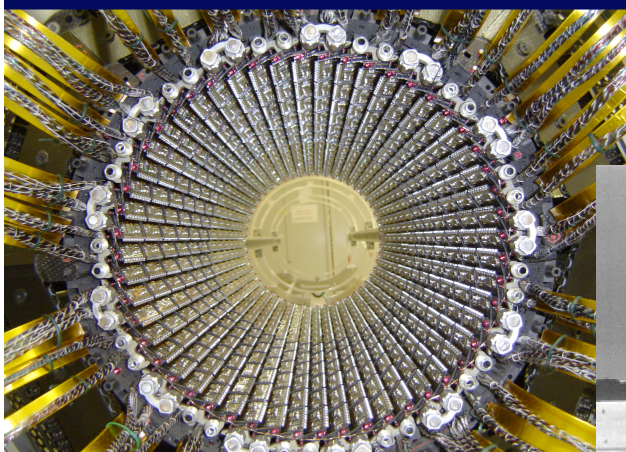
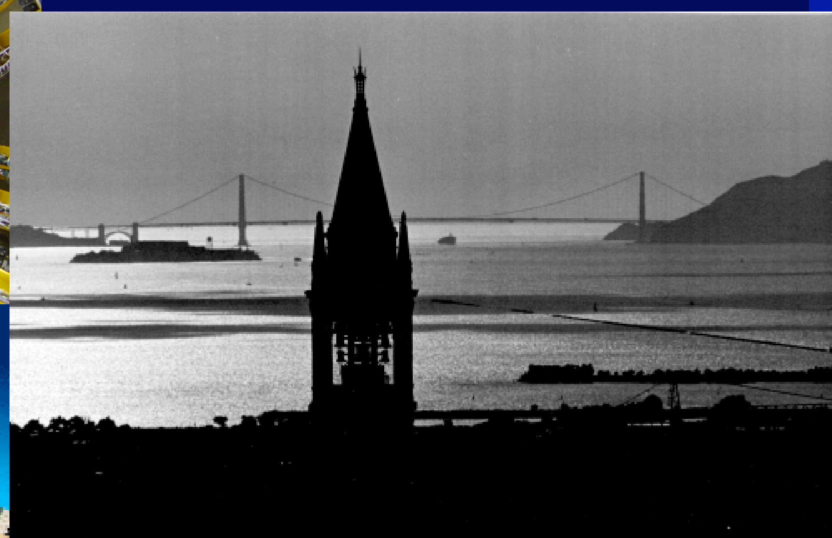
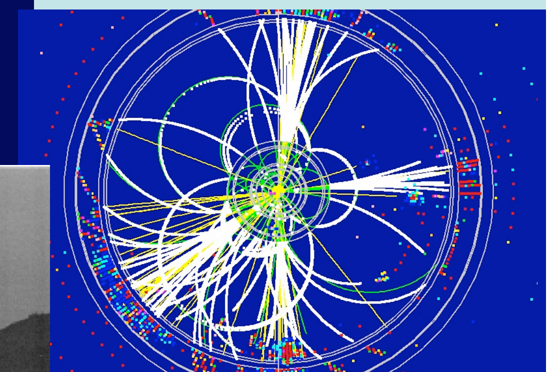
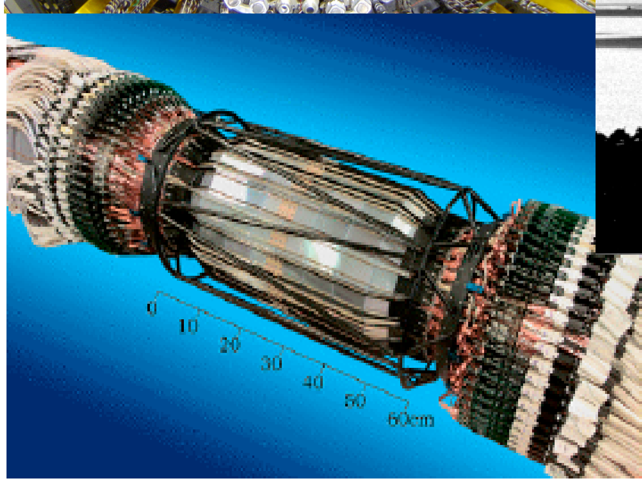
Experimental High Energy Physics

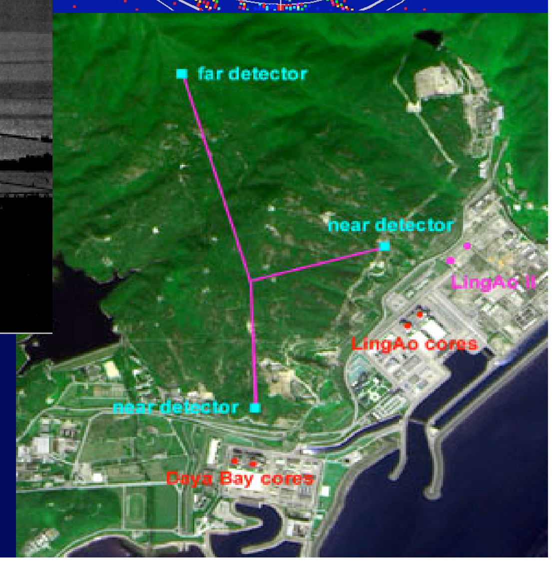
Beate Heinemann





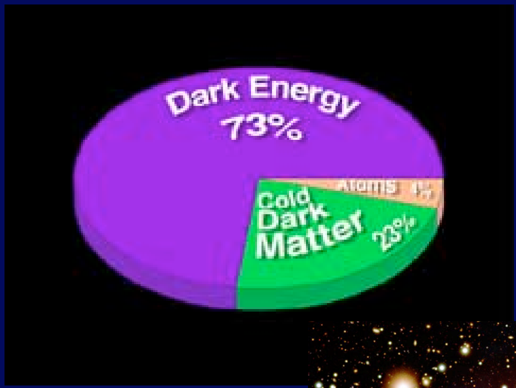


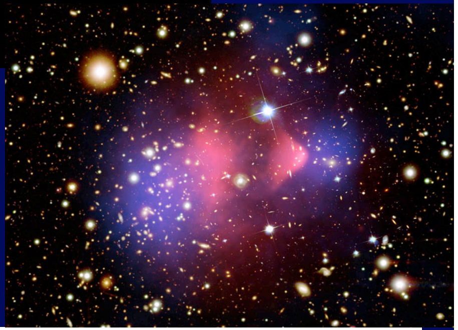


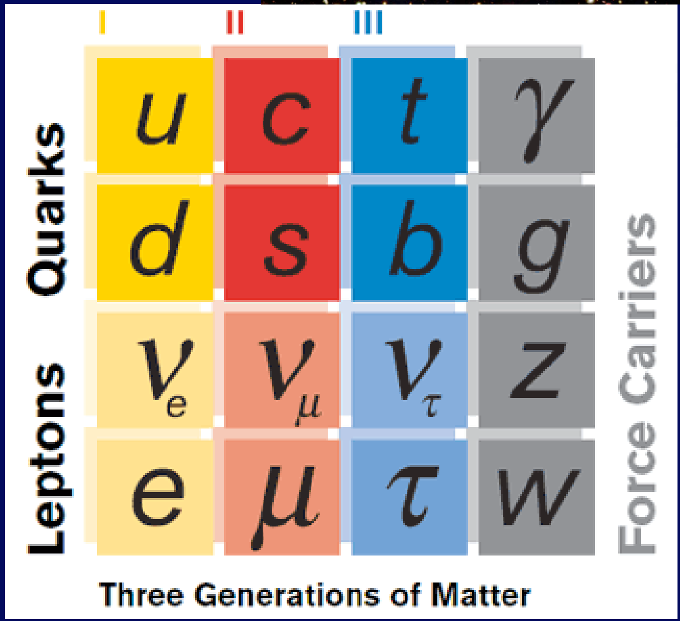


Fundamental Particles and Forces

- 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 anti-matter go?
    - Are neutrinos the clue?
  - Where is the Higgs boson?
    - Does it give mass to fundamental particles?
- 96% of the energy comes from unknown sources
  - Dark matter
  - Dark Energy







Good reasons to believe that some answers will be found during your PhD!

Confusion among Theorists?

by Hitoshi Murayama, UC Berkeley

UC Berkeley HEP Exp. Faculty

Marco Battaglia
BaBar, ILC

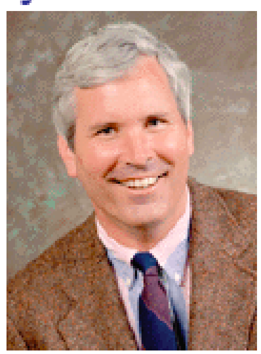
Stuart Freedman
Neutrino physics

Bob Jacobsen
BaBar, ATLAS

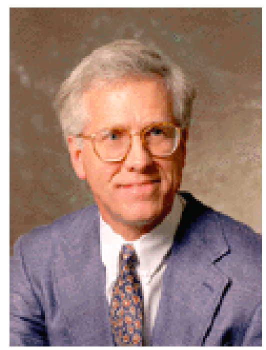
Yury Kolomensky
BaBar, ILC, CUORE

Kam-Biu Luk
Neutrino physics

Marjorie Shapiro
CDF, ATLAS



James Siegrist
CDF, ATLAS



Mark Strovink
SN Factory

Beate Heinemann
CDF, ATLAS

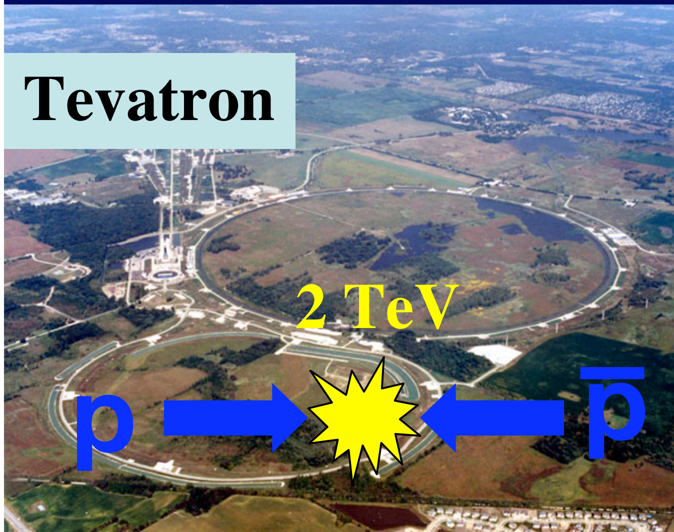
+ close collaboration with Lawrence Berkeley National Laboratory and faculty members from rest of the department

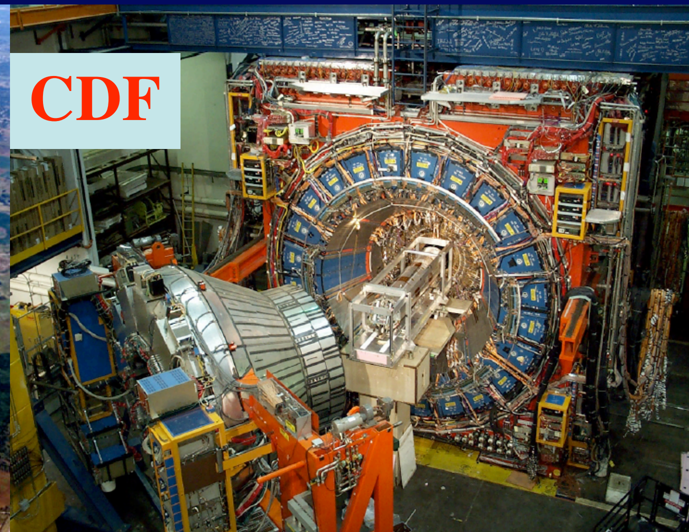
Experimental Programme

- **High Energy Frontier:**
  - **CDF/DØ** probe the highest energies and CP violation at the Tevatron (until 2009)
    - Shapiro, Siegrist, Strovink, Heinemann (will take no new students on CDF/DØ)
  - **ATLAS** probes the highest energies at the LHC (start: this year)
    - Shapiro, Siegrist, Heinemann
  - **ILC** probes high energies with high precision (start: >2020)
    - Battaglia, Siegrist, Kolomensky

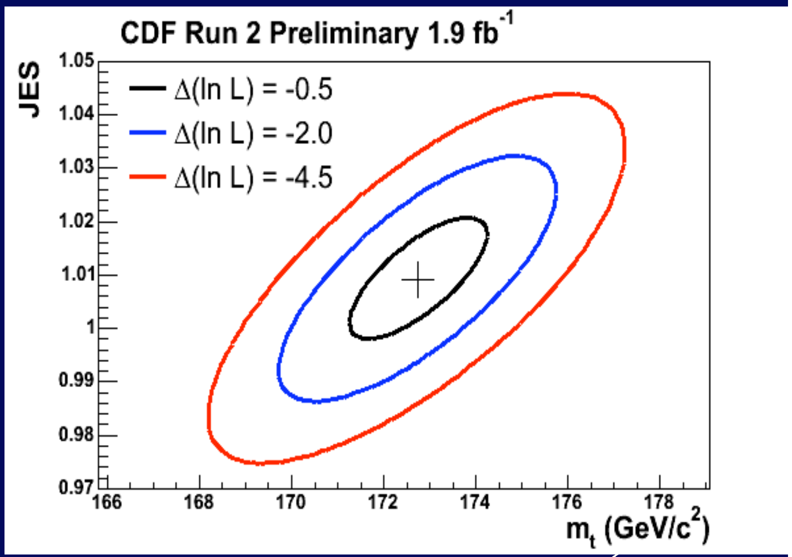
- **Matter vs Anti-matter, neutrino mass**
  - **BaBar** probes CP violation (matter-antimatter asymmetry) at SLAC (until 04/2008):
    - Battaglia, Kolomensky
  - **KamLand** probes neutrino oscillations in Japan (until 2008):
    - Freedman
  - **DayaBay** will probe neutrino oscillations (>2009):
    - Luk
  - **CUORE/Cuoricino** probe neutrino masses (>now):
    - Freedman, Kolomensky

CDF and DØ

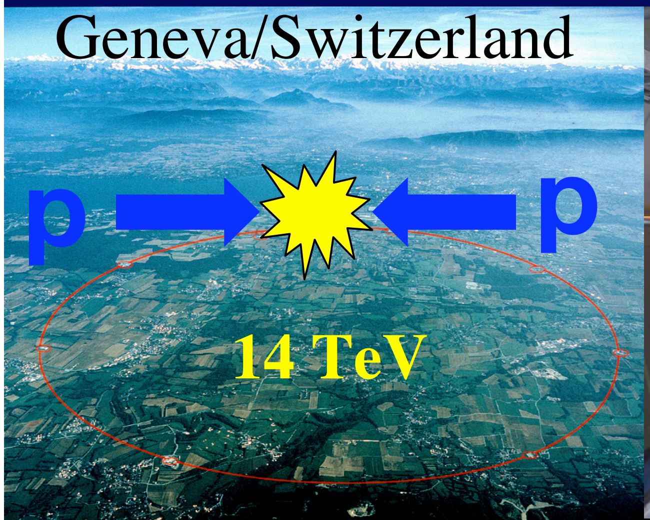


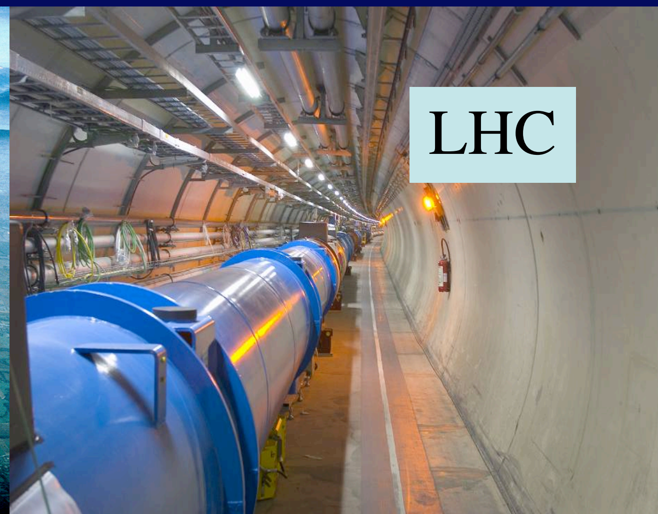


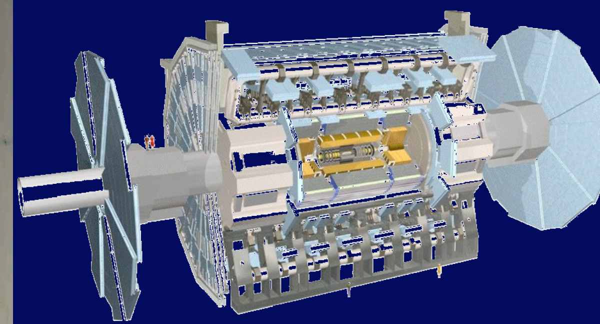
- **Collaborations of 700 physicists**
  - Major involvement of Berkeley in building, operating the detector and in physics analyses
- **Berkeley students made many unique and world's best measurements**
  - e.g. mass of the top quark
    - Tells us about the Higgs boson



ATLAS at the LHC

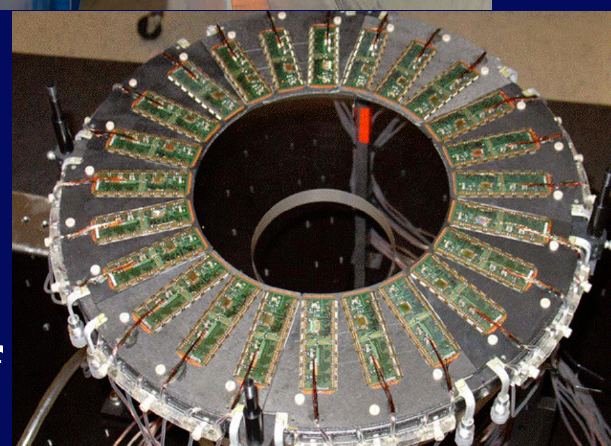


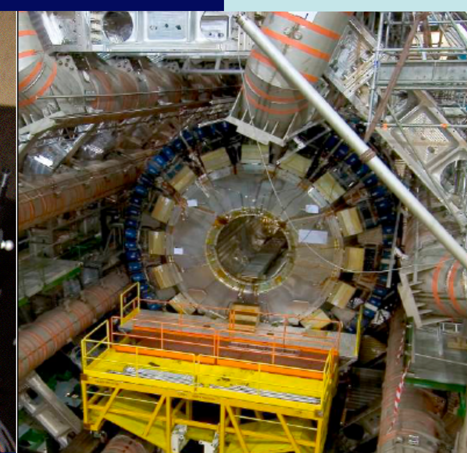




ATLAS

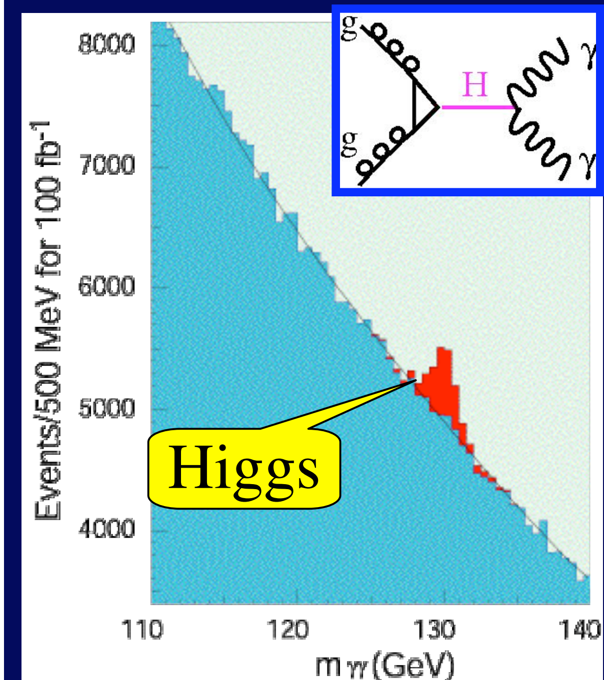
- **LHC will start 14 TeV collisions this year**
- **Berkeley group has diverse talents**
  - Design and construction of tracking detectors
  - Software experts
  - Physics analysis expertise
    - Also from CDF/D0
- **All needed for success!**

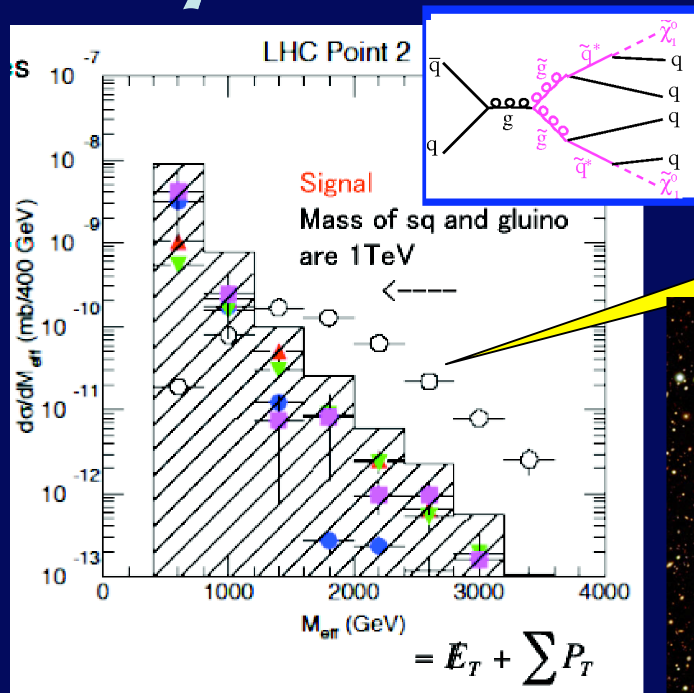


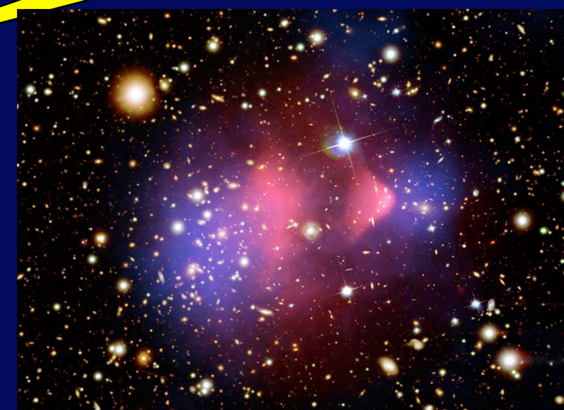


The advent of the LHC may revolutionize our understanding of physics

ATLAS: Physics Examples

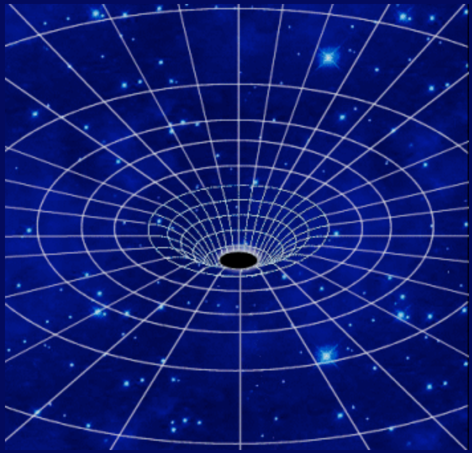


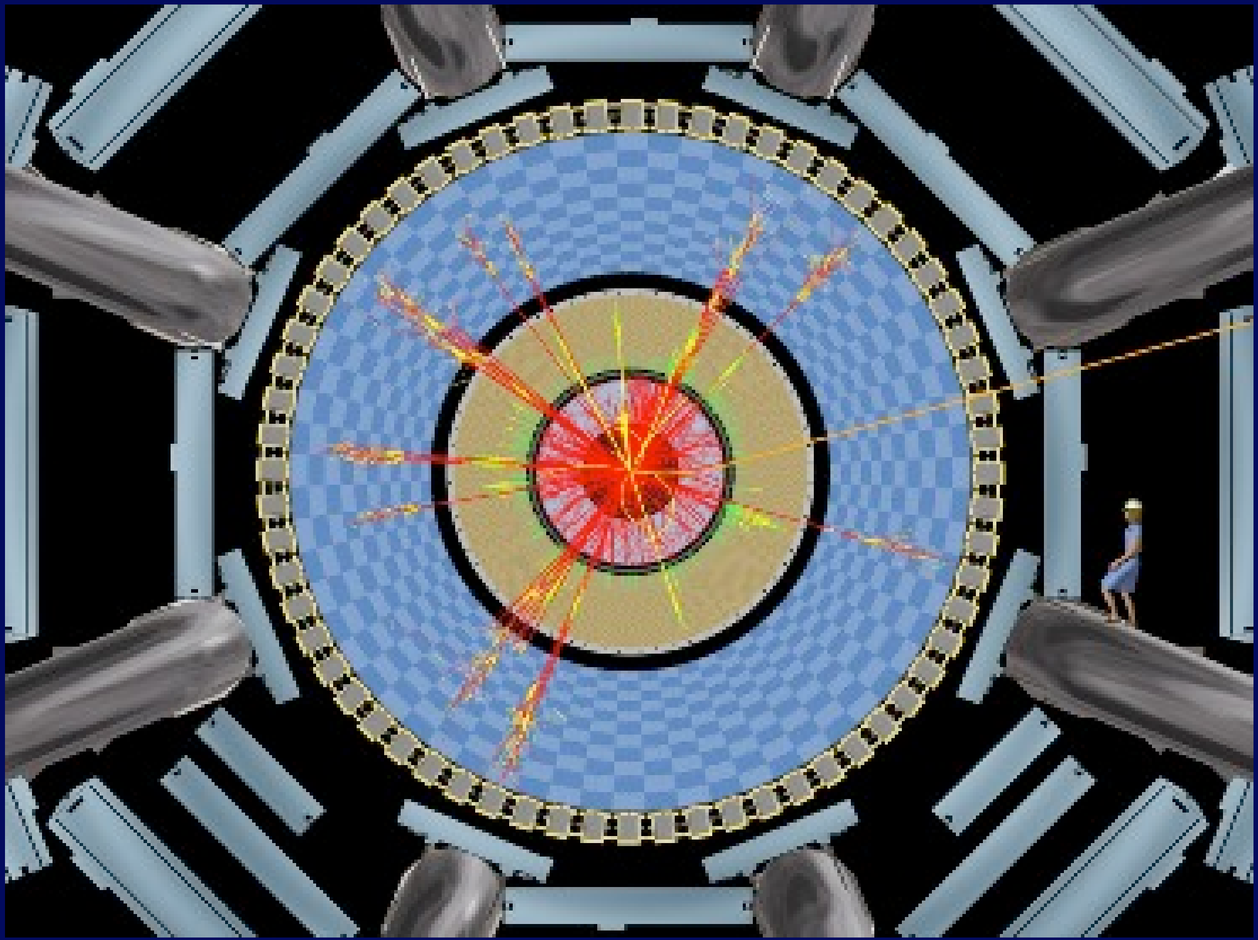




- **Discovery of the Higgs boson?**
  - Understand origin of mass
- **Discovery of Supersymmetry (SUSY)?**
  - Understand origin of Cold Dark Matter
- **Discovery of extra dimensions or black holes**
  - Understand weakness of gravity
- **….or the unexpected!?!**

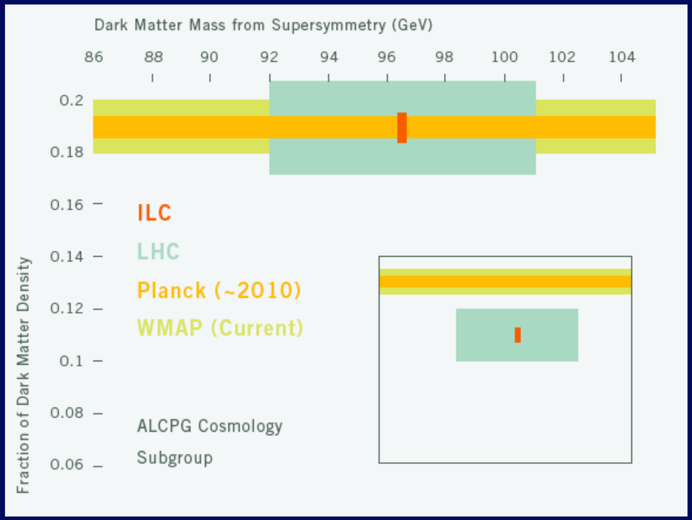
Micro-Black Holes in ATLAS???

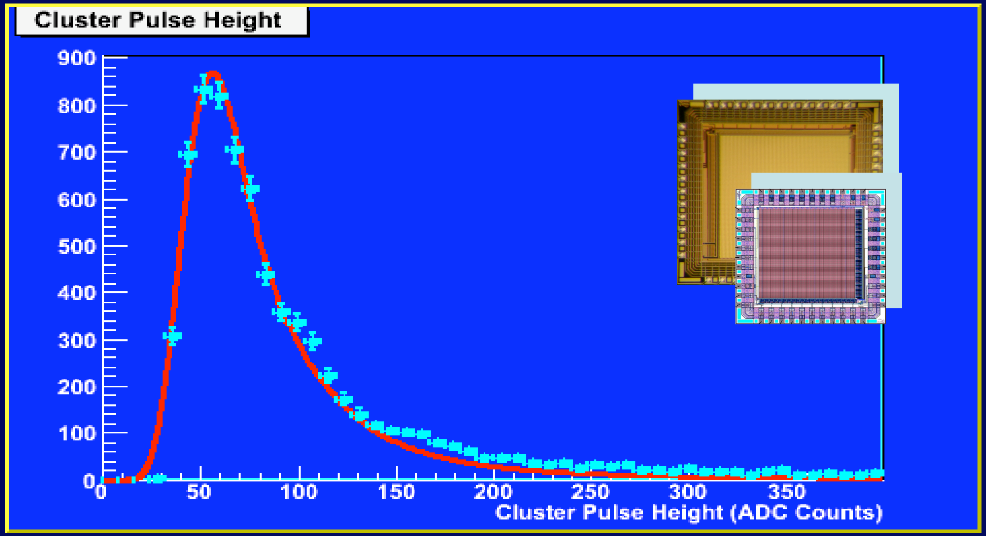




Evaporate via Hawking radiation
=> Spectacular signatures!

High Energy Frontier: Future

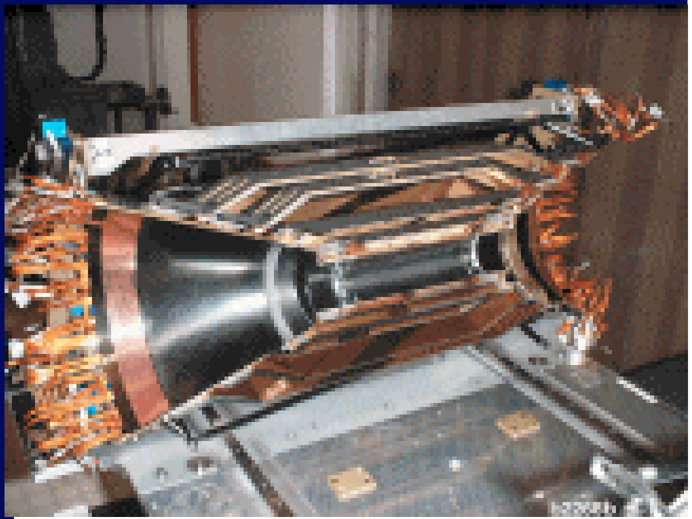


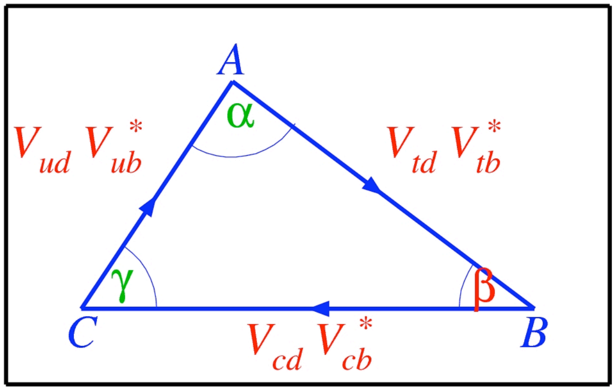


- **International Linear Collider: e^+e^- coll. at 0.5-1 TeV (~2020?):**
  - Vital to really understand high energy physics
  - Berkeley active in R&D for beam instrumentation and tracking detectors & physics feasibility studies
- **Super-LHC (start ~2016):**
  - Extends the capabilities of LHC (higher 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

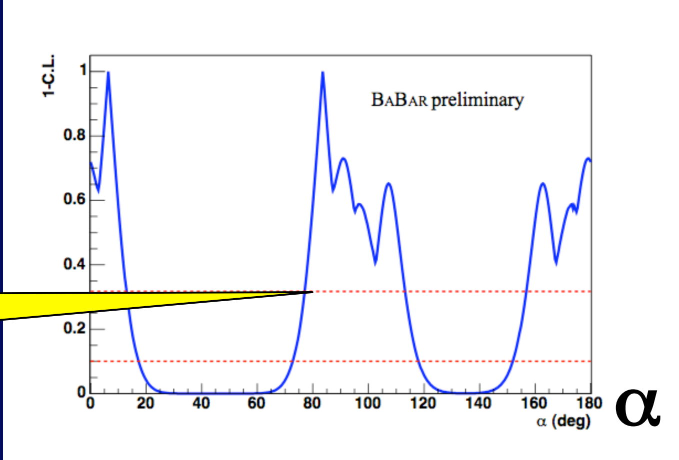
- **PEPII collider at SLAC:**
  - e+e- collisions at √s=10.6 GeV [Υ(4s)]
    - Produce pairs of b-quarks
  - Berkeley heavily involved in design, construction and operation of Silicon Vertex Tracker
- **Physics goals:**
  - Precision measurement of unitarity triangle
    - Understand quark sector of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





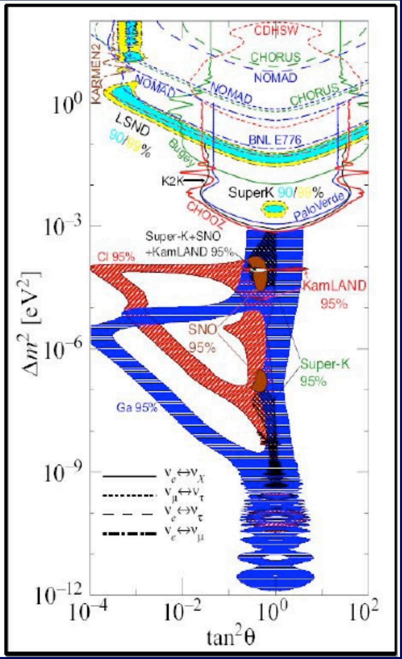
UCB thesis

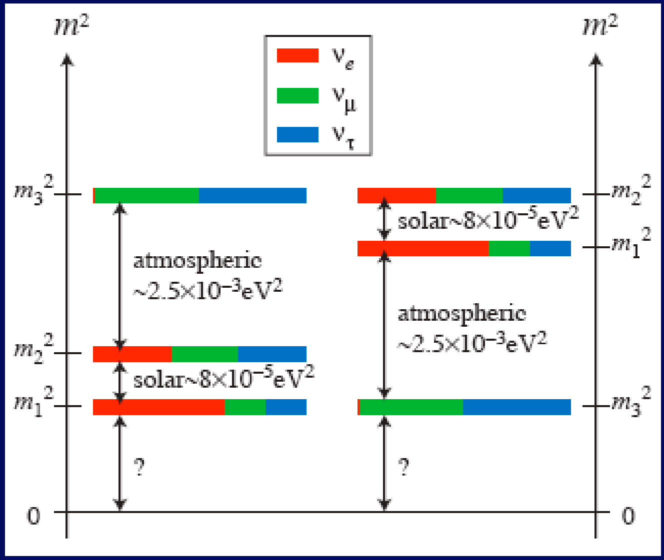
$\alpha = 84^{+30}_{-7}{}^{o}$



What are Neutrinos telling us?

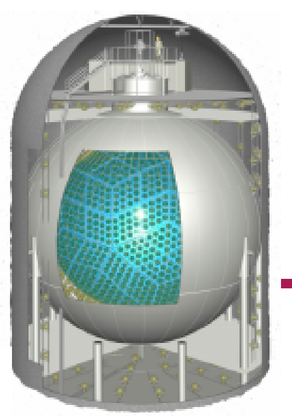
- **Neutrinos oscillate: $m_\nu>0$**
  - Super-Kamiokande 1998
  - KamLAND, K2K, SNO
- **That raises more questions than it answers:**
  - How do they mix (θ_{13}) ?
    - Mixing between 1st and 3rd generation still unknown
    - Why is the mixing so different to quark sector?
  - Is there CP violation in the neutrino sector?
    - Does that maybe explain the matter-antimatter asymmetry?
  - Are they their own antiparticle?
  - What are the actual mass values and why are they so small?
    - Do their small masses tell us anything about very high energies and unification?

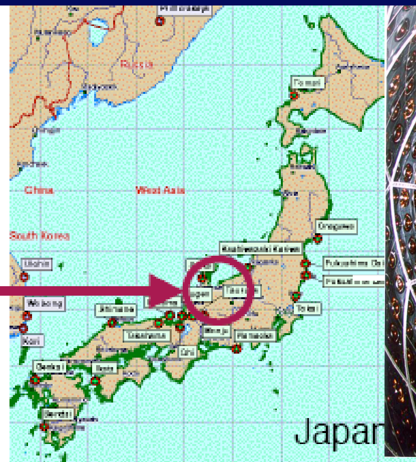


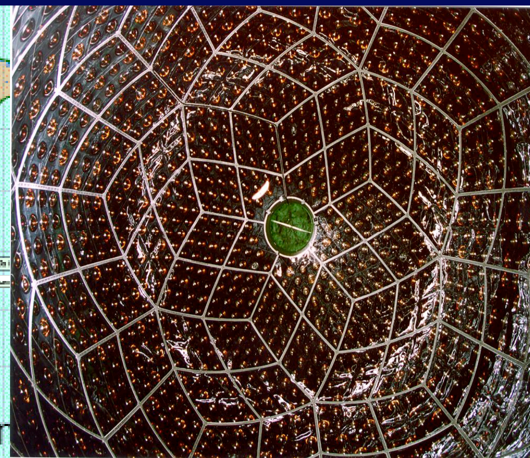


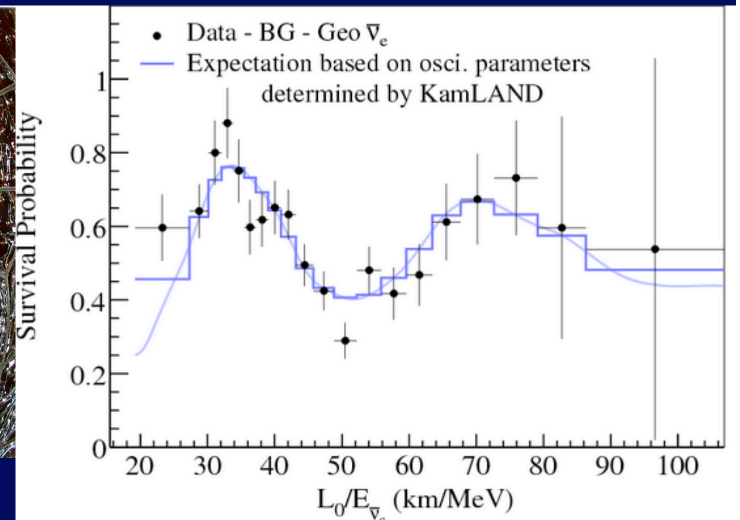
at least one $m_\nu>55$ meV

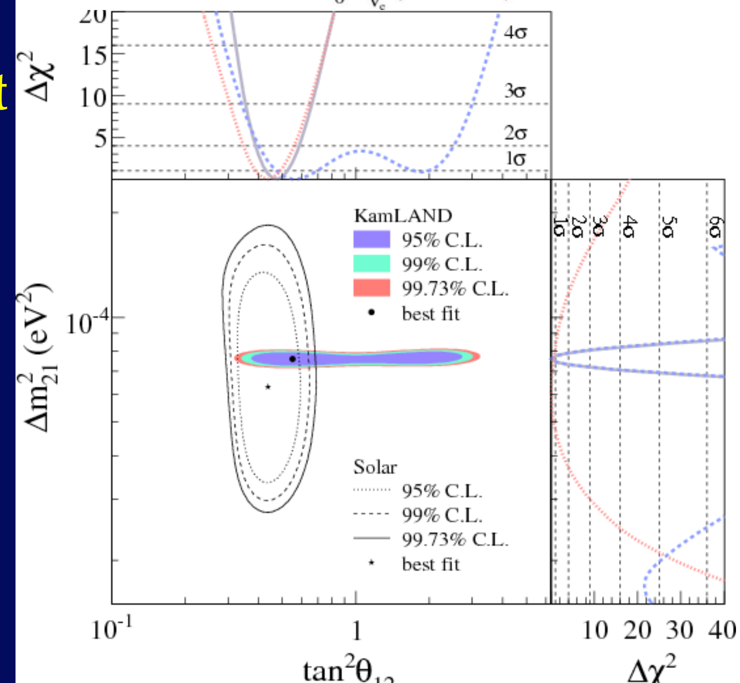
Neutrinos @ KamLAND











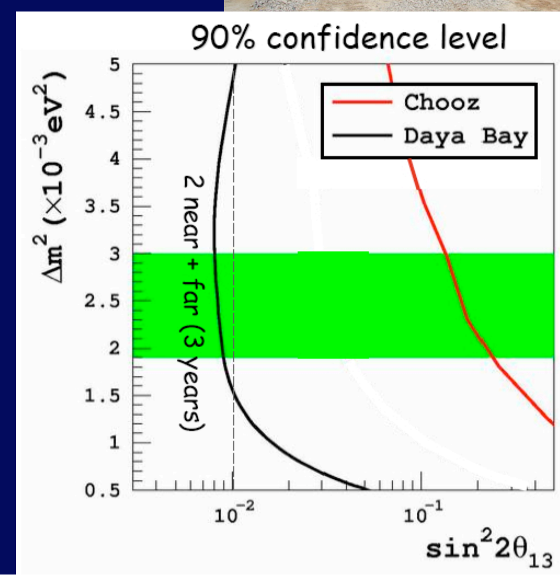
- Reactor neutrino experiment
  - Surrounded by many Japanese reactors that produce ν_e
    - Measure rate of ν_e disappearing
  - Recent results:
    - Most direct evidence for ν_e oscillations
      - Together with SNO constrains one of the mixing angles: θ_{12}
    - Also measures solar and geo neutrinos
- Future
  - Improve sensitivity at low energies

Neutrinos @ Daya Bay

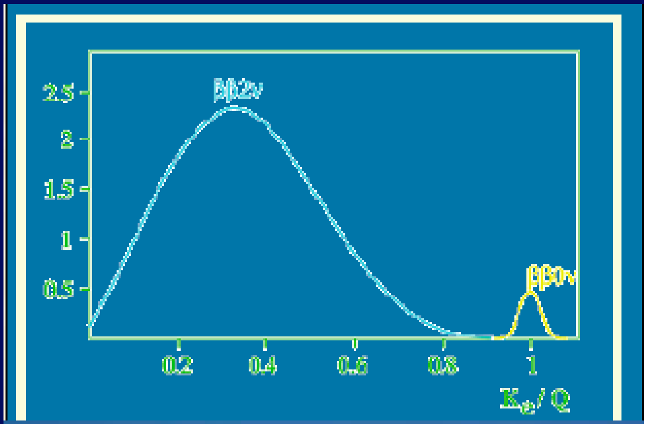
$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} 0.8 & 0.5 & U_{e3} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} \; ?$$

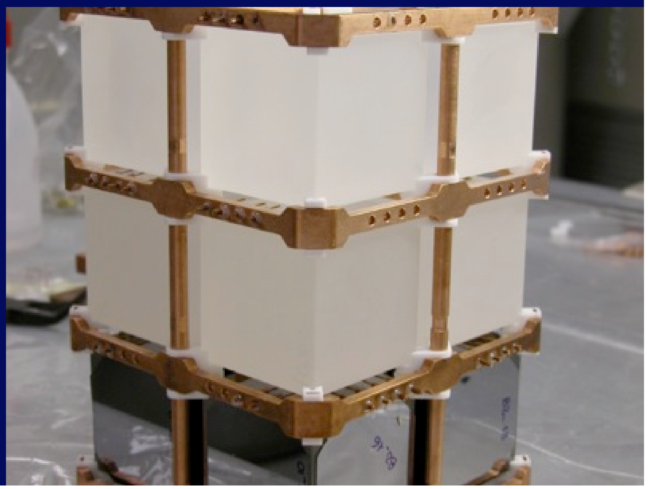
$$= \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{i\delta} & 0 & \cos\theta_{12} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0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

- **Reactor experiment near Hongkong**
  - Complementary to e.g. T2K and Nova
- **Goal: measure mixing angle θ_{13}**
  - Determines feasibility of measuring CP violating phase δ
- **Civil construction has just started!**
  - Tunnel building started Feb. 19th 2008!
- **Start data taking in ~2009**
  - Opportunities to work on construction and data analysis



CUORE: ββ-Decay without ν's

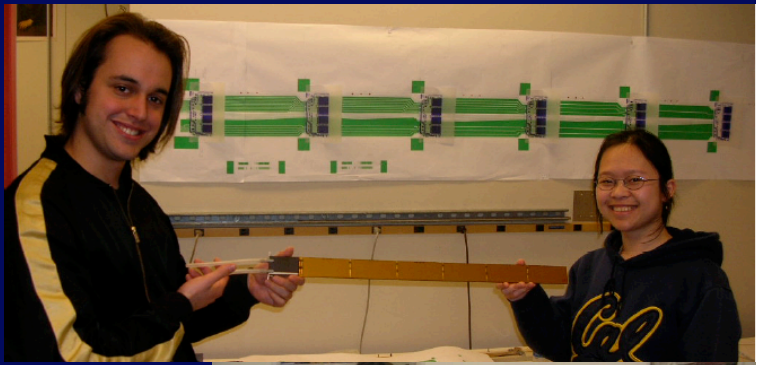


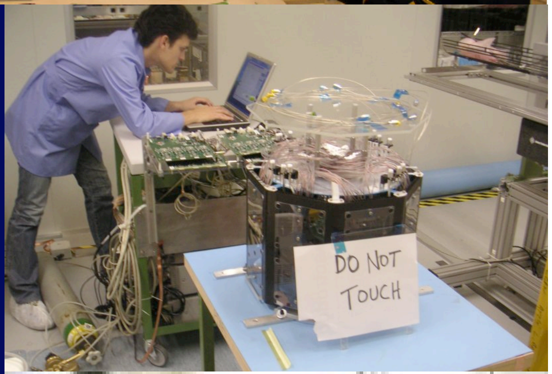


- **Neutrinoless ββ-decay**
  - ββ(2ν):Nucleus (A,Z) →(A,Z+2)+$2e^-$+$2\nu_e$
  - ββ(0ν):Nucleus (A,Z) →(A,Z+2)+$2e^-$+0ν
    - if neutrinos are there own anti- particles
    - Direct measurement of ν-mass
- **Status:**
  - Cuoricino runs with 40 kg detector (TeO_2)
  - Cuore starts in 2011 with 1000 kg detector
    - Sensitive to m_ν~100 meV
- **Opportunity to work on construction and data analysis**

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

- Start of Large Hadron Collider and new neutrino experiments
  - Particle Physics faces very exciting times
    - probably most exciting since the 60-70's!
- Berkeley Experimental HEP program very rich and diverse
  - Cutting edge physics at present and in the future in
    - pp collisions, e^+e^- collisions, neutrino experiments
- Excellent opportunities for 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,…)

Contact us and we'll tell you more!

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.

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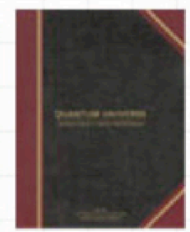

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