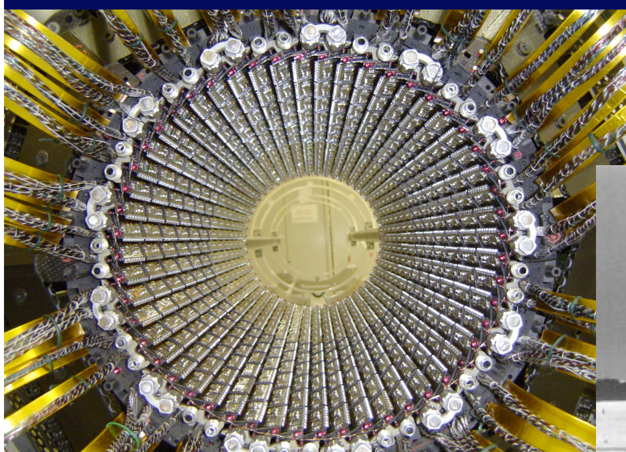
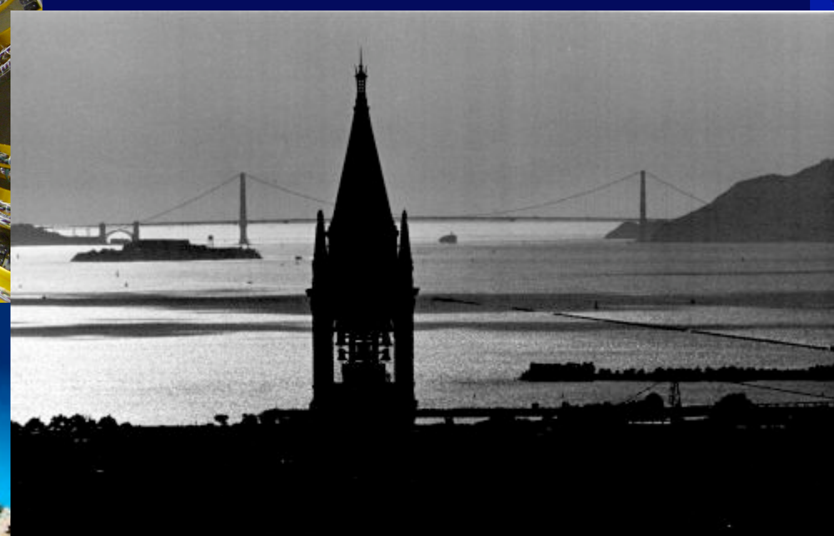
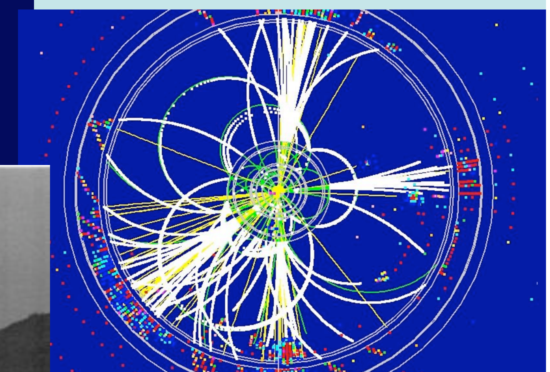
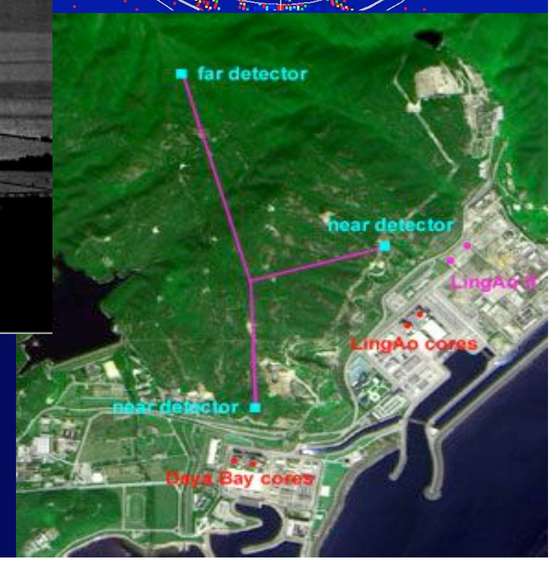
Experimental High Energy Physics

Beate Heinemann



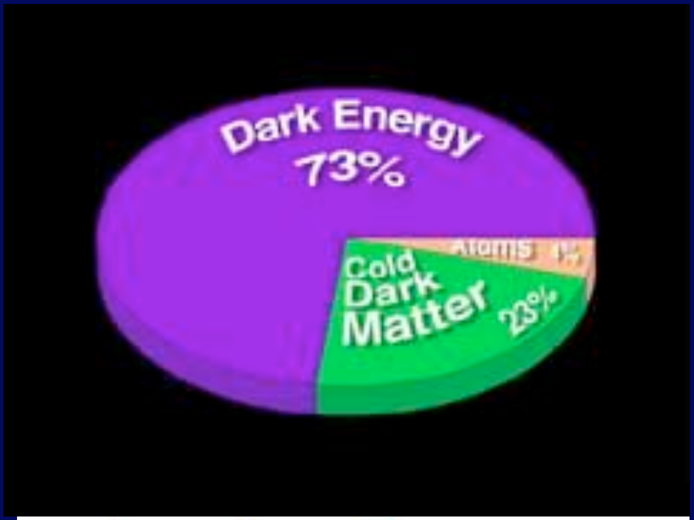


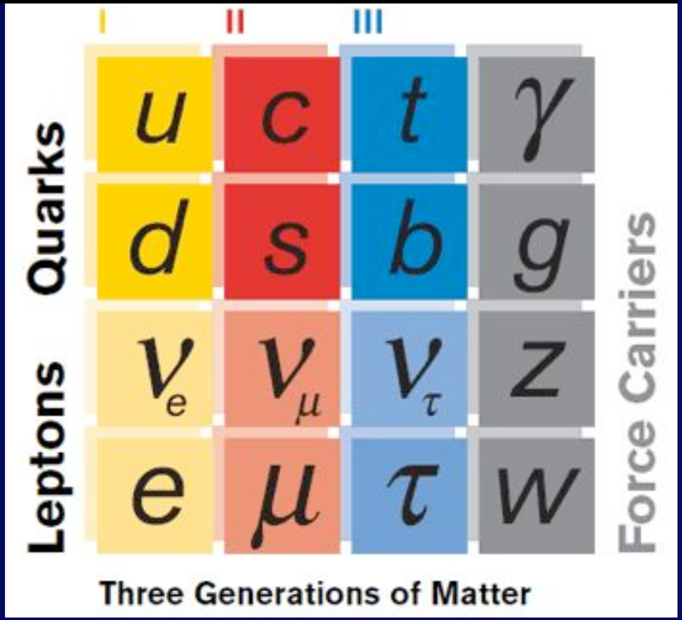




What we know and what we don't know

- 4% of energy in Universe arises from Standard Model particles
  - 3 generations with very different masses
    - why 3, why mass hierarchy?
  - 4 forces mediated by gauge bosons
    - Why do they have so different strengths?
    - Where they the same at the Big Bang?
  - Where did all the antimatter go?
  - Where is the Higgs boson?
- 96% of the energy comes from unknown sources
  - Dark matter
    - Supersymmetric particle?
  - Dark energy
    - ???





Good reasons to believe that some of these questions will be answered at ~1 TeV

Confusion among Theorists?

by Hitoshi Murayama, UC Berkeley

UC Berkeley HEP Exp. Faculty


Marco Battaglia
BaBar, ILC


Stuart Freedman
Neutrino physics


Bob Jacobsen
BaBar, ATLAS

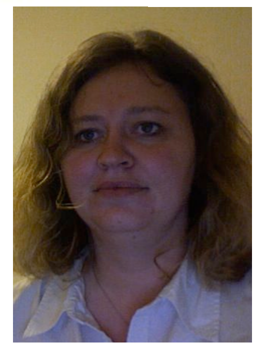

Yury Kolomensky
BaBar, ILC, CUORE


Kam-Biu Luk
Neutrino physics


Marjorie Shapiro
CDF, ATLAS


James Siegrist
CDF, ATLAS


Mark Strovink
SN Factory

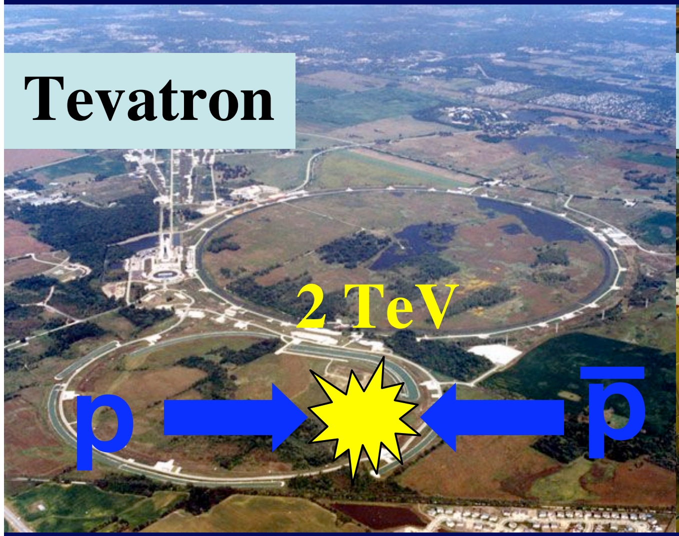

Beate Heinemann
CDF, ATLAS

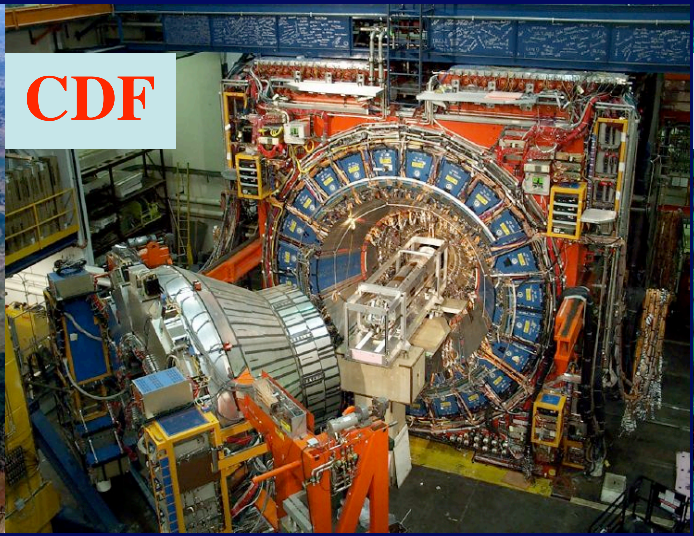
+ close collaboration with Lawrence Berkeley National Laboratory and faculty members from rest of the department

Experimental Programme

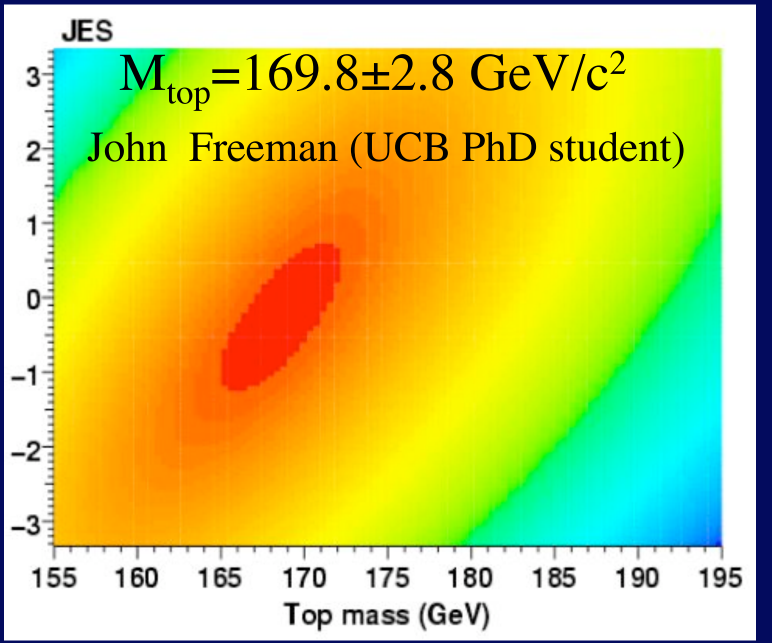
- **CDF/DØ** probe the highest energies and CP violation at the Tevatron (until 2009)
  - Shapiro, Siegrist, Strovink, BH (will not take students any more for CDF or DØ)
- **ATLAS** probes the highest energies at the LHC (starting next year!)
  - Shapiro, Siegrist, BH
- **ILC** probes high energies with high precision (>2020)
  - Battaglia, Siegrist, Kolomensky
- **BaBar** probes CP violation (matter-antimatter asymmetry) at SLAC (until 2008):
  - Battaglia, Kolomensky
- **KamLand** probes neutrino oscillations in Japan (until 2008):
  - Freedman, Luk
- **DayaBay** will probe neutrino oscillations in China (>2009):
  - Luk
- **CUORE/Cuoricino** probe neutrino masses (>now):
  - Freedman, Kolomensky

CDF and DØ

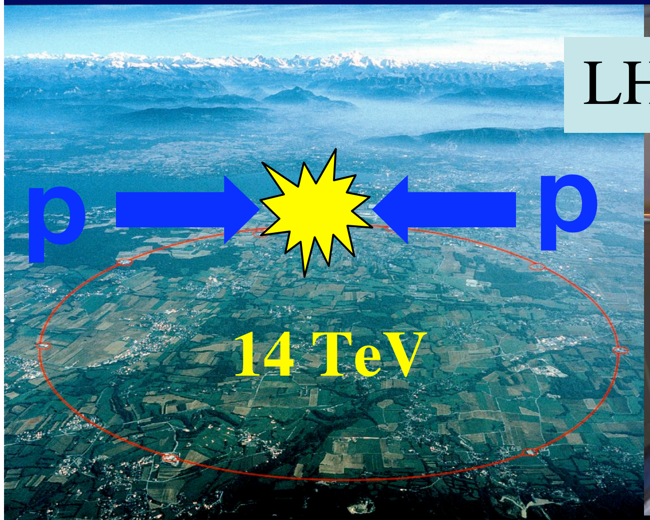


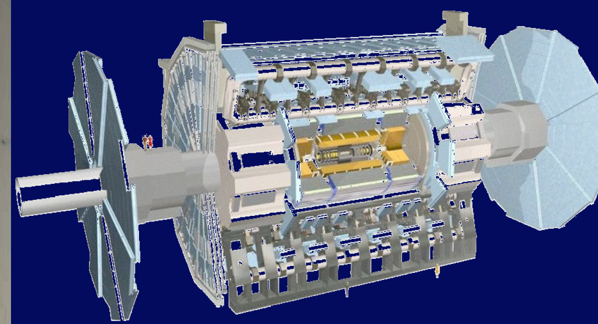


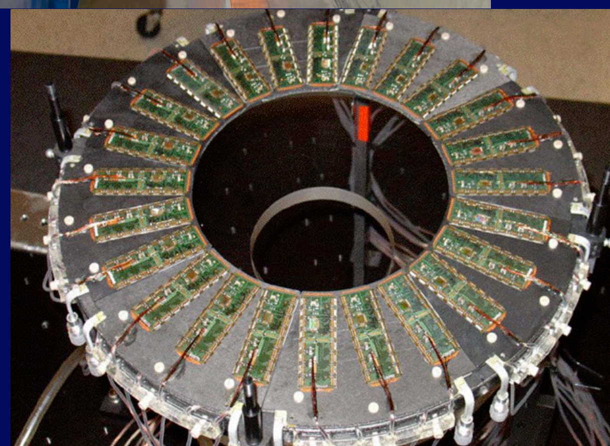
- Collaborations of 700 physicists
  - Major involvement of Berkeley in building, operating the detector and in physics analyses
- Berkeley students made many unique and world's best measurements
  - e.g. mass of the top quark
    - Tells us about the Higgs boson

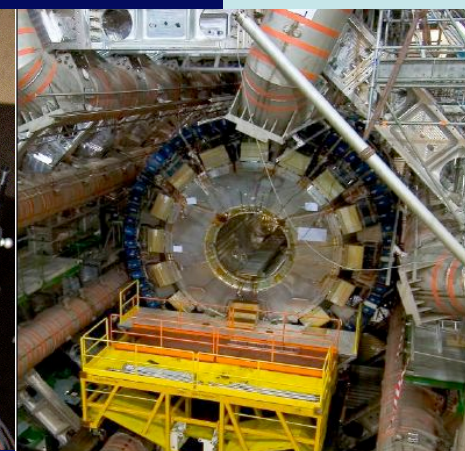


Energy Frontier: Very soon!





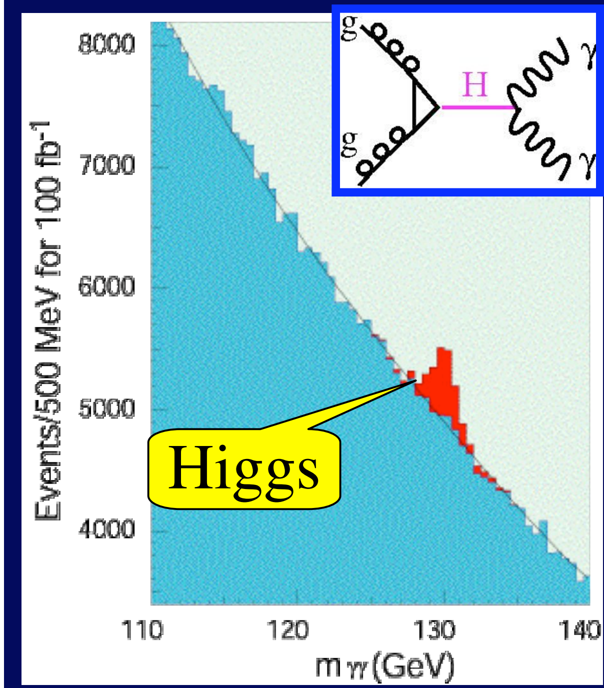


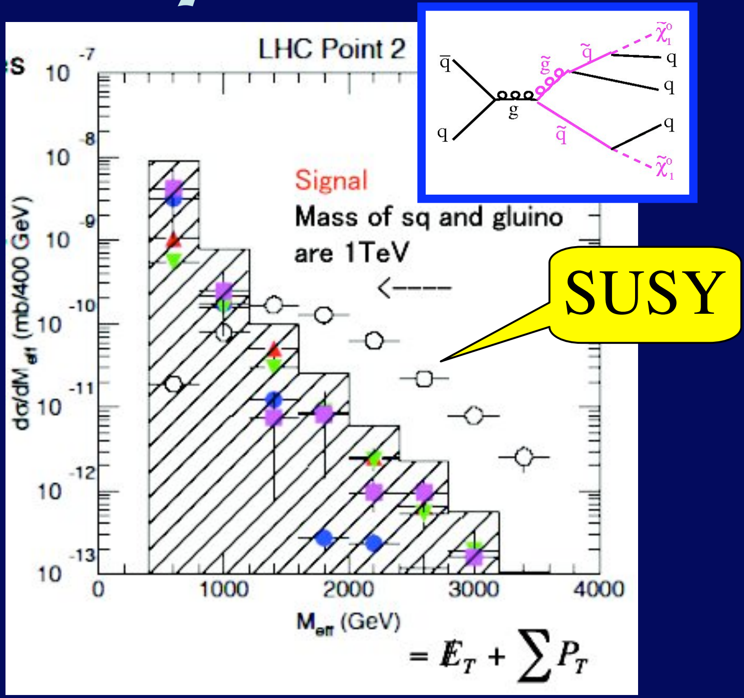


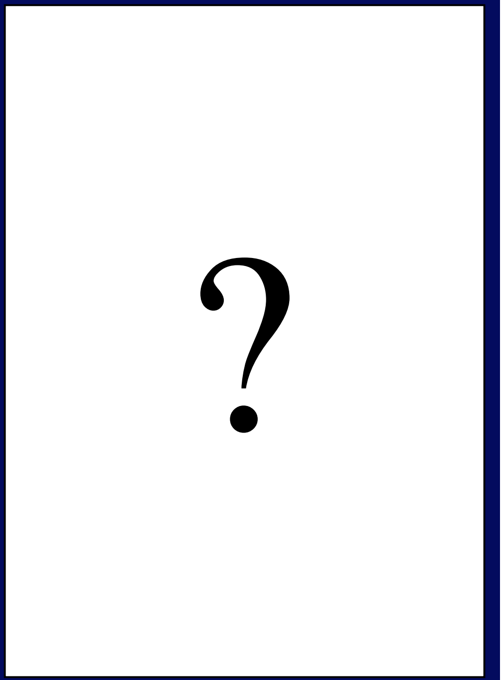
- LHC will start 14 TeV collisions in June 2008
- Berkeley group has diverse talents
  - Design and construction of tracking detectors
  - Software coordinator
  - Physics coordinator
  - Strong theory group
- All needed for success!

The advent of the LHC may revolutionize our understanding of physics

ATLAS: Physics Examples

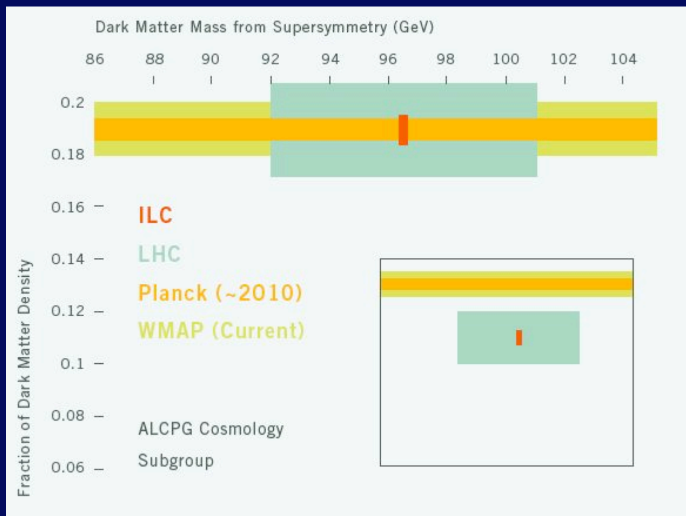


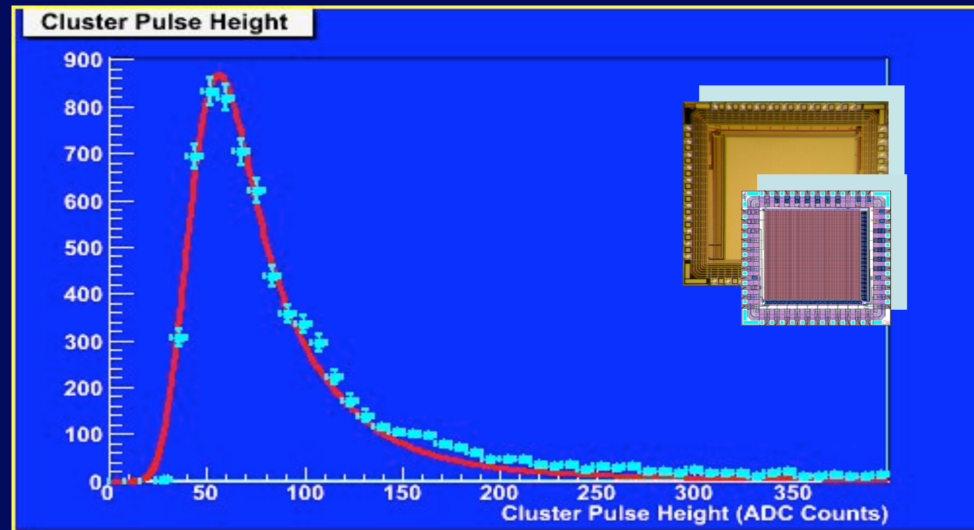




- Discovery of the Higgs boson?
  - Understand electroweak symmetry breaking
- Discovery of Supersymmetry?
  - Understand origin of Cold Dark Matter
- Or the UNEXPECTED ?
  - which would be most fun maybe!

High Energy Frontier: Future

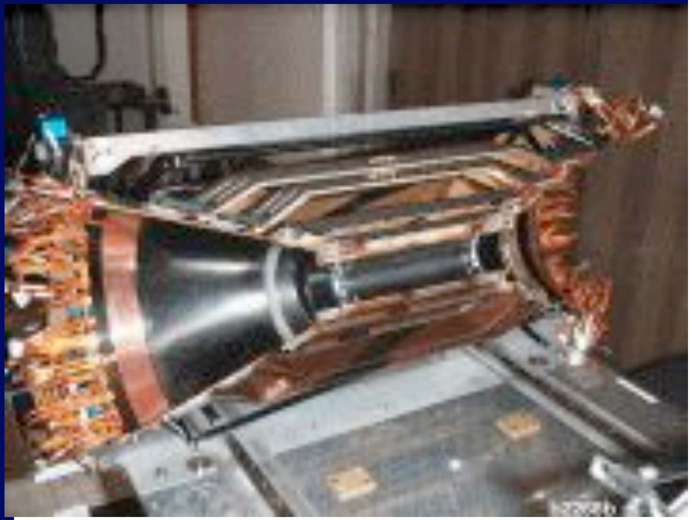


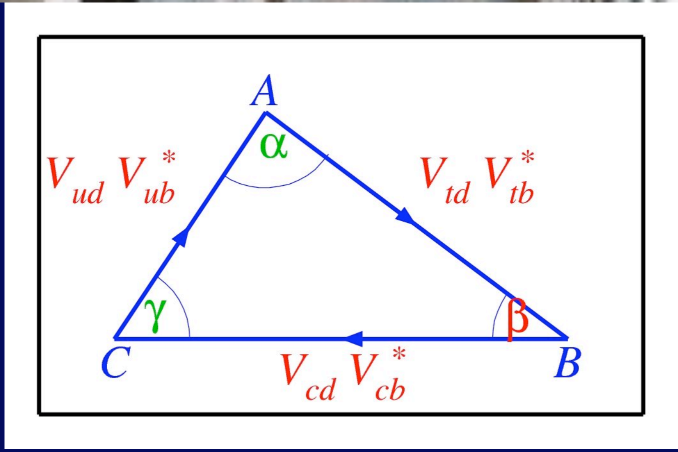


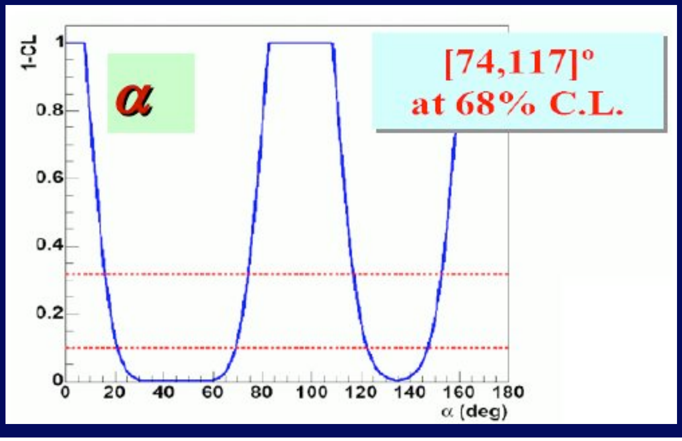
- International Linear Collider: e^+e^- coll. at 0.5-1 TeV (~2020):
  - Vital to really understand high energy physics
  - Berkeley active in R&D for beam instrumentation and tracking detectors & physics feasibility studies
- SuperLHC (start ~2016):
  - Extends the capabilities of LHC (higher collision rate)
  - R&D for tracking detectors ongoing in Berkeley
- Get cutting edge hardware experience in R&D phase
  - Then move on to running experiment for thesis topic

BaBar

- **PEPII collider at SLAC:**
  - e+e- collisions at $\sqrt{s}$=10.6 GeV [Y(4s)]
    - Produce pairs of b-quarks
  - Berkeley heavily involved in design, construction and operation of Silicon Vertex Tracker
- **Physics goals:**
  - Precision measurement of unitarity triangle
    - Understand quark sector of SM
  - Search for new physics contributions indirectly by precision measurements in b-quark sector



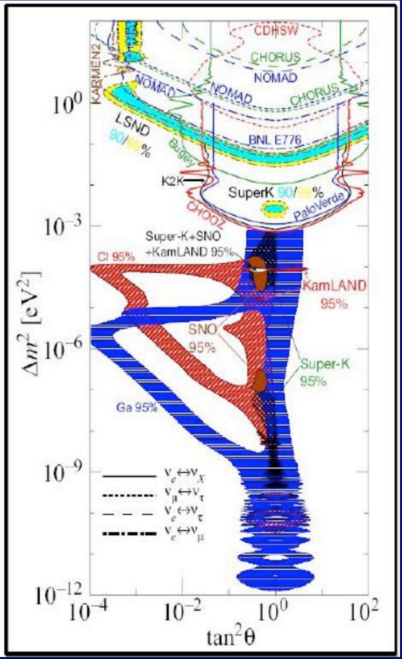


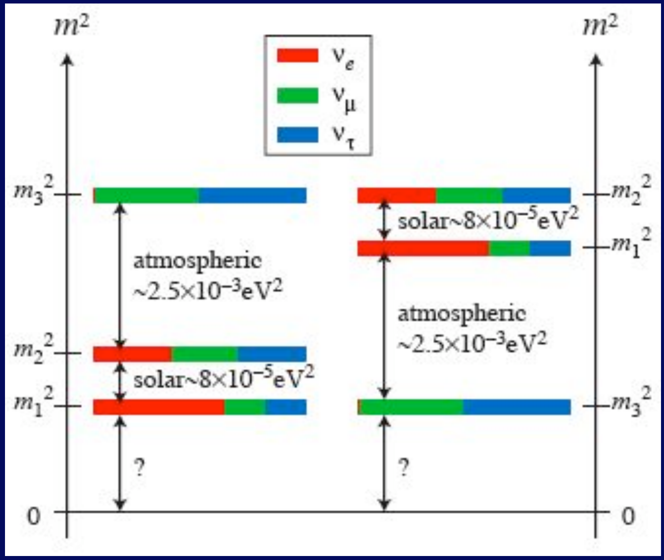


Berkeley student thesis

What are Neutrinos telling us?

- The latest discovery:
  - Neutrinos oscillate => they have mass>0!!
    - Super-Kamiokande 1998
    - KamLAND, K2K, SNO
- That raises more questions than it answers:
  - Are they Dirac or Majorana?
    - Are they their own antiparticle?
  - How do the 1st and 3rd generation mix (θ_{13}) ?
    - The other two angles are well measured
    - Why is the mixing so different to quark sector?
  - What are the mass values?
  - Is there CP violation?
  - Are there three neutrinos, or more?
    - 4th generation??
  - Do they tell us anything about very high energies and unification?

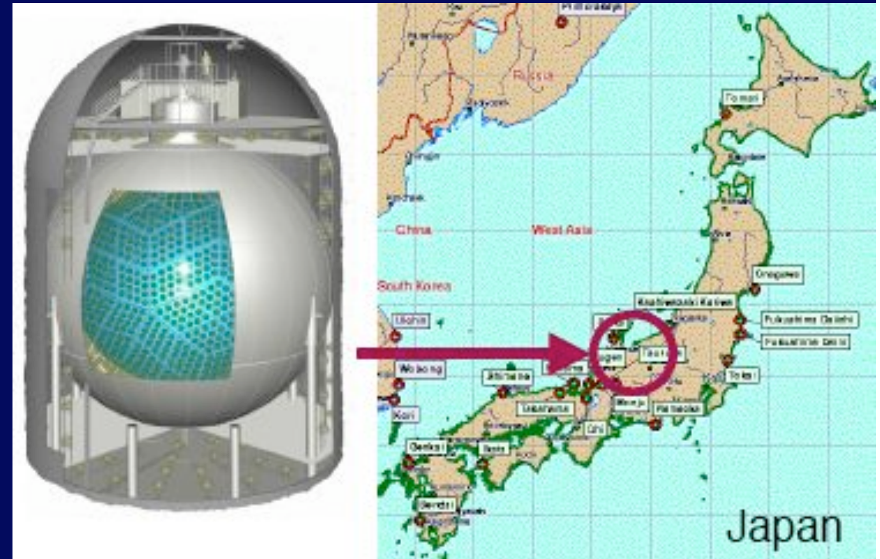


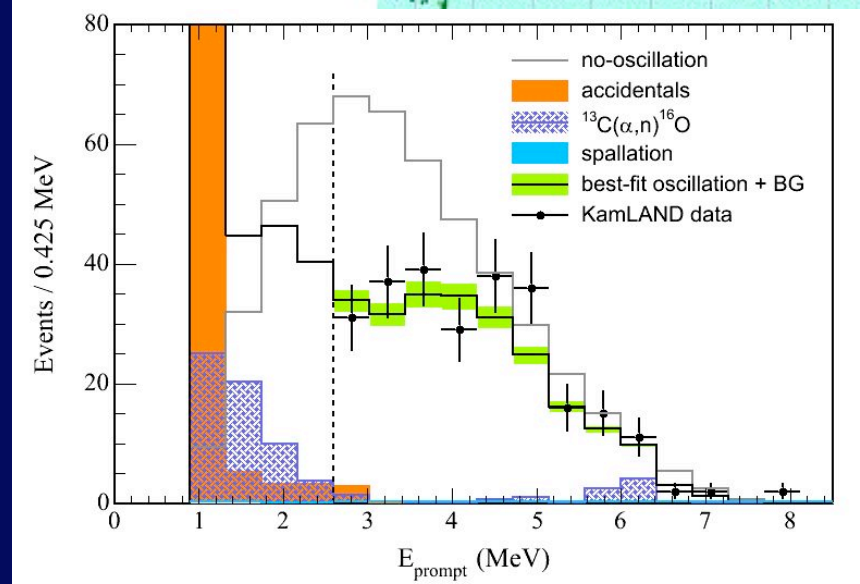


at least one m_ν>55 meV

Neutrinos @ KamLAND

- **Reactor neutrino experiment**
  - Surrounded by many Japanese reactors that produce $\overline{\nu}_e$ Demonstrated oscillations already!
  - Measures rate of $\overline{\nu}_e$ going to something else
    - Sensitive to $\overline{\nu}_e$ oscillations
  - Already showed results:
    - Together with SNO constrains one of the mixing angles
- **Future:**
  - Improved detector by adding muon detectors
    - Significant reduction in background to current analyses
    - improved sensitivity to oscillations
  - Many other analyses ongoing





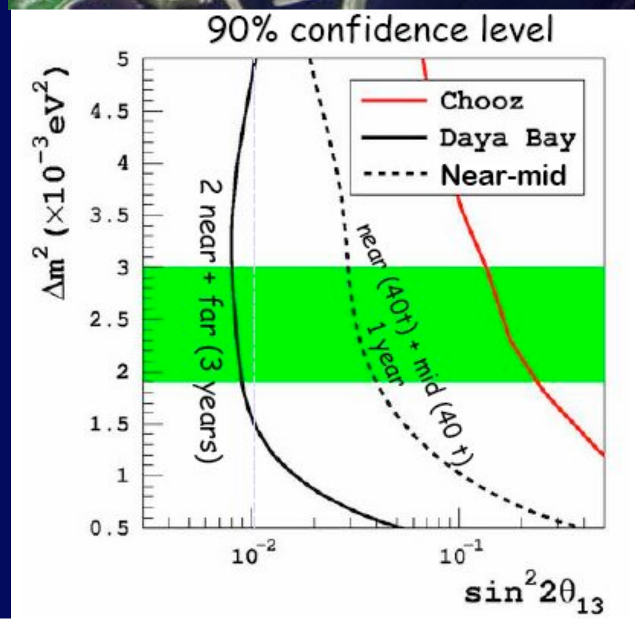
Neutrinos @ Daya Bay

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} 0.8 & 0.5 & U_{e3} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} ?$$

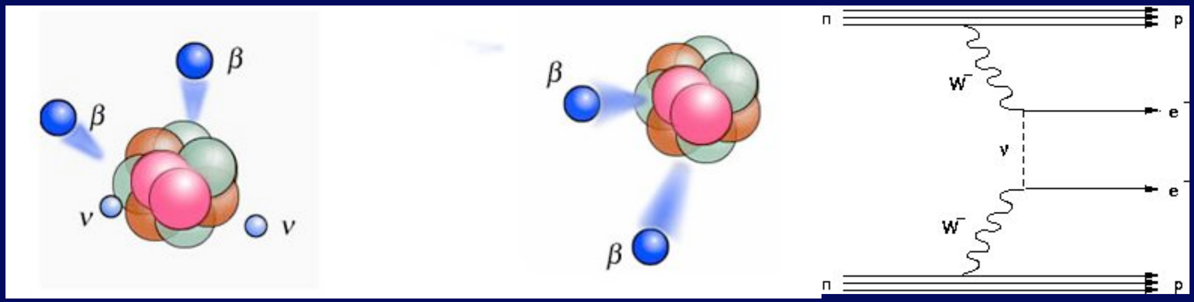
Majorana

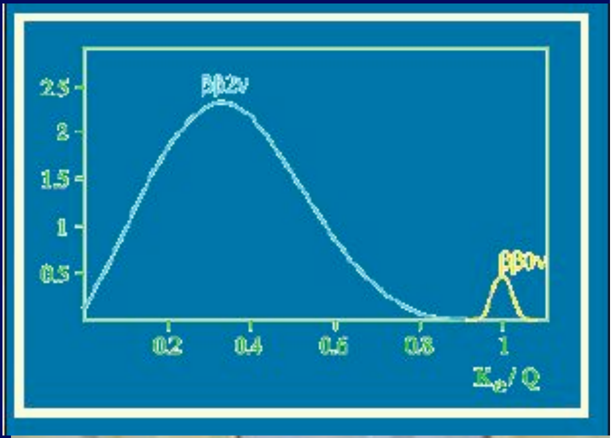
$$= \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{12} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} e^{i\delta_1} & 0 & 0 \\ 0 & e^{i\delta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- **Measure mixing angle θ_{13}**
- **Determines feasibility of measuring delta**
- **Complementary to e.g. T2K and Nova**
- **Design and construction starting**
- **Opportunity for participating in construction and data analysis**
  - **Start data taking in ~2009**



CUORE: Double β-Decay

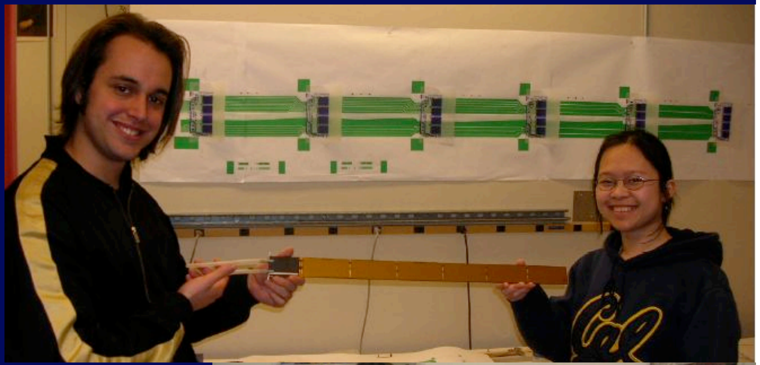


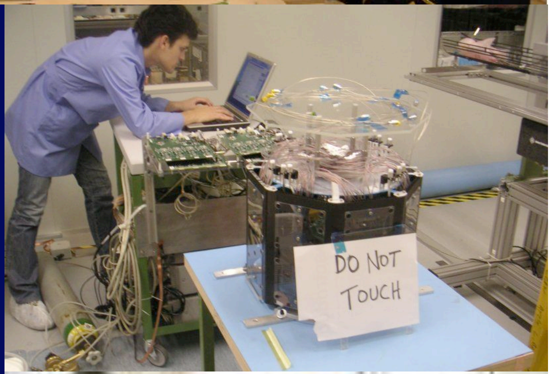


- Neutrinoless double β-decay
  - ββ(2ν):Neucleus (A,Z) →(A,Z+2)+2e$^-$+2ν
  - ββ(0ν):Neucleus (A,Z) →(A,Z+2)+2e$^-$+0ν
    - Lepton flavor violation
    - occurs if neutrinos are majorana
  - Direct measurement of mass of neutrino possible
- Status:
  - Cuorincino runs with 40 kg detector (TeO_2)
  - Cuore starts in 2011 with 1000 kg detector
    - Sensitive to m_ν~100 meV
- Opportunity to work on construction and physics exploitation

Can You Make a Difference?

- **HEP experiments are huge:**
  - # of physicists typically 100-2000!
- **Why?**
  - Because they are exciting :-)
  - The experiment are complex and use cutting edge technology
  - There is a large variety of measurements, each of which is a thesis topic
- **Should that worry you? No!**
  - You will become an expert on a particular topic
    - You will make a unique measurement
    - But will see a lot of other work also
  - There are smaller subgroups
    - You work with a subset of people
  - You work in a truly international environment
    - Get to know lots of world-experts and people from all over the globe





Even in these large experiments you make unique contributions to the understanding of Nature

Conclusions

- HEP faces very exciting times with advent of LHC and new neutrino experiments:
  - probably most exciting since the 60-70's!
- Berkeley Experimental HEP programme very rich and diverse
- Cutting edge physics at present and in the future in
  - pp collisions, e^+e^- collisions, neutrino experiments
- Excellent opportunities for both detector hardware development and operation and physics analysis on current and future experiments
  - Opportunities for work over this summer already on both hardware and analysis
- Inspiring connection between HEP experimentalists and theorists, cosmology, nuclear physics:
  - Uniquely placed due to tight connection to US Laboratory (LBNL) with large resources (scientists, engineers, technicians,…)

I just came to UC Berkeley, so how about you?!?

QUANTUM UNIVERSE

THE REVOLUTION IN 21ST CENTURY PARTICLE PHYSICS

Executive Summary □ About the Report □ Summary Tables □ Facilities Glossary □ Resources

What does "Quantum Universe" mean?

To discover what the universe is made of and how it works is the challenge of particle physics. Quantum Universe presents the quest to explain the universe in terms of quantum physics, which governs the behavior of the microscopic, subatomic world. It describes a revolution in particle physics and a quantum leap in our understanding of the mystery and beauty of the universe.

Office of Science
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DOWNLOAD REPORT

See http://www.interactions.org/quantumuniverse

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