Neutrino Oscillations in 2002.
Or where we are now

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Physics seminar
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Outline

• Why is it important to search for neutrino oscillations?

• What was known before 2002

• What did we learn during first half of 2002

• What new results can we expect before the year end

• Next steps
Why bother with neutrinos?

"I have done a terrible thing. I have postulated a particle that cannot be detected."  

W.Pauli

And he was almost right.  
Typical cross sections is $\sim 10^{-41}$ cm$^2$  
To detect neutrino one needs several light years thick detector!

Still many collaborations around the world are diligently working on neutrino detection.

Why?
Neutrinos are of fundamental importance

Particle Physics
- Neutrino Mass
- Neutrino Oscillations
- CP-violation
- Standard Model

Nuclear Astrophysics
- Supernovae Dynamics
- Production of Heavy elements

Cosmology
- Dark Matter
- Baryogenesis
- Galaxies formation
Why neutrinos are so light? (if not zero mass)

To make something light, one needs something heavy!!!

\[ m_\nu = \frac{M^2}{M} \]

if: \( m_\nu \sim \text{eV}, \quad M \sim 1\text{TeV} \rightarrow M \sim 10^{15} \text{GeV} \) (GUT)

Light neutrinos, are probing physics at

The Grand Unification Scale
Where is antimatter?

During the Big Bang equal amounts of matter and antimatter were created!!!

For us to exist, tiny asymmetry between matter and antimatter was created in the early universe.

**Sakharov’s Conditions for Baryogenesis**
- Baryon Number Violation
- $C$ and $CP$ violation
- Departure From Thermal Equilibrium

We have to understand an origin of $CP$ violation.

**Early Universe**

Matter: $10,000,000,001$
Antimatter: $10,000,000,000$

**Annihilation**

We now
Neutrino Oscillations

If $m_\nu$ is non-zero, then mixing between different neutrino flavors is possible.

$$|\nu_j\rangle = \sum_j U_{jl} |\nu_l\rangle$$

What is produced and detected is weak eigenstate $|\nu_j\rangle$

$U_{jl}$ is a $3 \times 3$ unitary matrix (like the CKM matrix for quarks)

What propagates is the mass eigenstate $|\nu_l\rangle$

Time evolution

$$|\nu_l(t)\rangle = e^{-i(E_i t - p_i L)} |\nu_l(0)\rangle \approx e^{-i(m_j^2/2E)L} |\nu_l(0)\rangle$$

Assuming $E_i = E \gg m_i$, $p_i \gg m_i$

Flight path
We can define a “transition probability”

\[ P(v_j' \rightarrow v_j, L) = \left| \sum_l U_{lj} U_{j'l}^* e^{-i(m_i^2/2E)L} \right|^2 \]

...a periodic function of the baseline \( L \)

For 2 flavors this simplifies:

\[ U = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \]

Only one parameter \( \theta \) (mixing angle)

\[ P(v_e \rightarrow v_\mu, L) = \sin^2 2\theta \sin^2 \frac{1.3\Delta m^2 L}{E} \]

\( \Delta m^2 \) in \( [\text{eV}^2] \)

\( m_1 - m_2 \) in \( [\text{eV}] \)
Neutrino oscillations are analogous to “beatings” in the sound waves.

\[ \nu_1 \text{ wave-function} \]
\[ \nu_2 \text{ wave-function} \]
\[ \text{neutrino flux} \]
Two type of Oscillations

**Vacuum**

\[ P(\nu_e \rightarrow \nu_\mu, L) = \sin^2 2\theta \sin^2 \frac{1.3\Delta m^2 L}{E} \]

**Matter enhanced (MSW effect)**

Out of three leptons, only electrons are present in our regular matter. Because of that \( \nu_e \) has both NC(Z\(^0\)) and CC(W\(^\pm\)) interactions.

However \( \nu_\mu, \nu_\tau \) have only NC.

Mixing angle and oscillation distance should be modified:

\[
\sin^2 2\theta_m = \frac{\sin^2 2\theta}{\{1 - 2(l_V/l_0)\cos 2\theta + (l_V/l_0)^2\}}
\]

\[
l_m = l_V/\sqrt{\{1 - 2(l_V/l_0)\cos 2\theta + (l_V/l_0)^2\}}
\]

\[
l_0 \sim \rho/Y_e, l_V \sim E/\Delta m^2
\]

Resonance conditions occurs when \( Y_e \Delta m^2/\rho E = \cos 2\theta \)

\[
\sin^2 2\theta_m \sim 1 \quad l_m \sim 0
\]
If neutrino oscillates:

- They have nonzero mass
  Test of Standard Model, Dark matter, et set..

- We have new tool to study CP violations
  $P(\nu_i \to \nu_j)$ vs. $P(\nu_i \to \nu_j)$
Status Before 2002

It was a long history of development, sometimes mixed and confusing signals.

But finally we ended up with three indications for neutrino oscillations:

- Solar Neutrino deficit
- Atmospheric Neutrino Anomaly
- LSND effect
Solar Neutrinos

\( \nu_e \) are abundant by-products of nuclear fusion in the sun.

\( p + p \rightarrow ^2H + e^+ + \nu_e + 0.42\text{MeV} \)

\( p + e^- + p \rightarrow ^2H + \nu_e + 1.44\text{MeV} \)

"pp" 99.75%

\( ^2H + p \rightarrow ^3\text{He} + \gamma + 5.49\text{MeV} \)

\( ^3\text{He} + ^3\text{He} \rightarrow \alpha + 2p + 12.86\text{MeV} \)

86%

\( ^3\text{He} + \alpha \rightarrow ^7\text{Be} + \gamma + 1.59\text{MeV} \)

14%

\( ^3\text{He} + p \rightarrow \alpha + e^+ + \nu_e \)

"hep" 2.4*10^{-5}

"\(^7\text{Be}\)" 99.89%

\( ^7\text{Be} + e^- \rightarrow ^7\text{Li} + \gamma + \nu_e + 0.8617\text{MeV} \)

\( ^7\text{Li} + p \rightarrow \alpha + \alpha + 17.35\text{MeV} \)

\( ^7\text{Be} + p \rightarrow ^8\text{B} + \gamma + 0.14\text{MeV} \)

0.11%

"\(^8\text{B}\)" 0.11%

\( ^8\text{B} \rightarrow ^8\text{Be} + e^+ + \nu_e + 14.6\text{MeV} \)

\( ^8\text{Be} \rightarrow \alpha + \alpha + 3\text{MeV} \)
Solar neutrino detection

3 types of experiments detecting solar neutrinos

- Chlorine: $^{37}\text{Cl} + \nu_e = ^{37}\text{Ar} + e^-$
  1 exp running >30 yrs (US)
- Gallium: $^{71}\text{Ga} + \nu_e = ^{71}\text{Ge} + e^-$
  3 exp (Russia, Italy)
- Cherenkov: $e^- + (\nu_e + 0.17 \cdot \nu_{\mu,\tau}) = e^- + \nu$
  3 exp (Japan, Canada)

$L = 10^8\text{km}$
Not enough Neutrinos!

Explanation → Neutrino Oscillations
Oscillation Parameters

Only one is real!!!
\[ \nu_e + p \rightarrow e^+ + n \]

\[ p \rightarrow d + \gamma(2.2 \text{ MeV}) \]
More neutrinos then expected

Many $\nu_\mu$, $\nu_\mu$, $\nu_e$, few $\nu_e$.

Excess positron events over calculated BG

$P(\nu_\mu \rightarrow \nu_e) = (0.264 \pm 0.067 \pm 0.045)\%$
Atmospheric Neutrinos

At low energy (~GeV), we expect twice more $\nu_\mu$ than $\nu_e$. Neutrino flight pass has strong azimuthal dependence.
Super Kamiokande

- Located deep underground - 2.5 km of water equivalent of overburden
- 50 kT of ultra pure water
- ~12000 20” PMTs
- Sophisticated calibration and monitoring equipment

Big Cherenkov detector

Muon from $\nu_\mu$ interaction generates single Cherenkov ring

Electron from $\nu_e$ interaction produces fuzzy ring from E-M shower.
Strong Indication for Oscillations

ν_e do not seem to have an oscillation pattern

ν_µ flux depends on the angle !!

Deviation from expected angular behavior is consistent with \( ν_µ \rightarrow µ_τ \) oscillations with parameters

\[ \sin^2 2\theta = 1, \ \Delta m^2 = 2.4 \times 10^{-3} \text{ eV}^2 \]

Super Kamiokande

Data

M.C.

What do we see?

Sub-GeV

E < 400 MeV

Sub-GeV

E > 400 MeV

E < 1.33 GeV

Multi-GeV

E > 1.33 GeV

Electrons

Muons

Up going

Down going
Super Kamiokande Implosion

In summer of 2001 SuperK was stopped for maintenance.
Water has been drained out, and some PMTs were replaced.
In September of 2001 collaboration started to fill it back with water.
On November 12th when detector was filled by 75% one tube imploded. ALL PMTs that was under water, collapsed. Total damage ~ 6600 20” PMTs + support structure.

SuperK produced outstanding results during many years for neutrino physics
Significant loss for the community
One BAD PMT

Interestingly, collaboration was able to reconstruct history of collapse

First Imploding PMTs
Can solar, atmospheric, and LSND results be incorporated together?

For 3 neutrino scenario

\[ \Delta m^2_{1-2} \pm \Delta m^2_{2-3} \pm \Delta m^2_{3-1} = 0 \]

\[ \Delta m^2_{\text{LSND}} \sim \text{eV}^2 \]
\[ \Delta m^2_{\text{atm}} \sim 3 \times 10^{-3} \text{eV}^2 \]
\[ \Delta m^2_{\text{solar}} < 10^{-4} \text{eV}^2 \]

Needs a **sterile neutrino**

*New type of neutrino with no weak interaction*

Four neutrino scenario

1 + 3 or 2 + 2

Looks very exotic.

Plenty of freedom for theoreticians

(100+ publications)

Strong consequence for experiments:

either solar or atmospheric neutrinos should disappear without trace
2001 summary

LSND $\bar{\nu}_\mu \to \bar{\nu}_e$

Quite exotic scenario how to incorporate all results together

+ One "dead" detector

Solar $\nu_e \to \nu_x$

Atm. $\nu_\mu \to \nu_x$
What is new in 2002
K2K
(KEK to Kamioka)
SuperK is not in operation, but collaboration continue data analysis!

Before SuperK implosion, KEK accelerator delivered $\nu_\mu$ beam to Kamioka.

First operational long baseline experiment!

Typical Neutrino Event

Neutrino Peak Energy $\sim 1$ GeV
K2K first result

Beam Time on 250 km base synchronized with GPS

Expected 80 events - seen 56 !!!
29 fully contained

First time we see oscillation ?!?!?

Null oscillation probability is less than 1%
$$\Delta m^2 = 1.5 \sim 3.9 \times 10^{-3} \text{ eV}^2 \text{ for } \sin^2 2\theta = 1 \text{ @ } 90\% \text{CL}$$

atm: $$\Delta m^2 = 2.4 \times 10^{-3} \text{ eV}^2 \sin^2 2\theta = 1$$
Should be no $\nu_\tau$ in Atm. Neutrinos

Direct production of the $\nu_\tau$ by cosmic rays is negligible, because of the low cross section of the $\tau$ production.

If lower flux of the muon neutrinos is due to the oscillations to the tau neutrinos, we should see plenty of $\nu_\tau$ coming from down under.
Search for $\nu_\tau$ appearance in Atm. Neutrinos

$\nu_\tau$ can be identified by detection of $\tau$

$\tau$ (mass $1.8$ GeV, Mean life time $2.9 \cdot 10^{-13}$ s)

Super K is a large Cherenkov detector and not optimized for that!!!

SuperK collaboration developed technique to analyze multi-ring events and select $\nu_\tau$ like events with efficiency of 44%

The price is a very big background - $S/N \sim 0.08$

To explain missing $\nu_\mu$ neutrinos, SuperK expected to have 37 $\nu_\tau$ events with B.G. of 461

Detected - 506 events
Details of multi-ring analysis

- \( \tau \) detection in atmospheric neutrinos

**Selection Criteria**
- multi-GeV, multi-ring
- most energetic ring is e-like
- \( \log(\text{likelihood}) > 1 \) (single-ring)
- \( > 0 \) (multi-ring)

\( \tau \) likelihood is defined using:
- total energy
- number of rings
- number of decay electrons
- \( \max(E_i)/\Sigma E_i \)
- distance between \( \nu \) interaction point and decay-electron point
- \( \max(p_\mu) \)
- \( P_{t/Evis}^{#34} \)
- PID likelihood of most energetic ring

**\( \tau \)-like selection:** \( \text{eff}\tau = 44\%, \text{S/N}=8\% \)

Observed \( \tau \)-like events: 506
MC expectation:
- CC \( \nu_\tau \): 37 events,
- BG: 461 events (CC\( \nu_e \): 43.1\%, CC\( \nu_\mu \): 24.5\%, NC: 32.4\%)
Indication for $\nu_\tau$ appearance

What is important that excess of $\nu_\tau$ like events is seen in the up going events!!!

All facts lead us to believe that atmospheric neutrino anomaly is due to $\nu_\mu \rightarrow \nu_\tau$ oscillations with parameters:

$$\Delta m^2 = 2.4 \cdot 10^{-3} \text{ eV}^2 \quad \sin^2 2\theta = 1$$
What is new in solar neutrinos?

The SNO Detector

17.8m dia. PMT Support Structure
9456 PMTs, 56% coverage

12.01m dia. acrylic vessel

1700 tonnes of inner shielding H₂O

5300 tonnes of outer shielding H₂O

Host: INCO Ltd., Creighton #9 mine
Coordinates: 46°28′30″N 81°12′04″W
Depth: 2092 m (~6100 m.w.e., ~70 μ day⁻¹)

Neutrino Detection in SNO

\( \nu \) Reactions in SNO

**CC** \( \nu_e + d \rightarrow p + p + e^- \)

- Good measurement of \( \nu_e \) energy spectrum
- Weak directional sensitivity \( \propto 1/3 \cos(\theta) \)
- \( \nu_e \) only.

**NC** \( \nu_x + d \rightarrow p + n + \nu_x \)

- Equal cross section for all \( \nu \) types
- Measure total \( ^8B \) \( \nu \) flux from the sun.

**ES** \( \nu_x + e^- \rightarrow \nu_x + e^- \)

- Low Statistics
- Mainly sensitive to \( \nu_e \), some sensitivity to \( \nu_\mu \) and \( \nu_\tau \)
- Strong directional sensitivity
Event count

#EVENTS

CC 1967.7 $^{+61.9}_{-60.9}$

ES 263.6 $^{+26.4}_{-25.6}$

NC 576.5 $^{+49.5}_{-48.9}$
SNO results

Physics Implication Flavor Content

$\Phi_{ssm} = 5.05^{+1.01}_{-0.81}$  $\Phi_{sno} = 5.09^{+0.44+0.46}_{-0.43-0.43}$

100% transition
Oscillation to $\nu_s$
No oscillations

Strong evidence of flavor change
Implication for mixing parameters

No sterile neutrinos. Most likely LMA solution
How about LSND?

To incorporate its we need four neutrino scenario, with either solar or atmospheric neutrinos transfers to sterile neutrinos.

Existing experimental data from several experiments strongly disfavors it !!!!

Looks like contradiction between one relatively “small” experiment and large set of various data.
Does LSND claim has a chance to survive?

In Neutrino Physics always be ready for Surprises
New desperate attempt to put everything back together.

Remember that:
LSND - anti-neutrinos
Solar - neutrinos
Atmospheric neutrinos + anti-neutrinos

What if neutrinos and anti neutrinos has different masses
CPT theorem

If we take particle:
Reverse charges - C
Reflect it in mirror - P
And reverse time - T
Everything should stay the same

Particles and anti particles should have the same masses, life times, et set.

Different masses for neutrinos and anti neutrinos $\rightarrow$ CPT violation

It just too good to be true!
Big impact on fundamental physics
(Extra dimensions, Lorentz non invariance, ......................
.......................................................... could be link to the dark force)
Next step - KamLAND

Test of solar neutrino oscillations with man made antineutrinos

To test neutrino oscillations we have to design experiment which will have $\Delta m^2 \frac{L}{E} \sim 1$

For solar neutrinos $\Delta m^2 \sim 5 \times 10^{-5}$ eV

Reactor neutrinos energies $\langle E \rangle \sim 5$ MeV

We need oscillation base $L \sim 10^5$ meters, or 100 km.

Because cross section is small and neutrinos from reactor isotropic – we need a lot of nuclear power plants around !!!
Location, Location, Location

World nuclear power plants

20% of world nuclear power produced here
KamLAND - joint Japan-USA experiment

Kamioka
Large
Anti
Neutrino
Detector


Tohoku University
T.Taniguchi
KEK
T.Chikamatsu

Miyagi Gakuin Women's School
H.Higuchi

Tohoku-Gakuin University
J.Busenitz, Z.Djurcic, K.McKinny, D-M.Mei, A.Piepke

University of Alabama

LPNL/UC Berkeley
L.Hannelius, G.A.Horton-Smith, R.D.McKeown, J.Ritter, B.Tipton, P.Vogel

California Institute of Technology
C.E.Lane

Drexel University
P.Gorham, J.Learned, J.Maricic, S.Matsuno, S.Pakvasa

University of Hawaii
S.Hatakeyama, R.C.Svoboda

Louisiana State University
B.D.Dieterle, C.Gregory

University of New Mexico
J.Detwiler, G.Gratta, H-L.Liew, D.Murphee, N.Tolich, Y.Uchida

Stanford University
M.Batygov, W.Bugg, H.Cohn, Y.Efremenko, Y.Kamyshkov, Y.Nakamura

University of Tennessee

TUNL
KamLAND Detector

- 1 kton liq. Scint. Detector in the Kamioka cavern
- ~1300 17” fast PMTs
- ~700 20” large area PMTs
- 30% photocathode coverage
- H₂O Cherenkov veto counter
- Multi-hit dead time-less electronics
- _m² sensitivity 7 × 10⁻⁶ eV²
- LMA-MSW solution

Detection scheme

\[ \bar{\nu}_e + p \rightarrow e^+ + n \]

\[ p \rightarrow d + \gamma(2.2 \text{ MeV}) \]

Transparent balloon to separate pure mineral oil from liquid scintillator
Expected rates

Signal without oscillations 3 events/day.

Estimated B.G. ~ 0.1 event/day

It is impossible to measure BG directly because we can not stop all Japanese reactor even for a short period.
KamLAND Discovery Potential

KamLAND accuracy

SNO most probable
Construction
Half way done
Looking up
Balloon installed
Liquid scintillator

Scintillator is a blend of 20% pseudocumene and 80% paraffin oil.

Different density paraffines are used to obtain the same density inside and out of the balloon.

PPO concentration is 1.5 g/l of the final blend.

During blending, the liquids are pre-purified.
Scintillator Purity

Measured from data:

- Th: using the $^{212}\text{Bi}-^{212}\text{Po}$ 300 ns correlation
  - $<1.8 \times 10^{-16}$ g/g
- U: studying the high energy background
  - $<6.4 \times 10^{-16}$ g/g
- $^{40}\text{K}$: fitting background spectra
  - $<2.3 \times 10^{-16}$ g/g

Consistent with Neutron Activation Analysis:

- Th $< 2.8 \times 10^{-15}$ g/g
- U $< 8 \times 10^{-15}$ g/g
- $^{40}\text{K} < 1.3 \times 10^{-15}$ g/g (record NAA sensitivity)
Top of the detector
Cables (30%)
Signals

Have full waveform digitizers on every central and veto channel.

Very important for exploring new physics and reject complex background signatures.

Signals from blue LED flashers in the detector.

Row waveforms

1 p.e.

After pedestal subtraction

2 p.e.

\[ \Delta t = 35 \text{ nsec} \]
First muon event Jan 2002

Time: Red soon, Blue late

Charge: Red a lot, Blue little
Stopped Muon

KamLAND Event Display
Run/Subrun/Event: 1100/0/19244
UT: Sat Feb 23 15:25:11 2002
TimeStamp: 13052924536
TriggerType: 0x3a10 / 0x2
Time Difference: 28.3 msec
NumHit/Num/Num2/NumHitA: 1317/264/1322/46
Total Charge: 3.21e+05 (465)
Max Charge (ch): 2.22e+03 (640)

Signal in Veto
Entry point
And following Michel Electron

\[ \mu \rightarrow e \nu_e \nu_\mu \]

\[ t_{1/2} = 2.2 \mu s \]

\[ \Delta t \sim 1 \mu s \]

\[ E \sim 10 \text{ MeV} \]
Energy deposition following cosmic ray muons traversing the detector

Using Ecal, the peak is here at ≈ 2.3 MeV

n-capture in hydrogen gives 2.2 MeV

n-capture in hydrogen gives 2.2 MeV

Prompt - delayed correlation time distributed as an exponential with 210±8 s

Expectation for neutron capture is ~223 s
Energy Calibration

$^{60}\text{Co}$: a 2.824 MeV in the detector

$\sqrt{E} = 4.2\%$

Light Yield

239 p.e./MeV
Energy Distribution (singles)

Trigger Nsum Spectrum

- $^{14}\text{C}$?
- $^{210}\text{Pb}$: 102 Hz
- $^{85}\text{Kr}$: 606 Hz
- $^{40}\text{K}$: 1.9 Hz: 2.1 Hz
- $^{208}\text{Tl}$: 3.2 Hz: 1.4 Hz
- $^{232}\text{Th}$, cosmogenic: 0.19 Hz
- High Energy (e.g. _): 0.33 Hz: 0.33 Hz

Source: Measured: Predicted

7Be$^+e$

1 MeV

Counts/second/PMT

Number of KamLAND Phototubes Hit
Anti Neutrino Candidate

Prompt Signal
E = 3.20 MeV
\[ \overline{\nu}_e + p \rightarrow e^+ + n \]

Delayed Signal
\[ \Delta t = 111 \mu s \]
\[ \Delta R = 34 \text{ cm} \]
\[ E = 2.22 \text{ MeV} \]
\[ p \rightarrow d + \gamma (2.2 \text{ MeV}) \]
Neutrino spectrum

Stay tuned
What if KamLAND see oscillations?

Very important step forward

- Conformation of Solar Neutrino oscillations with man made neutrino source
- Precise measurement of mixing parameters
- Test of CP with neutrinos
- More input for Solar model and nuclear astrophysics
What if KamLAND does not see oscillations?

Actually it can be even more interesting.

- LOW, SMA, VAC solutions (disfavored by other experiments)?
- strong $CP$ violation?
- $CPT$ violation?
- ????
What is next for neutrinos?

If will be plenty of work to measure full neutrino mixing matrix and study CP

However, from neutrino oscillations we can learn only that neutrinos have a mass and a difference in masses between mass eigenstates

To fix absolute value of neutrino masses we will need another set of experiments

Direct measurement of end point of beta spectrum gives a limit for the mass of $\nu_e < 2.2$ eV

Next generation proposal, Katrin (planning to start in 2007), has an aim to reach 0.35 eV sensitivity

Other alternative exists if neutrinos are Majorana particle (particle = antiparticle)
Double beta decay experiments

- **DBD2ν**: \((A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu_e\)
- **DBD0ν**: \((A,Z) \rightarrow (A,Z+2) + 2e^-\)

Best limits:
- Heidelberg-Moscow: 10.9 kg of isotopically enriched (86%) \(^{76}\text{Ge}\)
- IGEX three: 2. kg detectors of isotopically enriched (86%) \(^{76}\text{Ge}\)

\(<m_\nu> < 0.35 \text{ eV}\)

New neutrino properties:
- \(\nu = (\nu)^c\)
- \(m_\nu \neq 0\)

Helicity matching

2 electrons sum energy spectra:
Main experimental signature ...
(single electron E and angular distributions)

\(^{76}\text{Ge} t_{1/2}(2\beta2\nu) \sim 1.4 \cdot 10^{21}\text{y}\)
\(^{76}\text{Ge} t_{1/2}(2\beta0\nu) \sim \text{not seen yet}\)
New proposals
(None approved yet)

Goal is to have sensitivity more than order magnitude better than preset limits

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Isotope</th>
<th>Detector description</th>
<th>$&lt;m_\nu&gt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUORE</td>
<td>$^{130}\text{Te}$</td>
<td>760 kg of TeO$_2$ bolometers</td>
<td>0.027 eV</td>
</tr>
<tr>
<td>EXO</td>
<td>$^{136}\text{Xe}$</td>
<td>1t enriched Xe TPC</td>
<td>0.052 eV</td>
</tr>
<tr>
<td>GENIUS</td>
<td>$^{76}\text{Ge}$</td>
<td>1t enriched Ge diodes in liquid nitrogen</td>
<td>0.015 eV</td>
</tr>
<tr>
<td>MAJORANA</td>
<td>$^{76}\text{Ge}$</td>
<td>0.5t enriched Ge segmented diodes</td>
<td>0.025 eV</td>
</tr>
</tbody>
</table>

Atm. Neutrinos $\Delta m^2 \sim 2.4 \cdot 10^{-3} \text{eV}^2 \rightarrow m_i \sim 0.05 \text{eV}$

Getting very interesting !!!!
Conclusion

I listed the experiments which are likely lead us to the proof of neutrino oscillations

But be alert !!!!
Neutrino is very elusive particle.
We know about its presence for ~70 years.
We just started to learn about its properties.

You never know what surprises are around the corner!

Example
Imagine that we are on a hunt:
We are in the forest (100%)
We have a rifle and necessary gear (100%)
We know that deer is somewhere around (100%)

Still we have to find it....
Some times it is a tricky business

With neutrinos it is always like that !!!
If somebody would ask about ORLaND

• We made to the Spring 2001 Long Range Planning Meeting

• We been highly marked by community

• For DOE it was not good enough

• Collaboration always stated that we would like to do it in timely fashion and integrate with SNS construction

• After DOE decision not to proceed with funding in FY 2002, collaboration put the activity on hold.

But we will be back

Physics program is still important !!!

Nuclear Astrophysics

Test of Standard Model

Neutrino Oscillations (MiniBooNE is likely testing LSND in wrong place)
Test of LSND at MiniBooNE (FNAL)

Mineral oil Cherenkov detector

B.G. is 2.5 times large than expected signal
Test is in neutrino not antineutrino mode !!!