THE UNIVERSITY of WISCONSIN MADISON

November 25, 2012

Dear Colleagues:

It is a pleasure to write in support of **Jennifer Kile's** application for a post-doctoral position in your group. Jen is currently a post-doc in the particle theory group at Northwestern University. She completed her Ph.D. at Caltech, where Mark Wise and I jointly supervised her. She is a creative and independent physicist who likes to think outside the box, qualities I observed in her work with me at Caltech. During that time, I was impressed by her willingness to tackle a diverse set of research problems; her ability to master both the physics of each problem as well as the technical machinery needed to make a valuable contribution; her patience and persistence in asking probing, self-critical questions rather than rushing to publish results; and her ability to clearly and effectively communicate to others the context and significance of her research results.

At Brookhaven, Jen branched out by working with Soni on three nice papers: one on lepton flavor violation in top quark decays and two on novel dark matter scenarios and their phenomenology. The last was an intriguing paper on light dark matter and the possibilities for its detection in neutrino experiments. This work – which I believe was essentially Jen's idea -- illustrates her knack for looking at problems from a different angle rather than simply following the phenomenology crowd. At Northwestern, she and Andre de Gouvea recently wrote an interesting paper on dark matter "polyplets" – copies of multiplet fermions that for a 125 GeV Higgs boson and constitute a component of the observed relic density. I am sure that Soni and Andre will describe these projects in details, so I will concentrate on the work Jen and I did together in what follows.

The two projects that Jen worked on with me span the spectrum of energy scales of interest to particle and nuclear physics. Our first project involved analyzing the implications of neutrino mass on dimension six operators that can contribute to muon decay. Precise measurements of muon decay parameters – the so-called Michel parameters – have recently been carried out by the TWIST Collaboration at TRIUMF and by Danneberg *et al.* at PSI. With the context of specific scenarios for physics beyond the Standard Model (SM), studies of the Michel spectrum and positron polarization place stringent limits. In left-right symmetric models, the resulting bounds on the mass of a right- handed W boson can be comparable to those obtained from Tevatron W_R searches.

One may also use the muon decay studies to derive model-independent information on dimension six beyond the Standard Model (BSM) operators. Some time ago, it was pointed out by Prezeau and Kurylov that BSM operators containing both left and right-

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handed neutrino fields can also be constrained by neutrino mass. Since these operators involve a chirality flip, they can contribute to the neutrino mass operator through loop effects. In the absence of fine tuning, the scale of neutrino mass implies naturalness bounds on the operator coefficients entering these loops. In the original work of Prezeau and Kurylov, it was argued that the strongest limits derive from two-loop radiative contributions to neutrino mass. The computation, however, was carried out using a set of effective operators that were not invariant under SM symmetries and, thus, were not appropriate for consideration of effects derived from new physics above the electroweak scale. In our work, Jen developed a complete set of gauge invariant, dimension six effective operators that could reflect the presence of BSM physics above the electroweak scale and that could be used to perform a consistent analysis of both muon decay and radiative contributions to neutrino mass. She carried out a full, one-loop renormalization group analysis of dimension six operator mixing as well as a study of matching onto the dimension four neutrino mass operator. She also carefully analyzed the flavor structure of the operators in a way that had not been done in the original work on this problem.

Jen's analysis led to two important conclusions. First, she found that there existed one-loop bounds on most – but not all – of the dimension six operators containing RH neutrino fields that also contributed to muon decay. The corresponding neutrino mass naturalness bounds on the contributions to muon decay parameters are, thus, considerably stronger than originally proposed and several orders of magnitude more stringent than the new bounds obtained by the TWIST collaboration. Second, a careful analysis of the dimension six operator flavor structure showed that there exist operators that can contribute to muon decay but not to neutrino mass, thus evading the naturalness bounds – even beyond one-loop order. Thus, not all of the Michel parameter implications are as airtight as suggested by the original publication. These results of Jen's analysis have, understandably, generated considerable interest in the muon physics community.

Jen's second project with me was to study the effects of dimension six operators on Higgs production at a linear collider. After completing the muon decay project, Jen asked whether there could be implications of our effective operator bounds for high energy experiments. In discussing the possibilities, we realized that some of the operators contributing to both neutrino mass and muon decay could also modify the SM Higgs production cross sections in e^+e^- annihilation since these operators contained one or more Higgs fields. Moreover, the implications of these operators for Higgs production had not been considered previously in the literature. Although Barger *et al.,* had analyzed the implications of purely bosonic dimension six operators for Higgs production in e^+e^- annihilation, no one had performed the corresponding analysis for operators containing fermion fields. In fact, the 2005 Snowmass Higgs Working Group report identified this analysis as one that had not been – but should be – carried out.

In order to undertake this analysis, Jen quickly acquired the necessary technology to compute Higgs production cross sections generated by the dimension six operators, first

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working out the analytically tractable Higgstraahlung cross sections and then employing the calchep program to compute the more difficult phase space integrals for the WW and ZZ fusion processes. She subsequently obtained limits on the operator coefficients from existing precision electroweak data (primarily from the Z-pole observables), amplifying the well-known 1999 study of Barbieri and Strumia to include operators having RH neutrino fields that are not as well constrained by Z-pole observables. Jen found that despite the tight bounds on many operator coefficients, one could expect substantial deviations of Higgs production cross sections from SM expectations at a 500 GeV or 1 TeV linear collider. She also found that were it not for the neutrino mass naturalness bounds, some of the operators containing RH neutrino fields might also lead to noticeable effects. Thus, taking into account these neutrino mass considerations could have interesting implications for the interpretation of future Higgs production studies – especially if deviations from SM expectations are found. Although this work was published shortly before the real start of the LHC era, discovery of the 125 GeV Higgs-like boson has invigorated discussions of a Higgs factory, for which operator analyses like Jen's would be quite relevant.

In working with Jen on both of these projects, I became convinced that she has what it takes to identify interesting problems in particle phenomenology that are relevant to both high- and low-energy experimental efforts, acquire the tools necessary to obtain interesting results, and carry each project through to completion independently with minimal guidance from me. In our work on Higgs production, I learned as much from her as she has from me. Conference talks on her research have been well received. Although she is not as prolific as some of her peers, she has an independent, think-outside-the-box approach that is creative and valuable for the field even if it leads to fewer papers than mainstream phenomenology. I continue to see her as a physicist with real promise, and I encourage you to give her application serious consideration.

Sincerely,

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