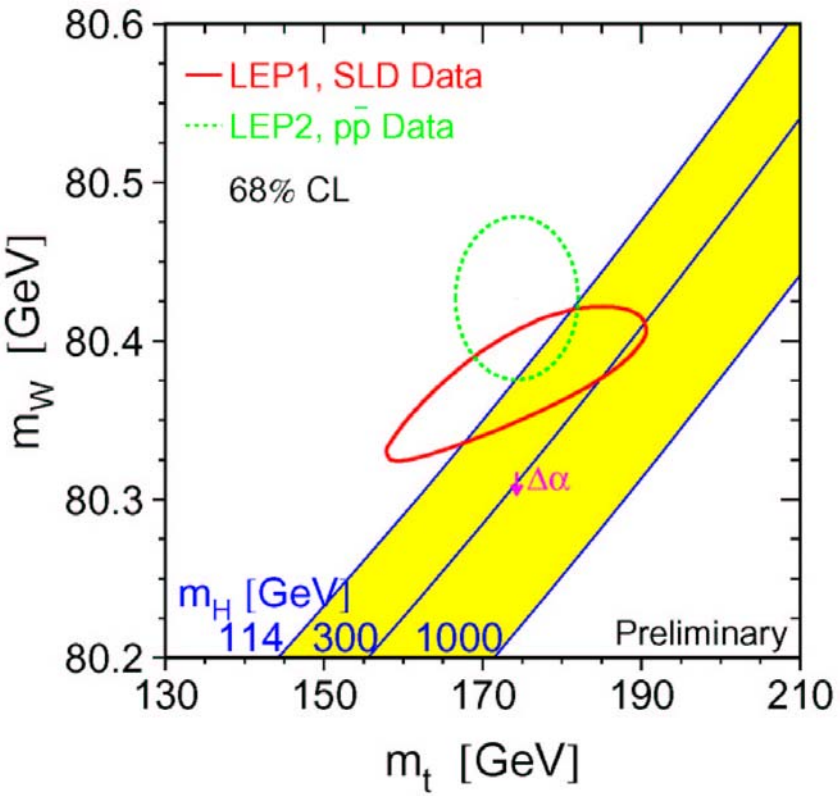
- Hidden Extra Dimensions
  - They can be used to disperse the intrinsic strength of gravity, gravity, making it seem weak to us.
  - Ultimate scale of physics: quantum gravity
- Supersymmetry
  - It stabilizes the Higgs mass.
  - It is necessary in string theory.
  - It leads to unification of gauge forces.
- Variation of technicolor
  - Higgs boson may be fermion-pair composite, analogous to Cooper pairs
- Something we have not thought of yet

The Great Questions

B. Electroweak Symmetry Breaking

- What causes the Higgs field?

- Improved top and W mass measurements soon
- Search for Higgs later

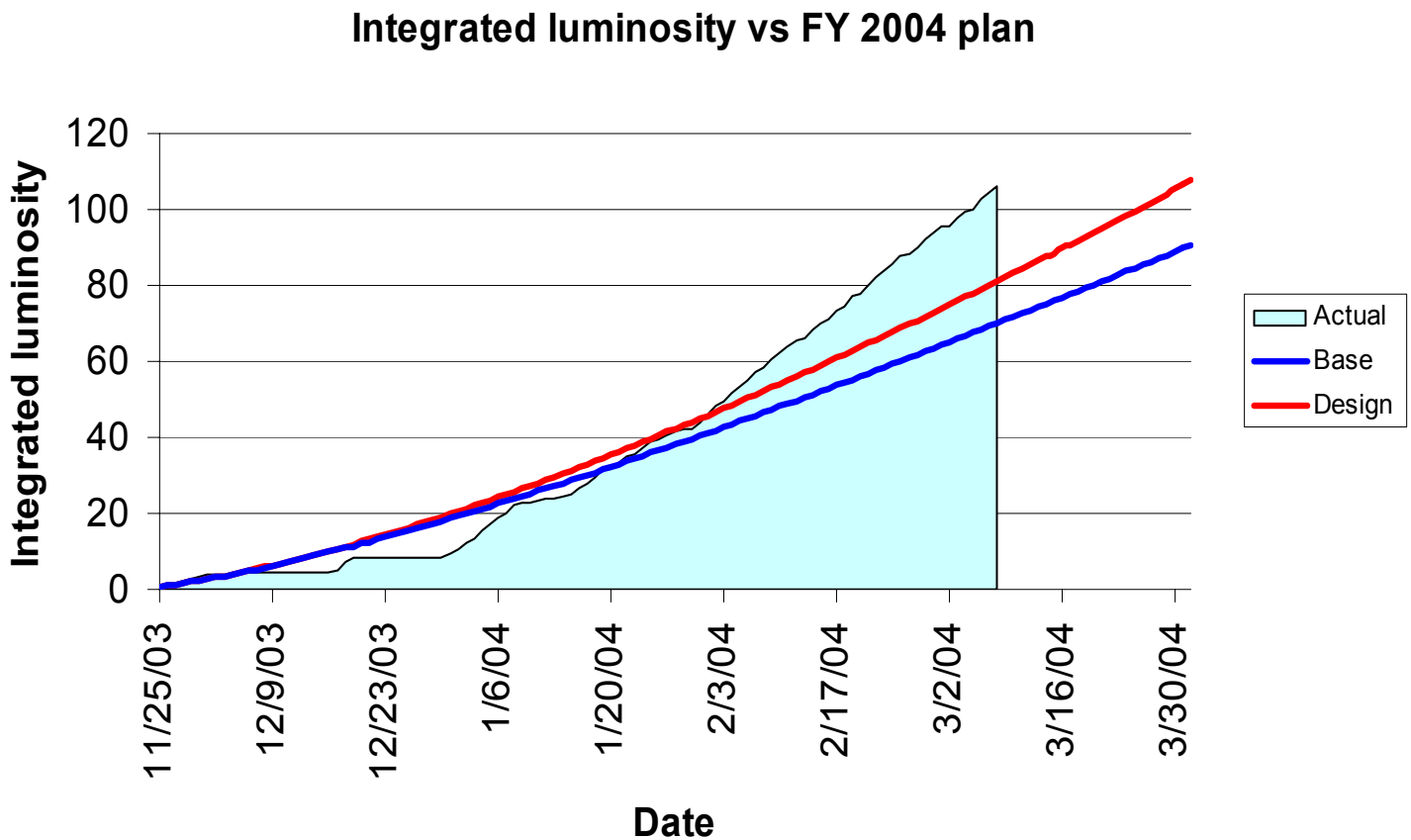


Run II

These questions must be addressed with colliders operating at the energy frontier. For now, that means the Tevatron.

- P5: "The Tevatron is the world's highest energy accelerator and, until the LHC produces physics, it will have an unparalleled opportunity to address the major questions in elementary particle physics. The Run II program attacks the most fundamental questions facing particle physics."

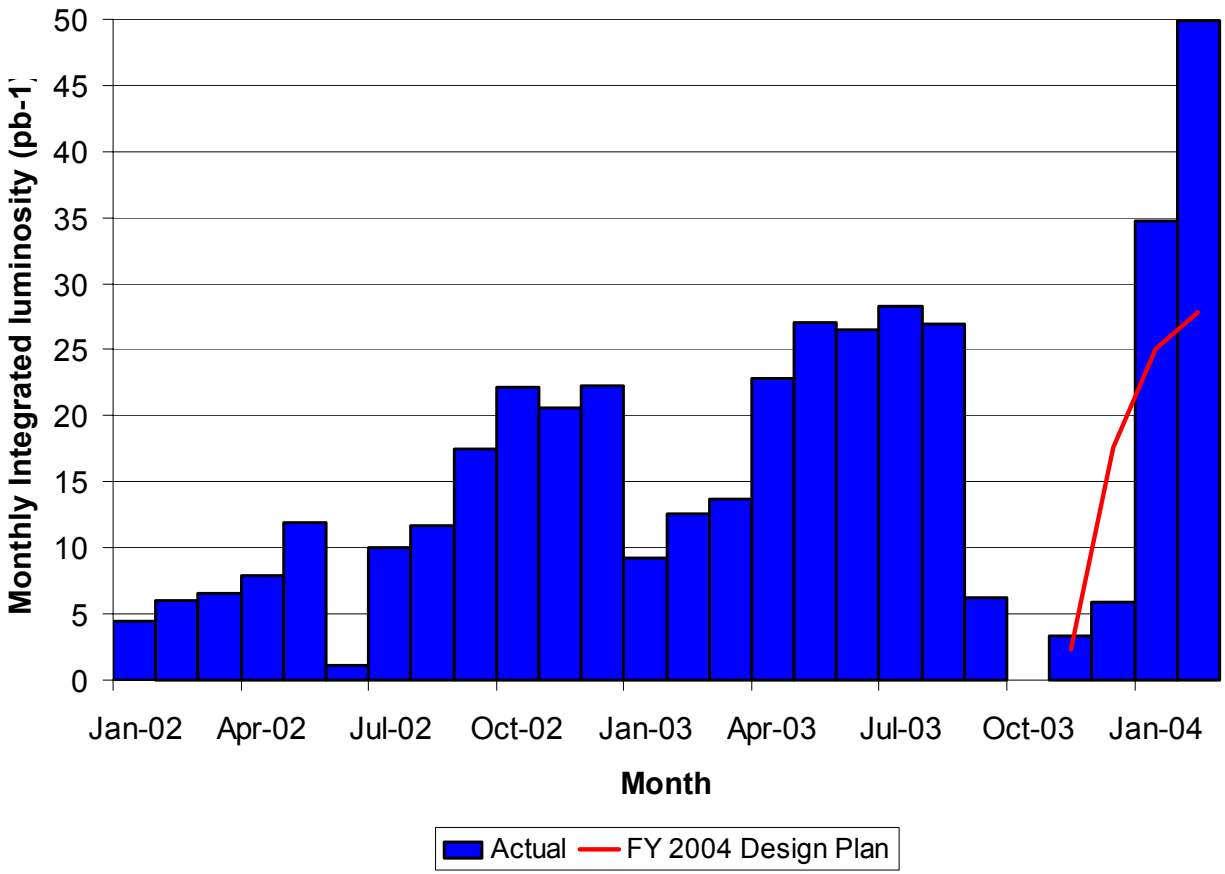
Tevatron Operations: FY 2004 Plan and Status



Physics total ~0.25 pb^{-1} on 10/03; plan ~0.55 pb^{-1} by 9/04

- As of 3/6/04, we are about 3 weeks ahead of design plan, with 2 week repair and maintenance shutdown to come

Progress of Run II



The last seven months

At the 7/21/03 accelerator review I said:

- "We will focus on
  - understanding and fixing limits to present luminosity, including several connected with the Tevatron,
  - reliability and maintenance issues,
  - Recycler commissioning, and
  - the upgrade program."

We have, and it has paid off.

DOE review closeout, 2/26/2004

Review Summary:

Great progress has been made since last review in July 2003.

Successful shutdown – accomplished goals

The Tevatron complex has never performed better.

At last review we said –

"Success requires the new management team to effectively lead and integrate the many technically complex activities that make up Run II. The next 6 months will be critical."

The successes of the past 7 months are indicative of the very hard work of high quality staff working on Run II and the capabilities of the management team to lead and organize the Division's efforts.

The Laboratory as a whole appears to be focusing on run II and providing support at the level needed for success. This is important.

DOE review closeout (cont.)

So what's the bottom line?

We're very impressed with the progress in the past seven months.

We have increasing confidence that Run II will be successful.

We look forward to continued progress toward the Tevatron complex being reliable and well characterized to serve as a platform for the cutting-edge upgrades.

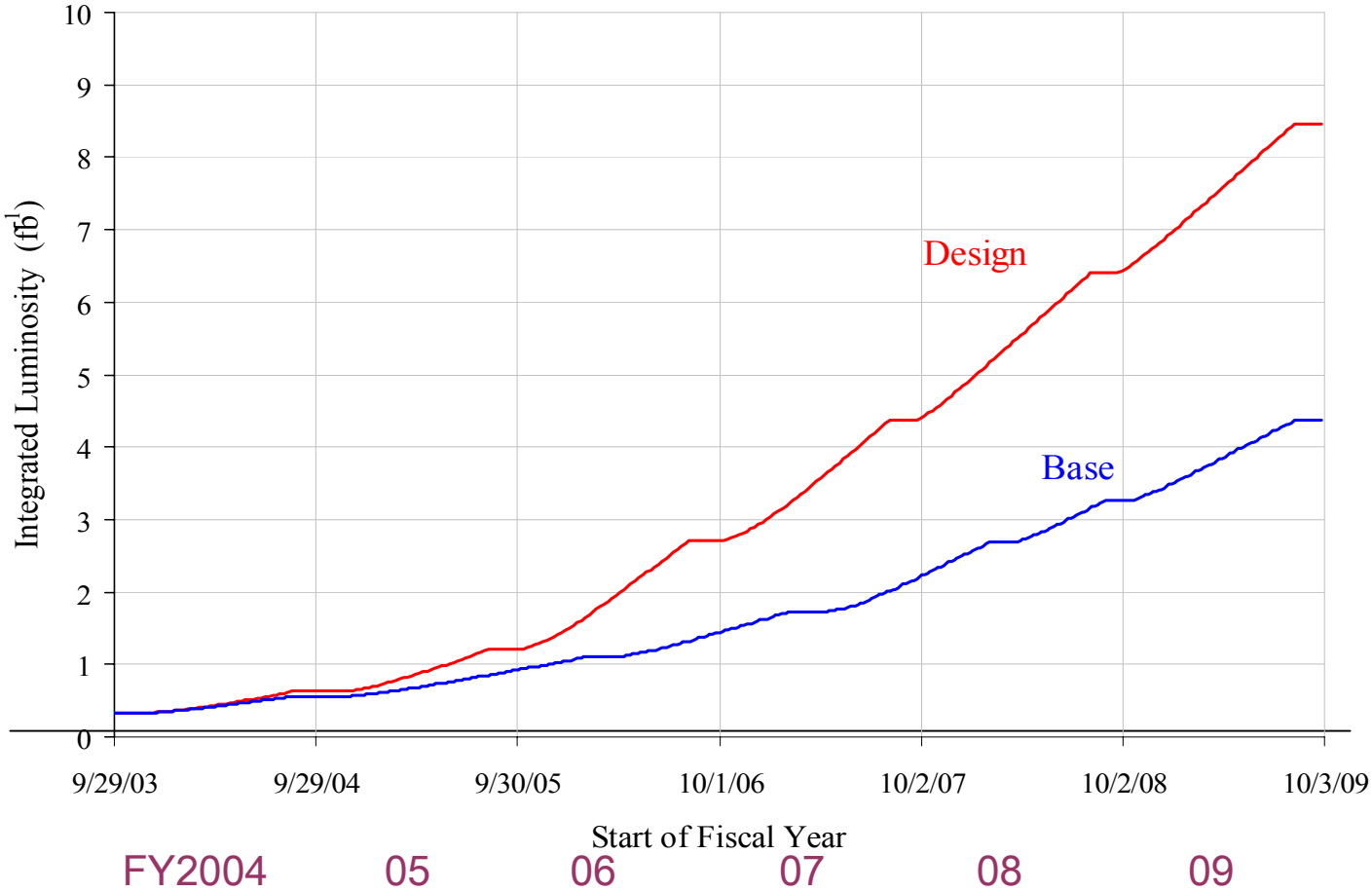
But there's a long way to go in the complex campaign of operations, maintenance, upgrades, R&D, and studies that must succeed if the luminosity goals are to be reached.

We see a significant challenge in the installation and successful commissioning of electron cooling in the next 16 months.

Keep up the discipline, focus, dedication and good work. We are very encouraged!!!

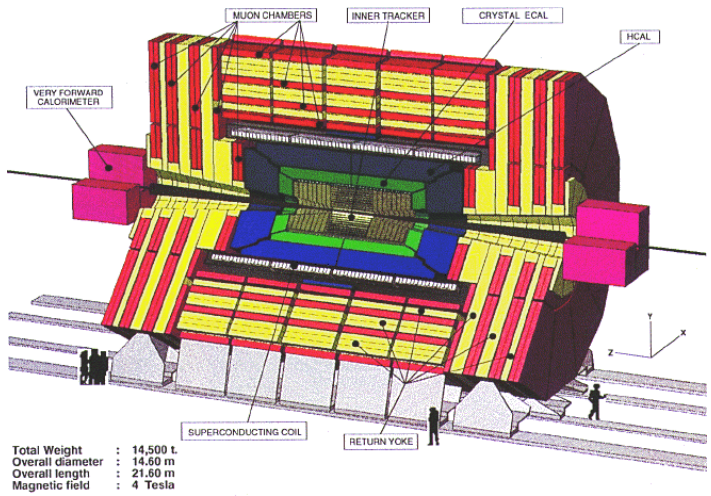
Projected Integrated Luminosity

Integrated luminosity will about double every year for next 4 years



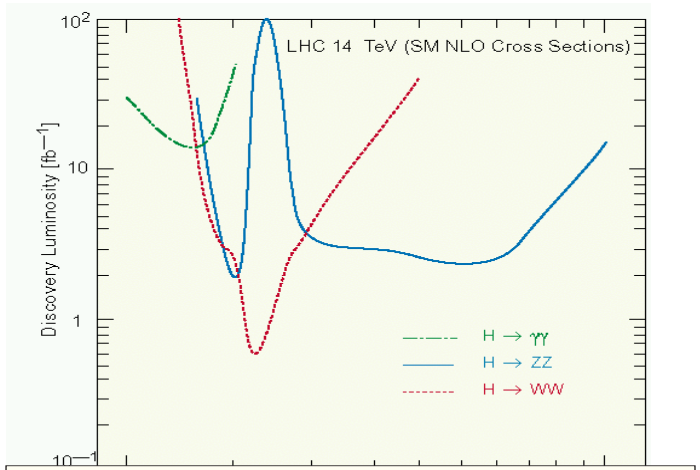
US-LHC and US-CMS

- A revolutionary jump in particle physics will come with the LHC.
- We are hosting the US-LHC accelerator project and LARP.
  - Great progress in the last year
  - LARP established
- We are hosting the US-CMS detector project and the the research program.
  - Project proceeding on the plan
  - Transition to research program

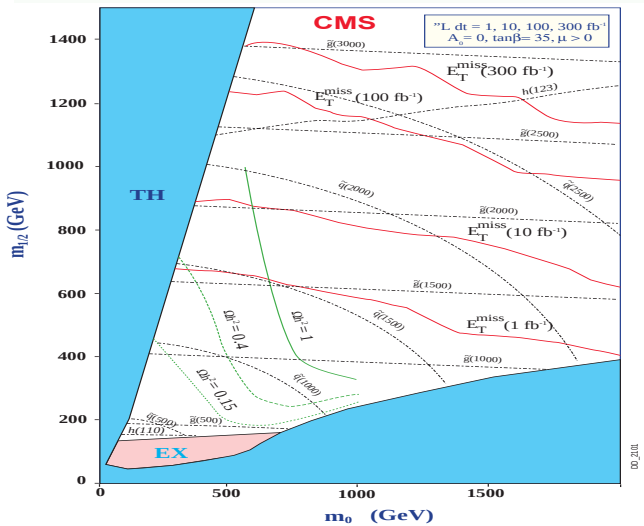


US-CMS physics

- The LHC will make possible the discovery of all the new physics at the TeV scale.
  - Higgs or replacement
  - Supersymmetry
  - Extra dimensions and other exotics
- The US-CMS physicists should be ready to take advantage of this opportunity.
  - CMS software and computing project
  - Physics Analysis Center
  - growth of Fermilab CMS physics analysis effort



The CMS $\tilde{q},\tilde{g}$ mass reach in E_T^{miss} + jets inclusive channel for various integrated luminosities



The Great Questions

C. Three generations

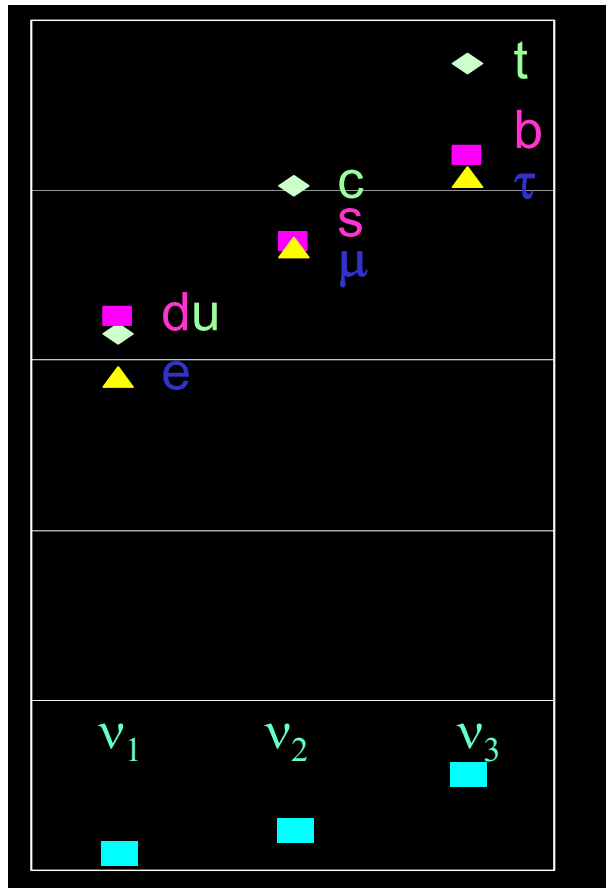
Why do the neutrinos have such small masses?

Why are there 3 generations?

What physics determines the masses?

What are the origins of CP violation?

What is the origin of the matter-antimatter asymmetry in the universe?

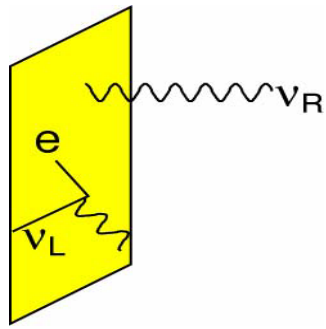


Masses of the quarks and leptons

Why is neutrino mass of special importance?

No right-handed neutrino $\Rightarrow$ Neutrino massless in SM

1. Could be ν_R is very weakly coupled, e.g. because of extra dimensions.
2. Neutrinos might get their mass from super-heavy neutrinos with masses near 10^{15} GeV.



LH massless ν + RH super-heavy ν

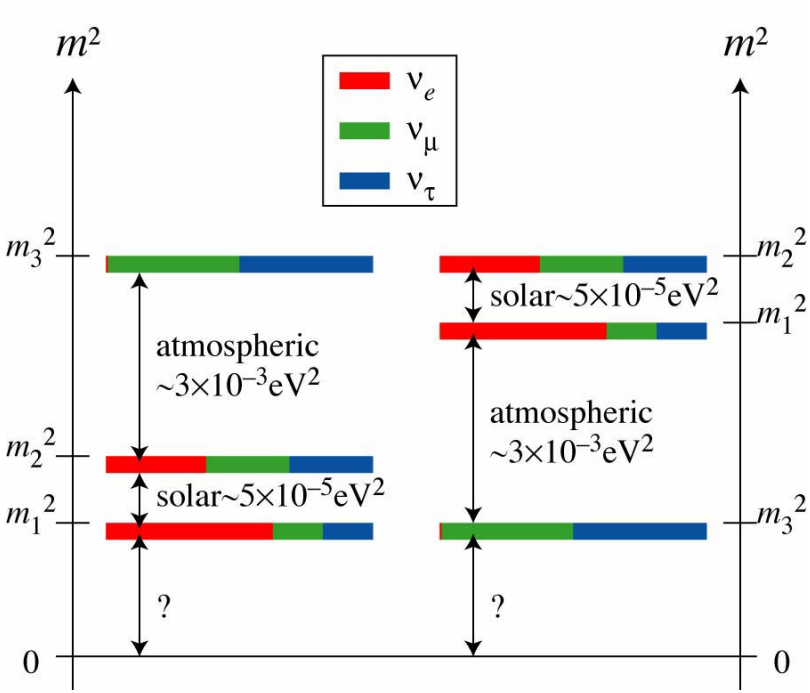
$\Rightarrow$ LH ν gains a tiny mass: $m_\nu \approx m_L^2/M$

If $m_L \sim m_{top}$, $M \sim 10^{15}$ GeV (GUT), then $m_\nu \sim 10^{-(1-2)}$ eV

Decays of these heavy neutrinos in the early universe could have led to the small baryon excess today.

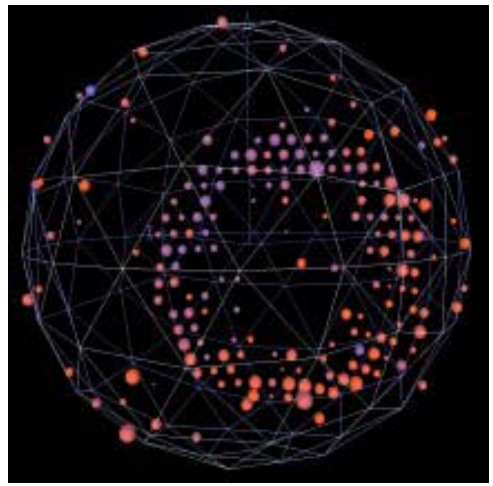
The Neutrino Program

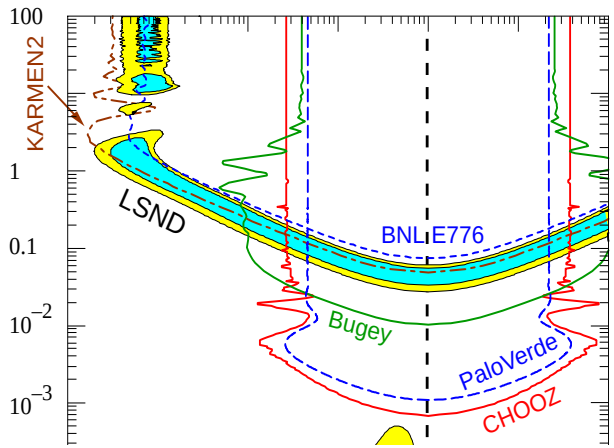
- Neutrinos have produced the surprising results at every step.
- The two observed mixing angles are very large.
  - If the third angle is not too small, it opens the chance to study a new source of CP violation in the neutrino sector.
- Fermilab is home of the US accelerator-based neutrino program:
  - MiniBooNE
  - NuMI/MINOS



MiniBooNE

- The LSND result requires either violation of CPT or a fourth neutrino, which would be sterile.
- MiniBooNE is designed to follow up on the LSND evidence.
  - If MiniBooNE confirms LSND, it will change the worldwide neutrino program overnight.
- The experiment is running well.
- Work on the Booster is designed to reduce beam losses, which would allow greater intensity on the MiniBooNE target.





MINOS

For atmospheric oscillation

- Demonstrate oscillations
- Measure parameters
  - Δm^2 to ~10%
  - $\text{Sin}^2 2\theta_{23}$ to ~5%
- Improved sensitivity to transition of ν_μ to flavors other than ν_τ
  - improved sensitivity to θ_{13}

NuMI/Minos Project Status

- The NuMI project is on track for delivering protons to MINOS by ~1/1/2005.
  - Surface Buildings and Outfitting construction is just complete.
  - Beamline installation started in fall 2003 shutdown
  - MINOS far detector installed and operating with cosmic rays

Quark Flavor Physics in 2009

Y. Grossman at Lepton Photon 2003:

- The Standard Model flavor structure is special
  - Universality of the charged current interaction
  - Flavor Changing Neutral Currents are highly suppressed
- Any New Physics model must reproduce these successful SM features.

Many proposed models of new physics lead to observable anomalies in the mixing and decays of K, B_d, and B_s mesons.

BTeV

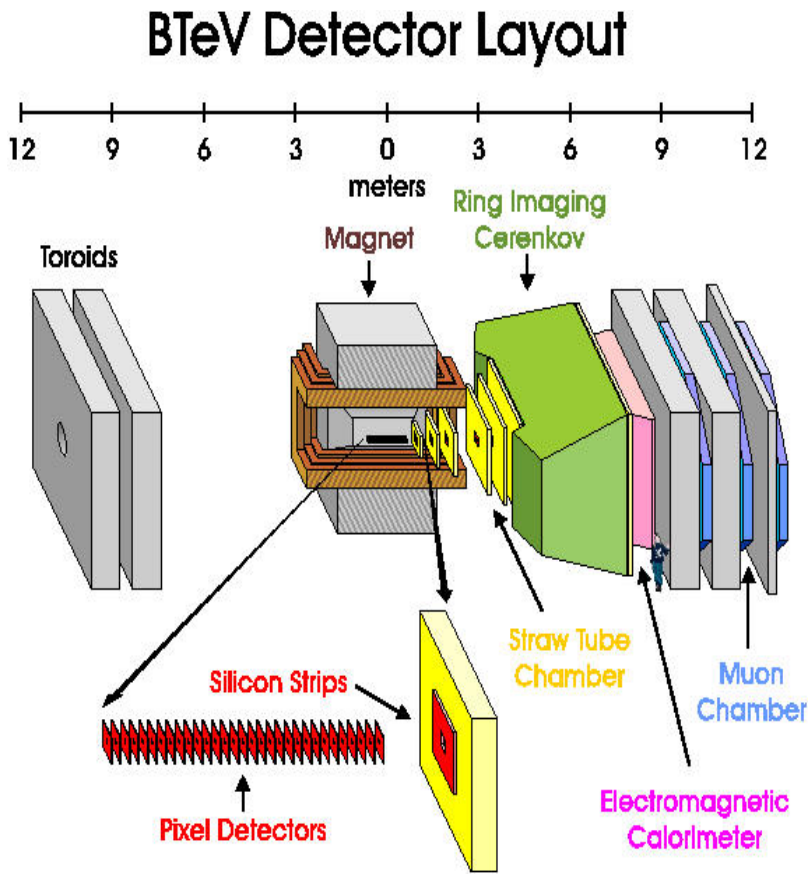
- BTeV will have a very broad particle physics program, including charm physics, but the primary motivation is the search for new physics through CP violation in the B_d and B_s systems.

- BTeV represents a breakthrough in designing collider experiments.

BTeV

P5:

- "The strength of the BTeV experiment comes from the combination of its vertex trigger with precision mass measurements for both charged and neutral decay modes and excellent particle identification capabilities."
- "P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area."
- Fermilab is developing the BTeV project with custom IR optics to optimize the luminosity.



FY 2005 DOE Congressional Budget

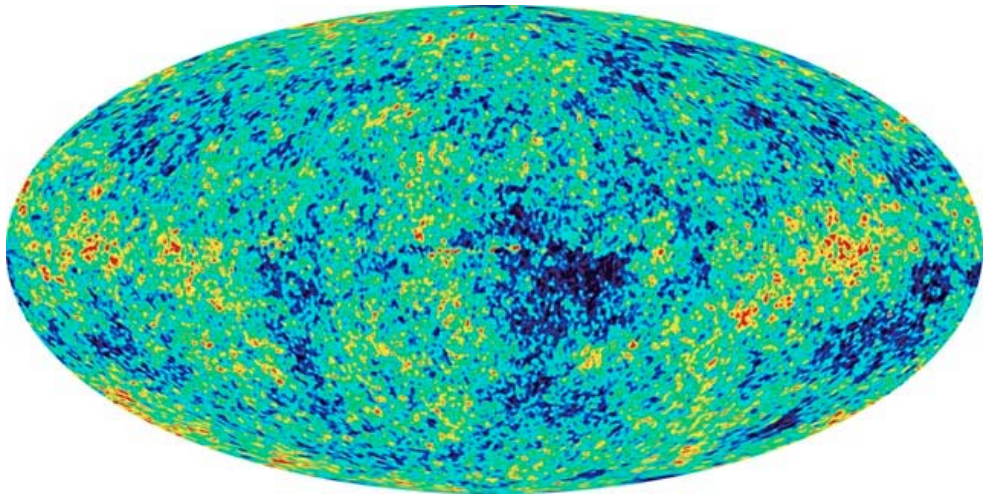
- In FY 2005 we will begin engineering design of a Major Item of Equipment, the BTeV experiment at Fermilab, subject to successful independent cost and technical reviews of the project to take place in 2004.

- This experiment will study CP violation and search for new phenomena in the B meson system with much higher statistics than is possible at the B-factories, including studies of B meson species which are inaccessible to the B-factories.

- The importance of the physics addressed by BTeV has been endorsed by HEPAP and recognized in the Office of Science's Report, "*Facilities for the Future: A Twenty Year Outlook*."

- HEPAP endorsed the P5 report that supported the fabrication of BTeV as the highest priority new project at Fermilab after completion of the Run II upgrades, subject to constraints within the HEP budget.

The Great Questions



D. Particles and the Cosmos

What is Dark Matter?

What is Dark Energy?

Dark Matter

We observe Dark Matter through its gravitational effects.

But its properties do not fit any of the standard particles.

To understand dark matter we need to study dark matter particles in controlled experiments.

Fermilab is attacking the problem of dark matter on all three fronts:

- Detecting the halo
  - Cryogenic Dark Matter Search
- Producing them in collisions
  - CDF and D0
- Observing the gravitational effects
  - Sloan Digital Sky Survey

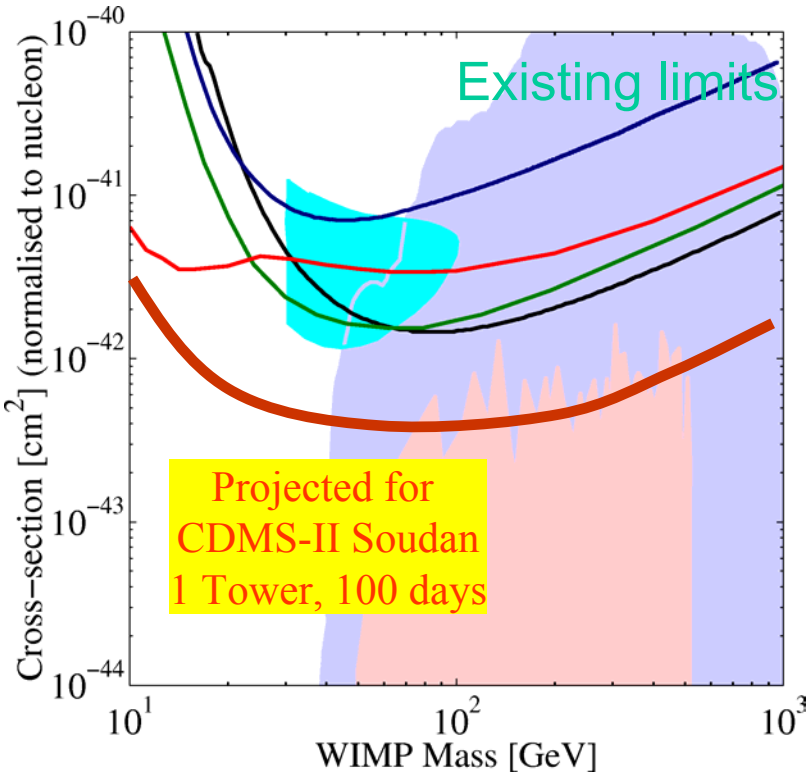
Observing the dark matter halo

Cryogenic Dark Matter Search detectors operate at T=20 mK.

- They measure ionization energy and recoil energy separately to reduce dominant radioactive backgrounds.

CDMS II is starting to operate at Soudan mine this month.

- reduced neutron background from ~1/kg/day to ~4/kg/year
- first physics run with 1 tower complete, results this spring



Experimental Astrophysics

- The experimental particle astrophysics effort
  - Auger cosmic ray observatory taking data
  - Cryogenic Dark Matter Search taking data
  - SloanDSS producing discoveries steadily
- We are planning how this area will evolve.
  - Auger, CDMS are starting to operate while construction continues and planning next steps.
  - A Fermilab group has joined the collaboration to develop a Joint Dark Energy Mission.
  - Smaller project to build camera for CTIO is being considered.

The FNAL Long Range Planning Committee

- From charge:
  - "I would like the Long-range Planning Committee to develop in detail a few realistically achievable options for the Fermilab program in the next decade under each possible outcome for the linear collider.
  - The goal in developing each option should be to optimize the opportunities available at Fermilab in this period for high energy physicists to answer the most important questions in our field.
  - The options should be guided by the priorities for the field as laid out in the HEPAP Subpanel and in the HEPAP response to the Office of Science on the facilities plan."

- This committee is completing its work. You will hear the almost-final status at this review.

R&D on Future Accelerators

- We are doing accelerator R&D aligned with the future facilities called out in the Fermilab Long-range plan and the SC facilities plan.
  - LHC luminosity upgrade
  - Linear collider
  - Proton driver
- We do a small amount of R&D toward the longer-term future.
  - High-field superconducting dipoles
  - Advanced accelerator R&D
- Other programs doing very good work have been curtailed.
  - Low-field superconducting magnets
  - Muon facilities
- R&D groups have made surprisingly good progress with very little budget.
- We are also working with university programs to provide opportunities for training students.

Project management

- We are well along on three construction projects in the $100-200 M range.
  - NuMI
  - US-LHC and US-CMS
- All of these are technically very difficult projects.
- The next project of this scale is BTeV.
- We have done well at managing those projects over the last two years, and the Lehman reviews have been very positive.
  - The Project Management Oversight office is important in this success.
  - We have added rigorous director's reviews, to make sure that we recognize problems early and move to correct them.
  - You should refer to the material and reports from recent DOE project reviews, which we have provided.

Theoretical Particle Physics

- The Fermilab particle theory group is doing excellent theoretical research related to all of the principal areas of experimental particle physics.
  - They do very well at training theoretical particle physicists working on problems relevant to the experimental program.
- The group has an important role in planning the U.S. program in particle physics.
  - Fermilab PAC and LRPC, SLAC EPAC, DPF Neutrino Study Co-chair, MUTAC, KITP advisory board chair
- The strong lattice QCD group has teamed with university groups in proposing to DOE a coordinated lattice QCD strategy for the U.S.

Theoretical Astrophysics

- The Fermilab theoretical astrophysics group has been a leader in research at the overlap of particle physics, cosmology, and astrophysics.
  - NASA renewed the grant that partially funds this group.
  - Members of the group directly participate in the SDSS science, as they will on JDEM.
- The group has an important role in planning the U.S. program in astroparticle physics.
  - Fermilab LRPC, Space Science Advisory Committee, SLAC EPAC,

Computing at Fermilab

- Fermilab is a leader in the development of the large-scale computing facilities needed for particle physics.
  - Run II computing project was a success.
  - We are planning the computing evolution for the rest of Run II.
- Fermilab is also leading the US-CMS computing and software effort.
- Other special projects
  - SciDAC
  - Grid projects

The last year at Fermilab

- Run II
  - Reorganized Accelerator Division for Run II.
  - Increased integrated luminosity per week by ~2x.
  - Delivered Run II total of 360 pb^{-1} total vs 120 pb^{-1} by 3/2003.
  - Brought Recycler up to specs for pbar storage.
  - Removed Silicon detectors from upgrade projects.
  - CDF and D0 started publishing physics results.
- Neutrinos
  - Delivered MiniBooNE total 2.1E20 pot vs 0.4E20 by 3/2003.
  - Started MINOS far detector operation on cosmic rays
  - Completed NuMI construction contracts.
  - Installed beam line components during fall shutdown.

The last year

- External 120 GeV beams
  - Installed MIPP experiment and started operation.
  - Started operation of MI test beam.
- Future experiments
  - BTeV endorsed by P5, Office of Science, given CD-0
  - BTeV language and funding in FY 2005 budget.
  - CKM not endorsed by P5.
- Experimental astrophysics
  - Completed initial CDMS-II and started operation in Soudan.
  - Building full Auger while taking data with largest operating array.
  - Completing SDSS survey while making regular discoveries.
  - Joined collaboration to propose Joint Dark Energy Mission.

The last year

- Future planning
  - Long range planning committee almost complete
  - US-CMS and US-LHC research programs
  - Linear collider charge
  - Proton driver charge

The FY 2005 Budget

FY	02	03	04	05	02-05
HEP	713	716	732	737	3%
Fermilab base	286	285	285	292	2%

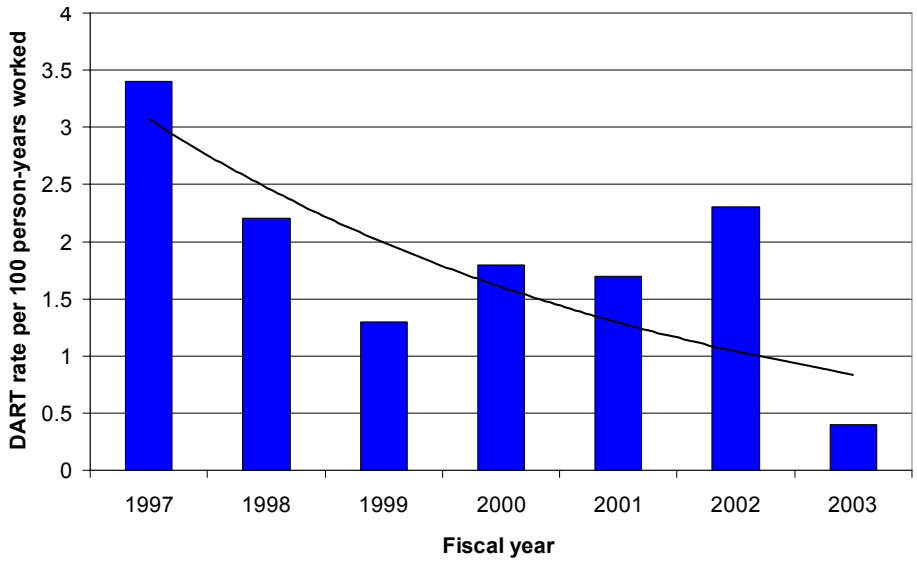
Annual budgets in $ millions

- Fermilab budget has been flat from FY 2002 to FY 2004, corresponding to ~$20 M less real effort.
  - We had a Voluntary Early Retirement Program in FY 2003.
- We have managed to support the full accelerator plan.
  - removing silicon detector upgrades
  - less work on the future, infrastructure than there should be
  - very little effort other than on existing commitments
  - redirecting manpower from inside laboratory
- In the President's budget, it will go up ~2% in FY 2005.
  - Run II accelerator improvements stay large.
  - NuMI project ends.
  - BTeV gets a small start.

Safety

The laboratory management and staff have embraced Integrated Safety Management and have worked hard to bring the accident rates down.

- We have been working recently on the more difficult problem of integrating first-time contractors into the safety culture we maintain.



- We reduced the DART (Days Away, Restricted, and Transferred) rate for FY 2003 to a record low of 0.4 per 100 worker-years.
  - compared to 0.8 for the SC laboratories

Summary

- Run II is proceeding well.
  - The integrated luminosity is ahead of the FY 2004 plan.
  - CDF and D0 are getting out many new physics results.
- The big projects are in good shape.
  - NuMI, US-LHC, US-CMS.
- Neutrino program moves to the next step.
  - MiniBooNE has a large data sample, is collecting more.
  - NuMI will start delivering beam to MINOS at the start of 2005.
- Budgets have hit future experiments and R&D hard.
- BTeV is ready to go.
- The Long Range Plan is emerging.