# Future Options Working Group

Physics Division

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# Working Group Membership

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## Charge to Panel

The panel will serve as a surrogate for the Physics Division in the exploration of future research options for the Division. It will report back to the Division, giving its evaluation of various options, listing potential for important discoveries, opportunities for participation, risks, etc.

# Structure of Report

- Executive Summary
- Introduction
  - Charge
  - Current Program
  - Other Reports
- Physics Issues and Experimental Status
  - Electroweak Symmetry Breaking
  - Supersymmetry
  - Neutrino Masses and Oscillations
  - Particle Astrophysics

- Opportunities at NLC
- Opportunities in Neutrino Physics
- Opportunities in Particle Astrophysics
- Conclusion

# Current Program

- Hadron Collider Physics
  - CDF: 9 FTE, till '07
  - D0: 3 FTE, till '07
  - ATLAS: 7 FTE, till '15
- $e^+e^-$ Physics
  - BABAR: 15 FTE, till '08+

- Other accelerator-based
  - Hyperon CP Violation: 2 FTE, till '00/01
  - Astrophysics
    - Supernova Cosmology Project: 4 FTE,
    - Cosmic Microwave Background: 2 FTE,
    - AMANDA/Kilometer-cubed/... 2 FTE

Conclude: Hadron collider, B-physics, cosmology all long term

## Electroweak Symmetry Breaking

- $SU(2) \times U(1)$ established by $W$, $Z$, etc.
- Remaining puzzles
  - Breaking from Higgs? technicolor?
  - Why is scale 250 GeV?
  - Pattern of fermion masses, generations
  - Neutrino masses?
  - CP?

# Supersymmetry

- Helps solve scale problem
- Needed by string theory
- Better grand unification
- Just around the corner?

# Neutrino Oscillations

$$P = \sin^2 2\theta \ \sin^2 \left[ 1.27 \frac{\Delta m^2 L}{E} \right]$$

- Appearance
  - LSND, MiniBooNE: $\nu_\mu \to \nu_e$, see $\nu_e \to e$
  - NOMAD, CHORUS $\nu_\mu \to \nu_\tau$, see $\nu_\tau \to \tau$

$$P \approx \frac{N_{\mathrm{appearance}}}{N_{total}}$$

If no signal set limit $P < \epsilon$

## How to choose $E$, $L$ for appearance experiment

$$N_{\text{appearance}} \propto \sigma\Phi\left(\frac{\Delta m^2 L}{E}\right)^2$$

$$\Phi \propto E^2/L^2; \qquad \sigma \propto E$$

Conclude need high $E$, any $L$

$$N_{\text{appearance}} \propto E$$

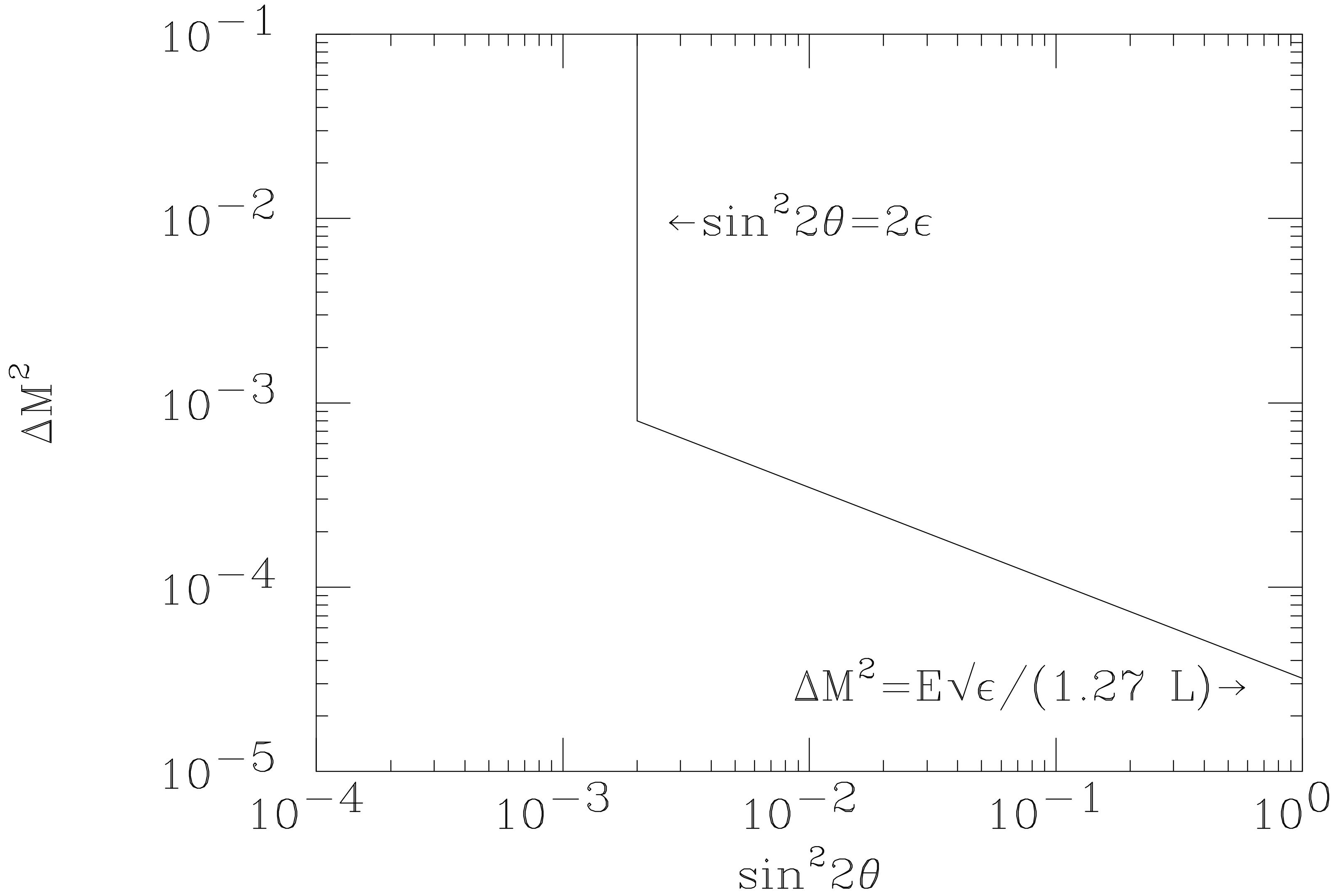


Figure 1: The region accessible in an appearance or disappearance experiment with the limit $\epsilon$ on the oscillation probability.

$$P = \sin^2 2\theta \;\; \sin^2 \left[ 1.27 \frac{\Delta m^2 L}{E} \right]$$

- Disappearance
  - CHOOZ reactor experiment $(\overline{\nu}_e)$
  - Super Kamiokande $(\nu_\mu)$

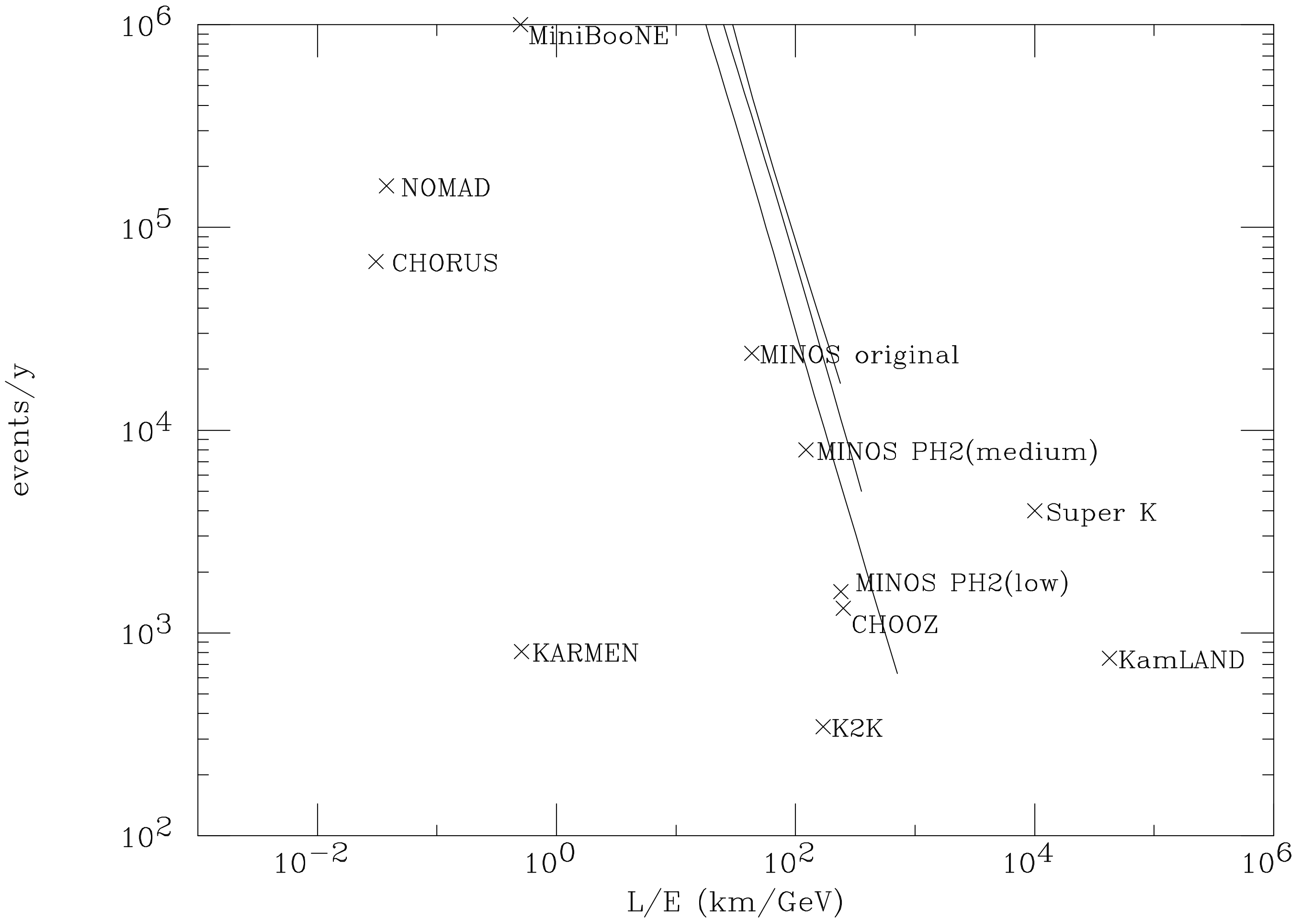


Figure 2: Parameters for a variety of neutrino oscillation experiments. The vertical axis shows $N$, roughly the number of charged current events per year. The horizontal axis shows $L/E$ is in km/GeV. The three straight lines correspond to a muon storage ring source with a beam energy of 20, 40, or 60 GeV.

# Particle Astrophysics

- Cosmic Ray Physics
  - Gamma rays - high energy, sudden appearance
    - GLAST - 10 MeV to 100 GeV $+$
    - MILAGRO - water cerenkov, 1 TeV to 100 TeV
  - Air showers - events beyond $10^{19}$ GeV??
    - Pierre Auger - South America first
    - HiRes -

- Neutrino Astrophysics
  - high energy $\gamma$s means $\pi^0$
    $\pi^0$ means $\pi^\pm \to \mu\nu$
  - AMANDA, Ice Cube
  - NESTOR
- Experimental Cosmology
  - Cosmic Microwave Background
    - Measure power as function of multipole
    - Balloon experiments: MAX, MAXIMA, BOOMERANG
    - Satellite experiments: COBE
  - Supernova Cosmology Project
    - 80 supernovae measured
    - Result contradicts standard explanation
    - Confirmed by competition
    - Need more distant SN's, nearby SN's

## NLC Opportunities

- AFRD already engaged
- Endorsed by HEPAP subpanel
- Competition from Japanese, German programs
- Detector designs being formulated
  - Low event rate
  - Must reconstruct complex events
  - CCD vertex detector possible
    - LBNL CCD (from Steve Holland)
      - Radiation hard
      - Thick depletion region, big signal
  - Basic design
    - TPC (expertise in PD, NSD)
    - All silicon (expertise in PD)

## NLC Opportunities *cont.*

- *Physics potential* great if energy is above threshold for new particle production, limited otherwise
- *Risk* is that it might not be funded, might be pre-empted by Japanese or German efforts, might be at too low an energy
- *Suitability for LBNL:* uses silicon, CCD's, TPC

## Neutrino Opportunities

- KamLAND
  - Outline of experiment
    - Reactor experiment, 1 kt liquid scintillator
      - In Kamiokande cavity
      - 140 - 200 km from reactors, 750 events/y
      - $\overline{\nu}_e p \to n e^+$ delayed coincidence
      - Six times detector volume of BOREXINO
      - $20 M funding from Japanese
    - If low background achieved, solar $\nu$ too
      - Can measure $^7$Be by suppressing background, or
      - Measure $^7$Be with seasonal variation

- *Physics Potential:* for reactor experiment
  - Two-order of magnitude step in $\Delta m^2$ for $\nu_e$ $(< 10^{-5}\mathrm{eV}^2)$
  - Definitive test of large mixing angle solution to solar $\nu$ problem
- *Physics Potential:* for solar neutrino experiment
  - Isolates $^7$Be
  - Tests small mixing angle solution to solar $\nu$ problem
  - Test vacuum solution, "LOW" solution
- *Risks:* funding by DOE, time schedule set by Japanese, backgrounds may be too great for solar $\nu$ exp.
- *Suitability for LBNL:* NSD brings SNO experience, Physics brings electronics

- MINOS
  - Outline of Experiment
    - Long baseline neutrino experiment
    - Fermilab to Soudan (730 km)
    - 3.3 kt to 5.6 kt fiducial volume
    - Calorimetery, muon measurement
    - $NC/CC$ ratio, energy spectrum
    - Identify electron showers
  - *Physics Potential* is looking better with higher $\Delta m^2$ reported by Super K. Energy already reduced to reach low $\Delta m^2$.
  - *Risks* include its low $L/E$ and competition with K2K, which will run earlier. $\tau$ id difficult
  - *Suitability for LBNL:* LBNL experience in large-scale projects valuable. Could be best entrée to $\nu$ physics

- Muon storage ring neutrino experiment
  - Outline of Experiment
    - ∗ Proposed by Steve Geer
    - ∗ Dedicated muon storage ring
    - ∗ Detector could be anywhere
    - ∗ Well defined spectrum of $\overline{\nu}_\mu$, $\nu_e$
    - ∗ Numbers assume 10 kt target
  - *Physics Potential:* limited by long development time. Can measure oscillations and perhaps appearance in $\nu_\mu \to \nu_\tau$, $\nu_e \to \nu_\tau$.
  - *Risks:* high cost, late timing, new kind of machine
  - *Suitability for LBNL:* possible entrée to $\nu$ physics and LBNL experience with big projects.

- HiRes
  - Outline of Experiment
    - Detects air shower fluorescence with mirrors and PMTs
    - Two detectors to be increased to 12
  - *Physics Potential:* can measure air showers above $10^{19}$ GeV cut-off.
  - *Risks:* statistics will be very small. The goal is more in astro-physics than in particle physics.
  - *Suitability for LBNL:* would complement our neutrino work (AMANDA).

- GLAST
  - Outline of Experiment
    - Detects $\gamma$s 10 MeV to 100 GeV +
    - 25 towers of Si strip detectors followed by CsI
    - In satellite, launch 2005
  - *Physics Potential:* Measure gamma ray bursters, AGN's, SN remnants, 20 times better than EGRET
  - *Risks:* Focus on astrophysics, not particle physics or cosmology
  - *Suitability for LBNL:* Relies on silicon strip technology, partners SLAC and UCSC already involved

- Large-Scale Neutrino Detectors
  - Outline of Experiment (AMANDA)
    - Strings of optical modules in Antarctic ice
    - Depths 1.5 to 2.4 km
    - Cerenkov light detected by PMTs
    - Trajectories reconstructed
    - Need upcoming events
    - LBNL developed digital optical modules
  - *Physics Potential:* explores entirely new domain. High energy neutrinos necessary consequence of pion production.
  - *Risks:* high cost of cubic-kilometer detector, uncertainty of event rates, discoveries may be unrelated to particle physics
  - *Suitability for LBNL:* LBNL electronics already a major advance for field, experience with large-scale projects, applicability of NERSC to data analysis

- Cosmic Microwave Background program
  - Outline of Experiments
    - Boomerang
      - Balloon experiment
      - Has circled Antarctica
      - Data likely to have big impact
    - MAP
      - Satellite to be launched in 2001
      - Five frequencies
      - Equivalent to $10^6$ pixels
    - Max Planck Surveyor
      - Satellite to be launched 2007
      - Nine frequencies
      - Equivalent to $10^7$ pixels
  - *Physics Potential:* can substantially narrow range of cosmological parameters, complementing Supernova Cosmology Project

– *Risks:* adequacy of funding, competition from other projects. Balloon experiments subject to vagaries of weather, geography.

– *Suitability for LBNL:* great LBNL experience, NERSC very valuable for major data analysis challenge

- Supernova Cosmology Project
  - Outline of Experiment
    - Continue to discover and measure supernovae
    - Extend measurements to lower and higher red shift
    - Increase statistics
    - Build new large CCD arrays
  - *Physics Potential:* has already profoundly influence cosmology, can pin down $\Omega_m$, $\Omega_\Lambda$, probe details of inflation
  - *Risks:* must continue to fight systematics, understand SN's themselves, struggle to get best telescope time
  - *Suitability for LBNL:* LBNL is the world leader and created the entire field, LBNL CCD opens new instrumentation possibilities