Neutrinos, they are very small
They have no charge and have no mass
And hardly interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold shoulder steel and sounding brass,
Insult the stallion in his stall,
And scorning barriers of class,
Infiltrate you and me! Like tall
And painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed—you call
It wonderful; I call it crass.

John Updike

Acknowledgments

What a long, strange trip it has been. The time I've spent working on my doctorate has been a period of great mental, physical, and spiritual change for me. With the deposit of this thesis, I've completed one major goal of my life: to become the third-generation Dr. Seligman in my family (the first two were MD's, whereas I am a PhD). As I stand at the end of my journey as a student of physics, I want to thank the friends and teachers who guided me to this point in my life. If you're bored by lengthy expressions of sentimentality, turn to the Table of Contents on page vii and start reading the thesis. If you're offended when such expressions are spiced with a dash of humor, again go to page vii. Otherwise, please read on.

Michael Shaevitz was my thesis advisor. He is well-suited to the job of advisor, because his advice was always excellent. At the first meeting we had as advisor and grad student, he told me, "To be a good physicist, physics should not only be your job, but your hobby." Not a day has gone by that I haven't recalled those words. The analysis described in this thesis turned out to be more complex than either of us expected it to be, which partly explains why this thesis is more than 400 pages long. (The rest of the explanation is our desire to share all the details of the analysis, our wish to include all the results, my natural prolixity, and my use of double-spaced paragraphs.) Throughout it all, Mike remained a good teacher, patient, understanding, and exhibiting a true love of physics. I shall be forever grateful that he made the time I spent at Nevis a positive and educational experience. A few years ago, Mike and I played a game of pool at the Fermilab User's Center. To make the game more interesting, we bet my thesis: if I won, Mike would write my thesis for me. So, if you like this thesis, please remember that Mike is a dedicated physicist and academician who would never allow the outcome of a pool game to affect his ethical standards. If you don't like this thesis, well… Mike lost the game.

When Janet Conrad first came to Nevis Labs to interview for the job of post-doc, I told her, "As you look around Nevis, remember that you're making an important decision. You can work with the finest physicists in the world, do work on the leading edge of scientific study, achieve world-wide recognition for the research that you do… or you can work here." Fortunately for me, Janet laughed at my feeble attempt at humor. She came to work at Nevis, became an assistant professor, and proved my joke to be the lie that it was. Janet didn't take my joke seriously, but she took me seriously. On her own initiative, she reviewed my thesis, pointed out errors and gaps in logic, indicated those places where I should mention the work of others and helped me to locate the references, and aided me in obtaining data for plots. Basically, she made Mike Shaevitz's life easier by making me fix the mistakes before he read the thesis. She also helped to prepare me for the rigors of the thesis defense. I am grateful to Janet, the Pheobe Fingerlilly of high-energy physics, for all the assistance she provided.†

The closest connections one forms in graduate school are with one's fellow grad students. Let's begin with the denizens of the infamous Room 116, the social center of Nevis Labs:

Walter Lefmann was my best friend during my time as a graduate student. I enjoyed the time I spent at Fermilab during the run of E770, and Walter was the most important reason why. Afterwards, as we both analyzed the data, Walter was always available to offer advice when asked: how to repair a car, how to fix a snapped-off shower head, or how to dress in costume for the Renaissance Faire. We also shared many interests: science fiction, D&D, martial arts, and Macintoshes. Unfortunately, Walter and I are now

† Pheobe Fingerlilly was the "real" name of Nanny in the 1970's TV series *Nanny and the Professor*. In the series, when Nanny was around, everything would come out for the best. It was never made clear whether this was due to coincidence, magic, or a lot of off-stage work on Nanny's part. In Janet's case, I suspect it's hard work.

separated by 800 miles and we communicate mostly by e-mail. I will always remember what his friendship meant to me. I shall also remember the Lefmann-Seligman Treaty: if one of us wins the Lottery, he must buy the other one the most powerful Macintosh available at the time. May the fulfillment of that treaty come soon!

Of all my office mates, Steve Rabinowitz was the most educational. He'd listen to WBAI, an ultra-liberal radio station, until 12 noon. Then he'd switch channels to Rush Limbaugh. The dramatic political shift from left to right always made us dizzy. A political discussion with Steve was often frustrating, but it was never dull. He also had the ability to send me into fits of uncontrollable laughter. Good luck, Steve, wherever you are.

Andrew Bazarko could not abide the long-standing Room 116 practice of reversing the gears on the office clock so that it ran backwards, and set the time to move forwards again. (The interior decorators of Room 116 have since reset the clock to its natural spin -1 state). Andrew was the epicure of the office. What little I know of good food, good wine, and QCD factorization comes from conversations with him. Andrew also supplied the right words when words failed me. I wish him the best of luck as he pursues his career in high-energy physics.

Carlos Arroyo does not like attention. In fact, he probably wishes I didn’t mention him here. His expertise in statistics was invaluable, and I could always turn around and bounce ideas off him. Thanks for the help, Carlos.

Cindy McNulty came to Room 116 while waiting for her X-terminal to be installed in her own office, but it turned out she came to stay. She has the toughest job of anyone I know: she’s both a grad student and a single mother. Cindy has my thanks for providing transportation when my car, the Talamobile, was in the shop. She also has my thanks for proving that my high-x results were right after all.

Now let's meet some of the graduate students outside of Room 116.

When I was living at Fermilab, I woke up one night with chest pains. I couldn't drive, so I asked Bruce King if he could drive me to the Fermilab medical center. It was closed. He drove me around for an hour, as I clutched my chest and tried to breathe, and we went from one closed clinic to another. Finally he brought me to the emergency room of DuPage Hospital, where I was diagnosed with a bad case of indigestion. So, since I can't thank Bruce for saving my life, I'll thank him instead for the muon calibration.

Since I've mentioned Walter and Bruce, I must also mention the remaining member of the Nevis Cold Fusion Team: Paul Stankus. When I grew discouraged with physics, Paul reminded me of the joys of science, in part through his instigation of our own private cold-fusion experiment. (I wish I could tell you the results of our study, but the patents have not yet been accepted.) Paul also renewed my faith in science education when he told me that any student in his celestial mechanics class could calculate the Deimos-Venus ballistic-trajectory problem posed in Robert Heinlein's novel *Space Cadet.* Wherever Paul is now, I hope his co-workers can keep up with him.

Sanjib Mishra, Paul Quintas, and Wing Cheong Leung were responsible for the previous analysis of the E744/E770 charged-current data. Ed Oltman performed the charged-current analysis on the E616/E701 data. I tried to maintain their traditions of quality in my own work, and I hope they find the analysis in this thesis to be up to their standards. Frank Sciulli was the thesis advisor for all these students, and was always available when I had questions on the work they'd done.

The Nevis staff provided me with an excellent environment in which to work. Ann Therrien kept my feet on the ground, Dorothy Palmer made sure the ground was stable, Bob Peters and Gail Smith made sure I had shoes on my feet, and Don Bunch kept

pulling my leg. Have I overworked the foot metaphor, or can I thank Dave Leon, who kept the Nevis computers running? I also wish to thank the Nevis machine-shop personnel: Lubo Kral, Ed Anderson, Dave Thomas, Paul Betts, Ralph Gardner, and the late John Perticare; they taught me that precision is important, whether building the SLD Endcap Calorimeter or a wizard's staff.

I must also give thanks to members of the CCFR collaboration from institutions other than Columbia. Wesley Smith was the project spokesman for E770, and provided the co-ordination that allowed me to work with the others on the project. Tim Bolton's expertise in statistics led to the global systematic fit technique that allowed for a precision measurement. I could tell more stories about the individual members of the CCFR collaboration and those of the new experiment, NuTeV. Instead I'll give a general thanks to Kurt Bachmann, Bob Bernstein, Arie Bodek, Fred Borcherding, Howard Budd, Pawel de Barbaro, Costas Foudas, Debbie Harris, Drasko Jovanovic, John Kim, Tim Kinnel, Mike Lamm, Bill Marsh, Frank Merritt, Donna Naples, Mark Oreglia, Alex Romosan, Willis Sakumoto, Pamela Sandler, Heidi Schellman, Panagliotis Spentzouris, Eric Stern, and Masoud Valiki.

The help I received was not restricted to the mundane world of physics. My folks, Stephen and Hannelore Seligman and Beatrice and Robert Prentice, gave me support during these years of work. Don Buskard and Bill Brady gave me support of quite another kind. I introduced Dan Holzman to high-energy physics, and he introduced me to Wicca; we both think it was a fair trade. I also received aid and comfort from a special circle of friends: Rosie, Tom, Kenny, Nancy, Isaac, Connie, Vann, Dave, Michele, Deborah, Roberta, Jennifer, Lisa, and Dan; and to this list I can now happily add beloved Susan. There's a warm place in my heart, and an icy spell on my lips, for the men,

women, elves, dwarves, and trolls of Boy Scout Explorer Post #510, the Live-Action Role-Playing Explorers—Winston Waterston sends his greetings from Wainscoting.

On the spiritual level I dedicate this thesis to Brigid, the Celtic Goddess of inspiration and intellect. On the mundane level, I wish to acknowledge the contributions of three of my Columbia physics teachers who, unfortunately, passed away during the time I was a graduate student. (A fourth Columbia physicist and teacher, Professor Gerald Feinberg, also passed away during this time, but I never had the fortune to be in a class he taught; I never met the late Professor I. I. Rabi.)

Professor James Rainwater was a Nobel Laureate, but I knew him as the teacher of the advanced physics lab course on the sixth floor of Pupin. I can still hear his admonition to use the $\hat{T} - \hat{H} - \hat{I} - \hat{N} - \hat{K}$ operator. His desire to teach exceeded his physical limits, but he never let that stop him. He remains an inspiration for me to this day.

When Paul, Walter, Bruce, and I decided to attempt the Nevis Cold Fusion Project, we went to **Professor Alan Sachs** for approval. He made sure we understood what we were doing, what electronics and materials were available at Nevis, what the physics of the phenomenon were, and why we couldn't expect to see any result at all with the equipment at our disposal. Then he authorized the expenditure of a small amount of money to buy D_2O and palladium. He let us play our game, as long we acted like scientists.

If it wasn't for **Professor Jacob Shaham**, I would never have made it through my first year of graduate school. When I had difficulty in advanced quantum mechanics, he made time to sit down with me and work through problems. Whatever skills I've acquired as a physicist I owe to him.

It is to these physicists and teachers that this thesis is dedicated.