Fermilab Theory Group

Christopher T. Hill
Theoretical Physics Dept.
Fermilab

DOE Annual Program Review
Fermilab, March 23-25, 2004

Theoretical Physics Department Personnel 2003/2004

Scientists (11)

Bill Bardeen
Marcela Carena
Estia Eichten
Keith Ellis
Walter Giele
Christopher Hill
Andreas Kronfeld
Joe Lykken
Paul Mackenzie
Stephen Parke
Chris Quigg

Associate Scientists (2)

Bogdan Dobrescu
Ulrich Nierste

Frontier Fellows(3)

Aida El-Khadra
Scott Willenbrock
Peter Zerwas

Distinguished Guest Scientist (1)

Boris Kayser

Research Associates (8)

Ayres Freitas
Masataka Okamoto
Tim Tait
Ulrich Haisch
Eduardo Ponton
Giulia Zanderighi
Olga Mena
Zack Sullivan

Users

C. Albright (NIU)
A. El-Khadra (Illinois)
Alex Kagan(Cincinnati)
S.P. Martin (NIU)
Y. Keung (UIC)
Ulrich Baur (Buffalo)

Personnel Changes

- Departures:

  Andreas De Gouvea→ Northwestern, (Asst. professor)
  Yasunori Nomura→ Berkeley, (Asst. professor)

- New Postdoc Hires Fall, 2003:

  Olga Mena (from Madrid),
  Giulia Zanderighi (from Durham)

- New Postdoc Hires Fall 2004:

  Jack Laiho (from Princeton),
  Peter Skands (from Lund),
  Jose Santiago (from Durham)

- Associate Scientist Search:

  Thomas Becher (offered)

- History of the Post-Docs, Associate Scientists and Frontier Fellows is posted on the web:

  http://theory.fnal.gov/people/ellis/alumni.html
  http://theory.fnal.gov/people/ellis/Assoc.html
  http://theory.fnal.gov/people/ellis/frontier.html

Visitor program

The Fermilab visitor program has long been part of the Fermilab Theory group.

- **Frontier Fellows**

  Senior distinguished visitors spending research time at Fermilab.

  (About 5 in 2002/2003)

- **Summer visitors**

  About 30 visitors spending about one month during the summer.

- **Short term visits**

  Scientific collaborators and workshop participants.

- **Speakers**

  Theoretical seminar (53 speakers in 2002)

  Joint Experimental-Theoretical Seminar

  (44 talks in calendar 2002).

Frontier Fellows

The Frontier Fellows Program allows active senior physicists to spend time at Fermilab

Vernon Barger (10-12/98)	Thomas Appelquist (10-12/98)
Howard Haber (9-12/98)	Pierre Ramond (6/99; 5/00)
Stuart Raby (2-6/99)	Steve Ellis (3-6/00)
Wu-Ki Tung (2-6/00)	Moshe Moshe (3-9/00)
Stefan Pokorski (9-12/00)	Mariano Quiros (9-12/00)
Jo Anne Hewett (9-12/00)	Alexei Yu. Smirnov (4/01)
Mariano Quiros (9-12/01)	Steve Gottlieb (9-6/02)
Ken Lane (9-2/02)	Ulrich Baur (2-4/02)
Eric Braaten (10-12/02)	Scott Willenbrock (7-12/02)
Aida El-Khadra (7-12/02)	Peter Zerwas (9-11/03)

HEP and Community Service

- M. Carena NSERC Grants committee, Canada
  Linear Collider Octet.
- B. Dobrescu Director's Fixed Target Review.
- E. Eichten APS Investment Sub-committee
- R. Ellis Scientific Program Sub-committee, LP2003
- C. Hill Fermilab Long Range Planning Committee; Saturday morning physics, Organized VLHC workshop
- B. Kayser P5, Academic Lectures
- A. Kronfeld Linear Collider Octet.
- J. Lykken PAC, EPAC, TASI, MUTAC, Aspen, Director Search Committee
- P. Mackenzie DOE SciDAC, National Committee
  Advisor to KEK on Large Scale Simulation.
- U. Nierste Chicagoland Flavor Workshop
- S. Parke Co-organizer: Nuhorizons, Academic Lectures
- C. Quigg Past chair of DPF, HEPAP,
  Program committee APS Albuquerque 2002 (chair), IMSA Board

Current Research Activties

- Beyond the Standard Model
  Carena, Dobrescu, Hill, Lykken, Ponton, Tait
- Supersymmetry Phenomenology
  Carena, Nierste, Freitas
- Linear Collider Physics
  Carena, Kronfeld, Freitas
- Neutrino Physics
  Kayser, Mena, Parke, Quigg
- Flavor Physics
  Bardeen, Eichten, Hill, Nierste, Haisch, Quigg
- Lattice Gauge Theory
  Bardeen, Eichten, Kronfeld, Mackenzie, Okamoto
- Perturbative QCD
  Ellis, Giele, Sullivan, Zanderighi

A Coming Revolution In Particle Physics!

- What Causes Electroweak Symmetry Breaking?

  Bardeen, Carena, Dobrescu, Eichten, Hill, Lykken, Quigg, Ponton, Tait

- Is Supersymmetry Associated with the Phenomenon?

  Carena, Dobrescu, Nierste, Freitas

- Are Extra Dimensions to be found near the Electroweak Scale?

  Carena, Dobrescu, Hill, Lykken

- What is the Origin and Physics of Neutrino Mass?

  Kayser, Mena, Lykken, Parke, Quigg

- What are the Indirect Signatures in Flavor Physics?

  Bardeen, Eichten, Hill, Nierste, Haisch, Quigg

- How do we Extract New Physics that's buried under QCD?

  Lattice: Bardeen, Eichten, Kronfeld, Mackenzie, Okamoto

  Perturbative: Ellis, Giele, Sullivan, Zanderighi

- How is New Physics Connected to Cosmology?

  Carena, Hill, Lykken, Quigg, Tait

Heavy-light mesons $\rightarrow$ "tethered" constituent–quark.

Bardeen, Hill, Eichten, hep-ph/0305049

QCD Gedanken Experiment: Modify QCD to restore both *explicit* and *spontaneously broken* light–quark chiral symmetries but maintain the confinement? Constituent–quark becomes massless – chiral symmetry exact! Heavy-Light Meson stays heavy!

$SU(3)_L \times SU(3)_R$ Orthogonal linear combinations:

$$H_R \sim \frac{1}{\sqrt{2}}(H(0^+, 1^+) + H(0^-, 1^-)) \leftrightarrow (1, 3)$$

$$H_L \sim \frac{1}{\sqrt{2}}(H(0^+, 1^+) - H(0^-, 1^-)) \leftrightarrow (3, 1)$$

Parity: H_R and H_L degenerate: $\rightarrow (0^-, 1^-)$ groundstate degenerate with $(0^+, 1^+)$ multiplet.

"Parity Doubling" of H-L Mesons in Chiral Symmetry Limit

Lifted by Constituent Quark Mass (Spontaneous Chiral Symmetry Breaking)

Main pionic decays $(0^+, 1^+) \rightarrow (0^-, 1^-) +$ "π", satisfy Goldberger–Treiman relation, $g_\pi = \Delta M / f_\pi$; ΔM is the $0^- 0^+$ mass difference.

Analogue of the Nucleon Mass: $g_{NN\pi} = m_N / f_\pi$

g_π is the $0^+ \rightarrow 0^- \pi$ coupling constant, $\sim g_{NN\pi}/3$

$D_s(2317)$ is first clear observation of general phenomenon.

Predicted Resonance Spectrum:

Center of mass of any $(0^+, 1^+)$ flavor multiplet will have a universal $\Delta M(m_Q)$.

Predict:

$$
\begin{aligned}
M(D_s(1^+)) &= 2460 \text{ MeV} \\
M(D^{\pm}(0^+)) &= 2122 \text{ MeV}; \\
M(D^{\pm}(1^+)) &= 2263 \text{ MeV}; \\
M(D^0(0^+)) &= 2117 \text{ MeV}; \\
M(D^0(1^+)) &= 2260 \text{ MeV}
\end{aligned}
$$

Predict:

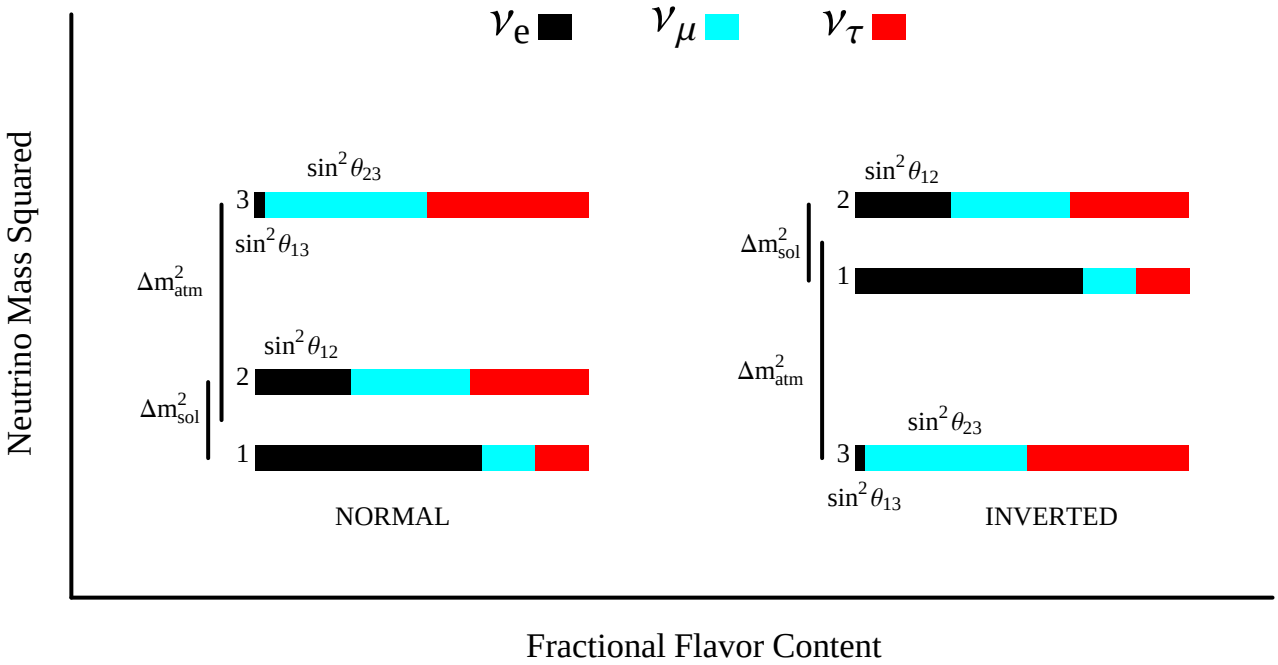
$$
\begin{aligned}
M(B^{\pm}(1^+)) &= M(B^0(1^+)) = 5579 \pm 35 \text{ MeV} \\
M(B_s(1^-)) &= 5417 \text{ MeV}. \\
M(B_s(0^+)) &= 5718 \pm 35 \text{ MeV} \\
M(B_s(1^+)) &= 5765 \pm 35 \text{ MeV}.
\end{aligned}
$$

These will be narrow analogues of $D_s(2317)$ $D_s(2460)$. Many mesonic and photonic transitions predicted.

Determination of Neutrino Mass Hierarchy in Long Baseline $\nu_\mu \to \nu_e$ Experiments:

Minakata, Nunokawa, Parke hep-ph/0301210

Mena, Parke hep-ph/0312131



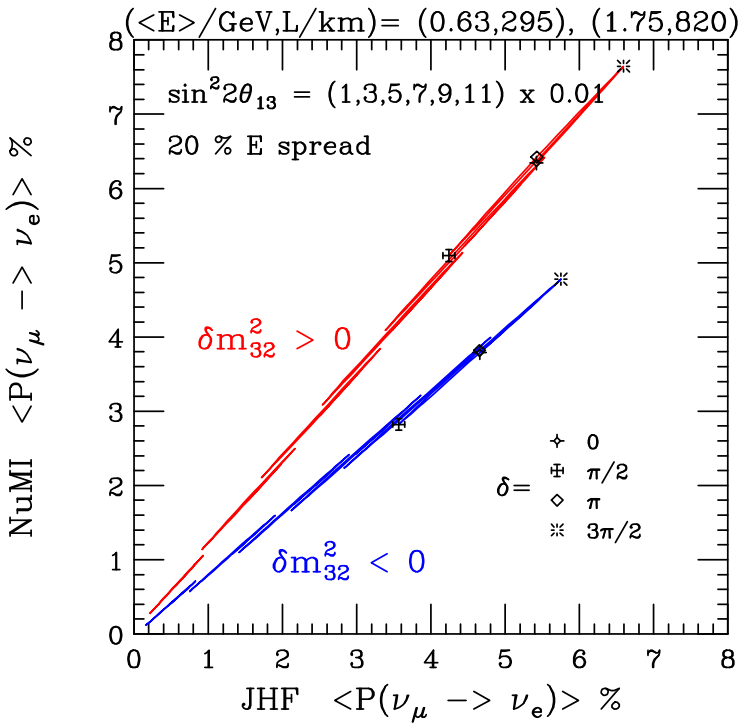
Compare JParc neutrinos with NuMI neutrinos with:

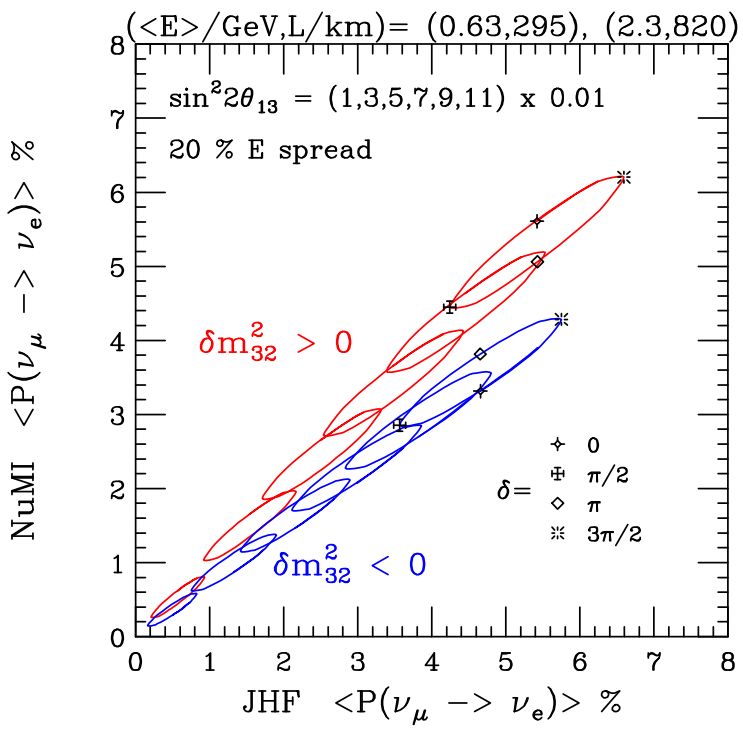
$$\frac{E}{L}\Big|_{NuMI} \leq \frac{E}{L}\Big|_{JHF}.$$

At Vacuum Oscillation Maximum $\frac{\delta m^2 L}{4E} = \frac{\pi}{2}$ find:

P_{NuMI}/P_{JParc} = (1.2 or 0.8) for normal or inverted hierarchy.

Approximately 100 events in each experiment determines hierarchy.


(<E>/GeV,L/km)= (0.63,295), (1.75,820)
$\sin^2 2\theta_{13}$ = (1,3,5,7,9,11) x 0.01
20 % E spread
$\delta m^2_{32} > 0$
$\delta m^2_{32} < 0$
$\delta =$ 0 $\pi/2$ π $3\pi/2$
NuMI <P(ν_μ -> ν_e)> %
JHF <P(ν_μ -> ν_e)> %


(<E>/GeV,L/km)= (0.63,295), (2.3,820)
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Instantons in $D = 4 \leftrightarrow D = 5$

Dobrescu, Hill, Ponton, Tait

In $1 + 3$ on the brane, the fermionic axial current must satisfy anomaly relation:

$$\partial_\mu j^{\mu A} \quad = \quad F_{\mu\nu} \widetilde{F}^{\mu\nu}$$

For Euclidean 4-volume have Stokes theorem:

$$\int_V d^4x \; \partial_\mu j^{\mu 5} \quad = \quad \int_{\partial V} d\Sigma^\mu j^5_\mu$$

Σ is 3-surface bounding Euclidean 4-volume on the brane.

In $1 + 4$ the anomaly is a conserved current flowing off brane:

$$F^a_{\mu\nu} \widetilde{F}^{a\mu\nu} \quad \longrightarrow \quad \epsilon_{A\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma} \equiv Q_A \ ,$$

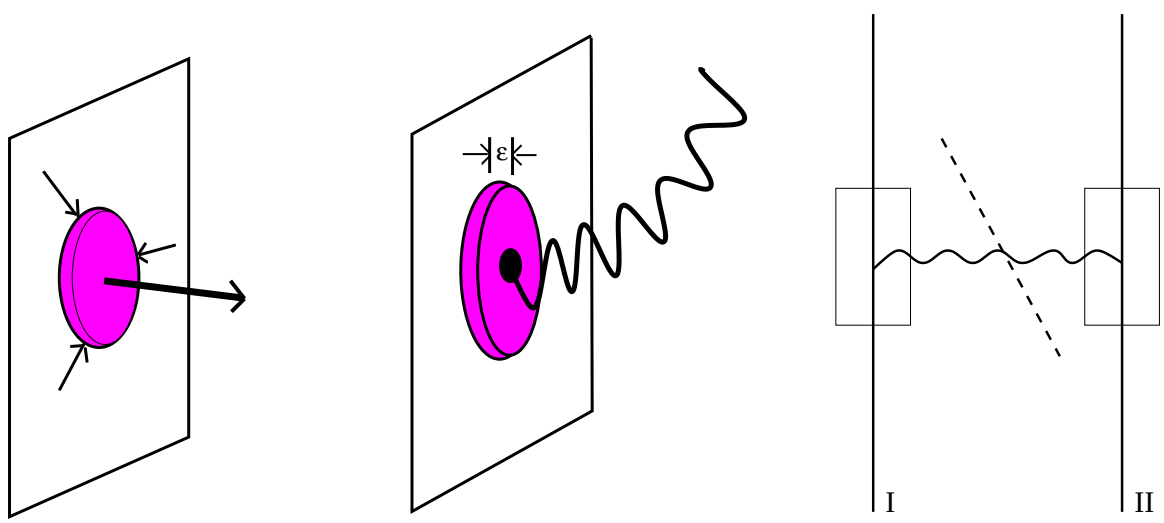
Conservation of $Q^A \rightarrow$

$$\int_{\partial V} d\Sigma^\mu j^5_\mu \quad = \quad - \int'_{\partial V} d\Sigma^A_4 \; Q_A$$

Axial current can flow into a region of brane and disappear into the bulk.

Ordinary $D = 4$ instanton is emission and absorption vertex for soliton $\rightarrow$ Modified picture of the $U(1)$ and θ problems, but also baryon number violation.

Ordinary instanton can be viewed as current discharge between capacitor (branes).



$\sim \exp(-M\delta) = \exp(-8\pi^2/g_0^2)$.

Application to Baryon Number Violation is $SU(2)_L \rightarrow SU(2)_1 \times SU(2)_2$ Models (deconstructed extra dimension). Potentially very large effects.