Experimental Particle and High-Energy Physics
HEP group at UT

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Will talk to you next week about collider physics
Example from my Past:

experiment L3 at Large Electron-Positron (LEP) Collider at CERN 1989-1995
L3 Detector at LEP constructed during 1980-1989

Hadron Calorimeter in L3 Detector

Reconstructed 100+100 GeV $e^+e^-$ event
How do we know that there are only three generations of quarks and leptons and only three types of neutrinos?

One of the LEP major results:

### Z Decay Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fraction ($\Gamma_j/\Gamma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^- e^-$</td>
<td>(3.363 ± 0.004) %</td>
</tr>
<tr>
<td>$\mu^+ \mu^-$</td>
<td>(3.366 ± 0.007) %</td>
</tr>
<tr>
<td>$\tau^+ \tau^-$</td>
<td>(3.370 ± 0.008) %</td>
</tr>
<tr>
<td>$\ell^+ \ell^-$</td>
<td>(3.3658 ± 0.0023) %</td>
</tr>
<tr>
<td>Invisible</td>
<td>(20.00 ± 0.06) %</td>
</tr>
<tr>
<td>Hadrons</td>
<td>(69.91 ± 0.06) %</td>
</tr>
</tbody>
</table>

**LEP data**

- Average measurements, error bars increased by factor 10
Present experiment KamLAND (>1997)

Search for Neutrino Oscillations with Reactor Anti-Neutrinos
Mounting 17" and 20" PMTs in KamLAND (Summer 2000)
Ratio of Measured and Expected $\bar{\nu}_e$ Flux from Reactor

First KamLAND result (2003)

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{12} \cdot \sin^2\left(\frac{\Delta m_{21}^2 \cdot L}{4E}\right)$$

Disappearance prediction from solar neutrino data


shaded area: prediction from global solar analysis

Statistically the probability that there is NO oscillations is 0.05%

Since 2003 publication this is the most cited paper in HEP (> 1000 citations)

UT graduate students: M. Batygov, Jiang Wei, O. Perevozchikov
Most precision measurement of neutrino mass difference $\Delta m^2$ is provided by KamLAND

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{12} \cdot \sin^2 \left( \frac{\Delta m_{21}^2 \cdot L}{4E} \right)$$

$\Delta m^2 = 7.9^{+0.6}_{-0.5} \times 10^{-5} eV^2$

$\tan^2 \theta = 0.40^{+0.10}_{-0.07}$
First Detection of Geo-antineutrinos in KamLAND (2005)

Antineutrinos are geologically produced in Earth by long-lived isotopes of $^{238}$U, $^{232}$Th, and $^{40}$K.
Low-energy antineutrino spectrum in KamLAND
(152 candidates; total background 127±13)

- First measurement of geo-ν
  Beginning of neutrino geophysics!

- Number of geo-ν observed is between 4.5 and 54.2 at 90% CL

- Measurement is consistent with current geological models

- Radiogenic Earth power is constrained to less than 60 TW at 99% CL. Geophysics measurements give: 41±1 TW (Pollack, 1993) 31±1 TW (Hofmeiser, 2005)
Example of software development work of UT PhD student M. Batygov (2006) (best in Collaboration vertex reconstruction algorithm)

Kat Vertex Fitter

V2 Fitter

data ($^{68}$Ge, centre) including 20” PMT charge dispersion (from Kyohei Nakajima)

\[ \sigma = 22.3 \text{ [cm]} \]

\[ \sigma = 12.2 \text{ [cm]} \]
Survival probability of reactor antineutrinos in case of three flavor oscillations:

\[
P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \cdot \sin^2 \left(\frac{\Delta m^2_{31} \cdot L}{4E}\right) - \cos^4 \theta_{13} \cdot \sin^2 2\theta_{12} \cdot \sin^2 \left(\frac{\Delta m^2_{21} \cdot L}{4E}\right)
\]

Presently measured to be < 0.16
Can be determined from precision measurement of reactor antineutrino flux

Is \(\theta_{13} \neq 0\) ?
Future of neutrino physics will depend on this answer.

Near Future: Double Chooz experiment in France
The Double-Chooz concept

8.4 GW_{th}
Chooz PWR station

\[ \bar{\nu}_e \]
\[ \bar{\nu}_e, \mu, \tau \]

D_1 \sim 350 m

New site
Near detector

D_2 = 1,050 m
Far detector

Existing Chooz site

DC is going to start measurements in 2009

UT group is working on photo-detection in DC together with groups from Japan, US and Spain
Double-Chooz, Ardennes, France

UT graduate students Ben Chevis and Brandon White are working on DC
Our group recently joined NO\nuA

**NO\nuA**

NuMI Off-axis $\nu_e$ Appearance

- $\nu_\mu \rightarrow \nu_e$ appearance measurement
- Measurement of parameters of neutrino mixing matrix
- Determining mass ordering of neutrinos
- Measure CP violation effect with neutrinos

NO\nuA will start operation in ~ 2012
Far Future: NNbar experiment at DUSEL

Deep Underground Science and Engineering Laboratory

to be built at Homestake mine in South Dakota

NNbar stands for neutron → antineutron transformation search

New national facility being created by NSF http://www.dusel.org
Transformation of matter to antimatter? How is it possible?

- Transformations of matter to antimatter is known for many years to occur e.g. with neutral kaons →

- It occurs when some approximate symmetries are broken. Noether’s theorem. E.g. in kaon → anti-kaon transformation strangeness quantum number is violated.

- Majorana neutrinos (future possible observation in neutrinoless double β-decay) would violate Lepton number.

- n → ¯n would violate Baryon number that we know is violated in nature, but so far it was not directly observed.

Why is it needed?

- New force of nature. New Physics beyond the Standard Model. Understanding of Unification of other forces. Possible explanation of matter-antimatter asymmetry of the Universe. Connected to new physics to be observed at Colliders. See recent workshop (Sept. 2007) organized at LBNL: http://inpa.lbl.gov/blnv/blnv.htm
Scales of $n \rightarrow \bar{n}$

Largest Collider

Low QG models


Mohapatra & Marshak (1980)

Left-Right symmetric GUT

Non-SUSY models

Supersymmetric Seesaw for $\nu$

SUSY GUT

Plank scale

$\sim \mathcal{U}_{B-L}^{-5}$

Mohapatra & Marshak (1980)

$\sim \mathcal{U}_{B-L}^{-2} \cdot \mathcal{U}_{WK}^{-3}$


Scale improvement from new measurement
How $NN\bar{n}$ can be done at DUSEL? at Homestake mine in SD
Neutron source needed:
small power 3.4 MW
TRIGA reactor

TRIGA Reactor picture courtesy of General Atomics
Schematic of NNbar Experiment at DUSEL

Annular Core TRIGA Reactor 3.4 MW with convective cooling. 2E+13 n/cm²/s central thermal flux.

Approximate scales: 1 m, 10 m.

10⁻⁵ Pa beam dump, 6Li, cosmic veto, calorimeter, tracker.

Neutron trajectory, transition point, annihilation target, dia ~ 2 m.
Annihilation detector.

Vacuum tube L~1000 m dia ~ 4 m.

If approved by funding agencies, N-Nbar experiment will start in ~ 2015.

Not to scale.
UT HEP group supports with DOE grant Master and PhD research of small number of highly motivated students
Particle Physics, Astrophysics, and Cosmology Seminar

you might like to start attending from the next semester.

It is P599 class (section 599003) = 1 credit hour

seminar meets on Wednesdays at 3:30 pm

http://hep.phys.utk.edu/~physics/