DOE Progress Report

Task D

November 2011

Y. Meurice and M. H. Reno

Task D consists of two theorists, Y. Meurice and M.H. Reno. Our report consists in a brief summary of the recent progress of each of the two members in alphabetical order, a list of articles written or published since November 2010, a list of recent talks, and a list of graduate students involved in our research programs.

Our current budget (March 2011-February 2012) is 100K. Our proposed budget for March 2012 to February 2013 is $119,623. This includes travel to the Lattice conference (in Australia in 2012) for one faculty and two graduate students in their final year before graduation. Attending this conference at this stage of their career is crucial for their future employment.

Accomplishments and Planned Activities of Yannick Meurice

Summary of Recent Progress

- We proposed new methods to extend the Renormalization Group (RG) transformation to complex coupling spaces and found that the Fisher's zeros are located at the boundary of the complex basin of attraction of infra-red fixed points. The scaling of the Fisher's zeros with the volume allows to decide whether models are confining or not. The results appeared in *Phys. Review Letters* **104** in 2010.

- Two recent papers in *Phys. Rev.* **D 83** in 2011 show that the RG flows approximately follow the Fisher zeros along the separatrice between different basins of attraction. Two preprints describing the Fisher's zeros for the 4D $U(1)$ and $SU(2)$ lattice gauge theories are at an advanced stage. Calculations for $SU(3)$ with various numbers of flavors are in progress. We plan to use this method to settle controversies regarding the conformal window for possible candidates for BSM Physics.

- Our student Daping Du has been awarded a URA fellowship to stay at Fermilab in spring and summer 2011 and work with the Fermilab lattice group. He calculated a ratio of form factors that allows to determine the branching ratio for the decay $B_s \to \mu^+\mu^-$ (which is sensitive to BSM Physics) in terms of numbers of events observed experimentally.

- In order to understand the large order behavior of perturbative series in QCD, we have started to do simulations for the $SU(2)$ perturbative coefficients of the average plaquette in lattice gauge theory with Francesco di Renzo. A proposal of class C for this project was approved and Fermilab computer facilities are now being used.

- Our student Alan Denbleyker has build a new cluster with nodes having 4GB of Ram and 2.33Ghz Core2 Quad processors which is now fully operational.

- The idea of using optical lattices to do lattice gauge theory calculations has received interest from both the atomic physics and lattice gauge communities and could lead to funding from Atomic and Molecular physics.

- The visibility of our research program has increased significantly as witnessed by invited talks and recent organization of workshops. One proposal for a five weeks program at the Kavli Institute for Theoretical Physics in China in July-August 2012 has received final approval from the board.
(see http://www.kitpc.ac.cn/program.jsp?id=PC20120724).

- I was a guest editor for the a theme issue of the Phil. Trans. A of the Royal Society on recent applications of the RG method. The issue appeared in June 2011 (see http://rsta.royalsocietypublishing.org/content/369/1946.toc)

- Daping Du graduated in June 2011 and got a postdoc the U. of Illinois in Urbana. I supervise 3 graduate students: Yuzhi Liu, Alan Denbleyker and Haiyuan Zou. All the students have passed the qualifying exam and the TA certification. They all attended the Lattice 2011 conference.

Motivations

The ongoing experimental effort at the LHC has motivated a renewed interest for nontrivial infrared fixed points in asymptotically free gauge theories As recent experimental results have not shown clear evidence in favor of the most popular perturbative scenarios for mass generation, it is urgent to consider nonperturbative alternatives. Given the successes of the local gauge invariance principle, it is natural to consider the possibility that new gauge interactions are responsible for the electro-weak symmetry breaking

One particularly interesting situation from a phenomenological point of view is when the Callan-Symanzik β function for the new gauge coupling approaches zero from below and the running coupling constant encounters only small changes over a significant range of scale. We then say that the "running" coupling constant "walks". This in principle allows to have light fermions without flavor changing neutral currents. This nearly conformal situation can be reached by tuning a parameter (typically the number of light fermions) in such a way that zeros of the β function, and the corresponding fixed points of the Renormalization Group (RG) transformation, disappear in the complex plane. Other models where conformality can be lost and restored by tuning a parameter (for instance the quantum mechanical $1/r^2$ potential) have been studied recently

This motivated us to study extensions of the RG flows in the complex coupling plane published in *Phys. Rev. Letters* **104** 251601 (2010), *Phys. Rev.* **D 83** 056009 (2011) and *Phys. Rev.* **D 83** 096008 (2011). A general feature that we observed is that the Fisher's zeros - the zeros of the partition function in the complex coupling plane - act as "gates" for the RG flows ending at the strongly coupled fixed point. This can be seen as a complex extension of the general picture proposed by Tomboulis : in confining theories, the gate stays open as the volume increases and RG flows starting in a complex neighborhood the UV fixed point where asymptotic freedom is valid, can reach the IR fixed point where confinement and the existence of a mass gap are clearly present.

We plan to pursue this effort in the case of $SU(3)$ with various number of fermions in the triplet or sextet representations. The recent conference Lattice 2011 has witnessed many animated discussions regarding the critical number of flavors where a conformal IR appears. We think that the calculation of the Fisher's zeros at different volumes will provide definitive answers to these questions.

Complex Renormalization Group Flows in Spin Models

Calculations of RG flows and discrete β functions in lattice gauge theory are notoriously difficult. One of the main question asked is how many flavors does it take to destroy the confining properties of the theory. For gauge theories, the absence of long-range order (no massless gluons) is associated with confinement. The absence of long-range order also characterizes the 2-dimensional $O(N)$ sigma models with $N \leq 3$. By using some approximations, it is possible to calculate complex RG flows and Fisher's zeros much more easily than for gauge theories.

In *Phys. Rev.* **D 83** 056009 (2011), we were able to monitor RG fixed points disappearing in the complex inverse temperature (β) plane using the two-lattice matching procedure for Dyson's hierarchical model. In this model, the local potential approximation is exact and RG flows can be calculated numerically with good accuracy. The model has a free parameter that plays the role of the dimension and can be tuned continuously. For $D = 3$, the model has a nontrivial Wilson-Fisher fixed point. As we lower D continuously, the fixed point on the real axis moves to the right and eventualy disappears at infinity for $D = 2$ in agreement with rigorous results. The complex RG flows are shown in Fig. 1. On the left, for $D = 2$,

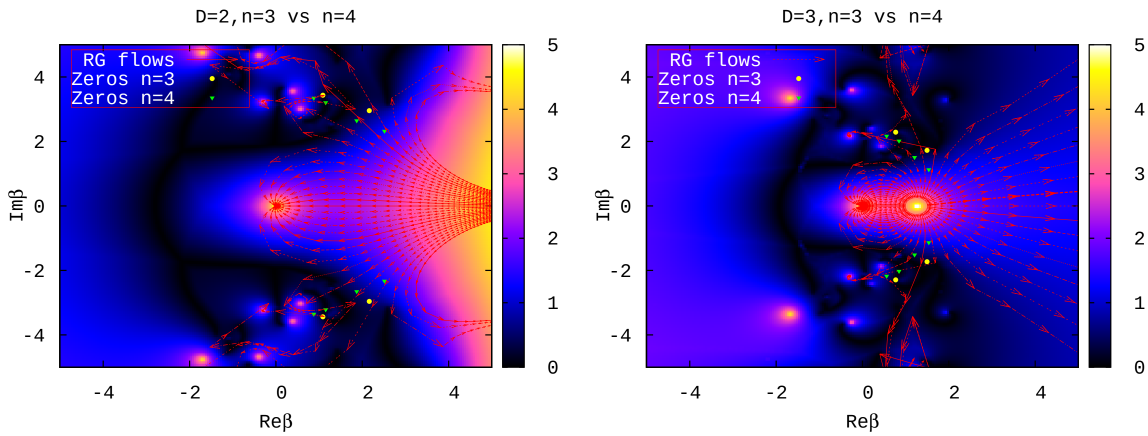

FIG. 1. Complex flows for the hierarchical Ising model for $D = 2$ (left) and $D = 3$ (right).

the complex flow lines go smoothly from infinity to zero, which indicates that the system has no phase transition. For $D = 3$, the complex flow lines start from β_c and end to either zero or infinity. The darker region of the graph signals competing solutions for the matching condition .

An important feature that can be observed on this figure is that the RG flows approximately follow the Fisher zeros along the separatrice between different basins of attraction. More specifically, in one discrete step, the RG flows approximately go from the zeros at one given number of lattice sites to the zeros for a smaller number of sites as obtained after block spinning. This example shows that the global properties of the RG flows (difficult to calculate) can be inferred from the location of the Fisher's zeros at successive volumes (easier to calculate). Similar observations were made for the $2D$ $O(N)$ non-linear sigma models in the large-N limit in *Phys. Rev.* **D 83** 096008 (2011). We constructed the Riemann sheet structure and singular points of the finite lattice size L mappings between the mass gap and the 't Hooft coupling. We argued that the Fisher's zeros appear on "strings" ending approximately at the singular points. We compared finite volume complex flows obtained from the rescaling of the ultraviolet cutoff in the gap equation and from the two lattice matching. In both cases, the flows are channelled through the singular points and end at the strong coupling fixed points, however strong scheme dependence appear on the ultraviolet side.

At Lattice 2011, Yuzhi Liu discussed the possibility of constructing a continuous beta function from the discrete one by using functional conjugation methods described in Gell-Mann and Low. He presented results showing that zeros of the discrete β function can disappear when the volume is increased and stressed the importance of nonlinear effects in scaling functions. These findings will be relevant to recognize pitfalls in the search of nontrivial fixed points in multiflavor lattice gauge theory models.

Fisher's zeros in lattice gauge theory

In the case of a pure $U(1)$ gauge theory, we used the multi-canonical algorithm to construct the density of states numerically. We calculated the lowest three zeros for three volumes $4^4, 6^4$ and 8^4. For these small volumes, we were able to locate the lowest zeros with a precision of order 10^{-5}. The zeros cross at $\beta_c = 1.0113(2)$. The imaginary part of the zeros scales with $L^{-3.07}$, or $\nu = 0.326$, consistent with a second order phase transition. However the zeros from higher volumes show that the scaling is "rolling" and ν is decreasing with volumes . This is consistent with another study based on Binder cumulants. Our more recent analysis including volumes up to 20^4 shows the compatibility with the first order

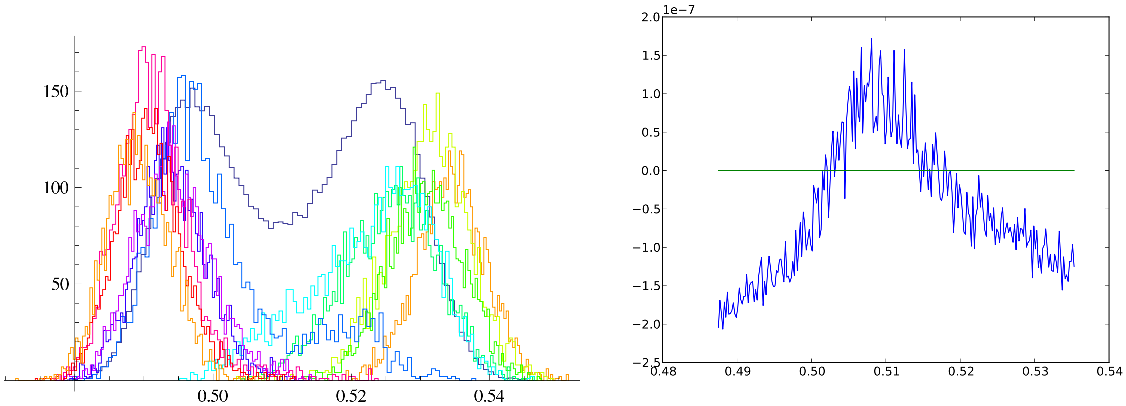

FIG. 2. Left: plaquette distributions for the ten values of β described in the text. The high-statistics double peak distribution at β =5.124 is superimposed. Right: Second derivative of the log of the density of states.

scenario. This is described in a preprint in progress.

For a pure gauge $SU(2)$ with a Wilson action, the lowest complex zeros for the volumes 4^4 and 6^4 are shown in a preprint in progress. The locations of the partition function zeros, while the lower points approach the complex roots of $f''(x) = 0$ (which indicates the boundary of the region where the saddle point approximation breaks down and non-Gaussian distributions become possible) mapped to the β-plane. At Lattice 2011, Alan Denbleyker showed that the addition of a positive adjoint term to the action lowers the zeros and allows to study the zeros more easily. He is planning to study the finite size scaling near the critical point.

Plans for work on multiflavor models

We plan to extend our work in the case of lattice gauge models with fermions, which is much more computationally intensive. In order to estimate the computer time necessary to reconstruct densities of states at fixed bare fermion mass, we first used existing data from D. Sinclair for $SU(3)$ with 3 light quarks on 4×8^3 and 4×12^3 lattices. Together with Yuzhi Liu, we then tried to reproduce this result with low statistics (5000 configurations for each β) and without using the precise knowledge of the critical value of β. The density of states was constructed shown in Fig. 2. The numerical second derivative of the log of the density of states is shown on the right side of Fig. 2 and show a clear evidence for a convex region. In other words, it is possible to figure out the region of interest with limited statistics and coupling resolution. We plan to extend the code to N_f up to 16 with fractional increment and follow the region of the complex β plane where Fisher's zeros with low imaginary part appear.

Comparison of improved perturbative methods

Perturbation theory has played an essential role in developing and establishing the standard model of electroweak and strong interactions. The renormalizability of the theory guarantees that we can calculate the radiative corrections at any order. On the other hand, a generalization of Dyson's argument (in QED, the transformation $e^2 \to -e^2$ leads to a vacuum instability) suggests that the perturbative series are divergent and one needs to truncate the series in order to get a finite answer. We realized that the factorial growth of perturbative series is related to configurations with arbitrary large fields (Y. Meurice, Phys. Rev. Lett. 88, 141601, 2002). This method is numerical and conventional Feynman rules cannot be derived. However, recently the Amherst group has proposed a sequence of approximants to tame the large field contributions while keeping Wick theorem and Feynman rules. At Lattice 2011, Haiyuan Zou compared the efficiency of the two methods for integrals and quantum mechanical problems. He plans to apply similar methods for non-linear sigma models and U(1) lattice gauge theory. The ultimate goal is to be able to take the continuum limit and generate modified Feynman rules relevant for collider processes (for instance W-production, see P. Arnold and M. H. Reno, Nucl.Phys.B319:37,1989).

QCD calculations with optical lattices?

By trapping cold polarizable atoms in periodic potentials created by crossed laser beams, it is now possible to experimentally create "clean" lattice systems. Experimentalists have successfully engineered local and nearest-neighbor interactions that approximately recreate Hubbard-like models on table tops. I discuss the possibility of using this new technology in order to: 1) calculate correlation functions and determinants, 2) design new systems with local gauge invariance.

Branching Ratio for $B_s^0 \to \mu^+\mu^-$

The rare decay $B_s \to \mu^+\mu^-$ is a sensitive probe of new physics. At LHCb, the branching ratio will be obtained by using comparison with other normalization channels like $B_u^+ \to J/\psi K^+$ or $B_d^0 \to K^+\pi^-$ in the following manner:

$$BR(B_s^0 \to \mu^+\mu^-) = BR(B_q \to X)\frac{f_q}{f_d}\frac{\epsilon_X}{\epsilon_{\mu\mu}}\frac{N_{\mu\mu}}{N_X}$$

where the efficiencies ϵ and count numbers N come from experimental measurements. Significant uncertainty comes from from the ratio f_q/f_s for which a precise estimate is yet to be seen. As a result, the fragmentation ratio can be expressed explicitly by

$$\frac{f_d}{f_s} = 12.88\frac{\tau_{B_s}}{\tau_{B_d}}\frac{\epsilon_{D_s\pi}}{\epsilon_{D_dK}}\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)}\frac{a_1(D\pi)}{a_1(DK)}/\frac{N_{D_s\pi}}{N_{D_d\pi}} \quad (1)$$

The error on the measurement can be reduced using a ratio of semileptonic form factors for $B \to D$ and $B_s \to D_s$ at non-zero recoil. Daping Du worked with Andreas Kronfeld and other members of the Fermilab Lattice-MILC collaboration. He succeeded to extract this ratio using Asqtad staggered light quarks and clover heavy quarks. Here we report on preliminary results obtained from a subset of the MILC ensembles. The preliminary result is $F_0^{(s)}(m_\pi^2)/F_0^{(d)}(m_K^2) = 1.035(39)(20)$.

Accomplishments and Planned Activities of Mary Hall Reno

The work supported by DOE is primarily on the topic of neutrino physics. My graduate student Yu Seon Jeong completed her PhD in July 2011, and I have begun meeting with Mr. Haiyuan Zou, a current graduate student at the University of Iowa. I continue to collborate with Professor Ina Sarcevic, Dr. Arif Erkoca and Dr. Tolga Guver at the University of Arizona, and with Professor Rikard Enberg at Uppsala University in Sweden.

The DOE contract covers a portion of my summer salary and provides partial RA support for a graduate student. The budget also includes some travel money. My DOE funds are supplemented by University of Iowa support that I receive as Chair of the department.

In the next subsections, the work accomplished and planned activities for the coming year are described.

Neutrinos signals from the Moon

With Ina Sarcevic, and as part of Yu Seon Jeong's PhD thesis research, we have looked at radio Cherenkov signals of neutrino interactions in the Moon. The basic principle is that neutrino interactions produce showers which result in a charge excess which travels faster than the speed of light in the material, hence, the radio Cherenkov signal generation. This is called the Askaryan effect. There have already been searches for the radio signal using radio telescopes (Hankins et al., MNRAS 283, 1027 (1996) and Gorham et al., Phys. Rev. Lett. 93, 041101 (2004)), and there are further efforts in this area including by a group at the University of Iowa (Jaeger et al., Astropart. Phys. 34, 293 (2010)). Our original hope was to constrain the ultrahigh energy neutrino cross section by a lack of observed events, assuming a neutrino flux prediction. We used the flux predictions in Kotera, Allard and Olinto's paper (JCAP 1010, 013 (2010)) for neutrinos coming from cosmic ray interactions with the microwave background.

To evaluate the neutrino signals, we used the approximate analytic expression of Gayley et al. (Ap. J. 706, 1556 (2009)) for the effective aperture of the Moon. There are contributions from neutrinos which pass through most of the Moon and interact near the surface, producing an "upward" shower and from neutrinos which produce "downward" showers, as seen from the Earth. The key element with the downward showers is that there are various angles for the radio signal (Cherenkov angle, refraction and Cherenkov cone size) plus corrections coming from the fact that the surface of the Moon is uneven. All these contributions are included in the Gayley et al. expression. We extended the Gayley et al. result to include cosmic ray production of radio Cherenkov signals (all downward), and modifications of the neutrino cross section including much lower cross sections and much higher cross sections. The cosmic ray calculation involves accounting for attenuation of the cosmic ray flux in the lunar regolith, strongly attenuating the cosmic ray flux. This type of correction also modifies the neutrino downward rate if the neutrino cross section with nucleons is strongly enhanced, as in, for example, extra dimensional models in which mini-black holes can be produced.

The approximate analytic approach is useful because one can consider a range of parameters, both for the cross sections and for detectors. In Fig. 1, we show our result for radio Cherenkov signal rates for 100 hrs of viewing time, as a function of radio frequency assuming standard model interactions with cosmogenic neutrino flux predictions from Kotera et al. and the cosmic ray flux. The solid lines are the cosmic ray induced events, while the dashed lines are the neutrino induced events. The integer labels, $n = 8 - 11$ label the minimum detectable electric field with $\varepsilon_{\rm min} = 10^{-n}$ V/m/MHz. Currently, detectors operate at roughly $n \sim 8$. It is clear from our figure that for standard model interactions and fluxes, the current detector capabilities are far from being able to observe a signal in 100 hrs of observing time.

Improvements in the minimum detectable electric field will probe lower neutrino energies, hence larger neutrino fluxes, but also even larger cosmic ray fluxes.

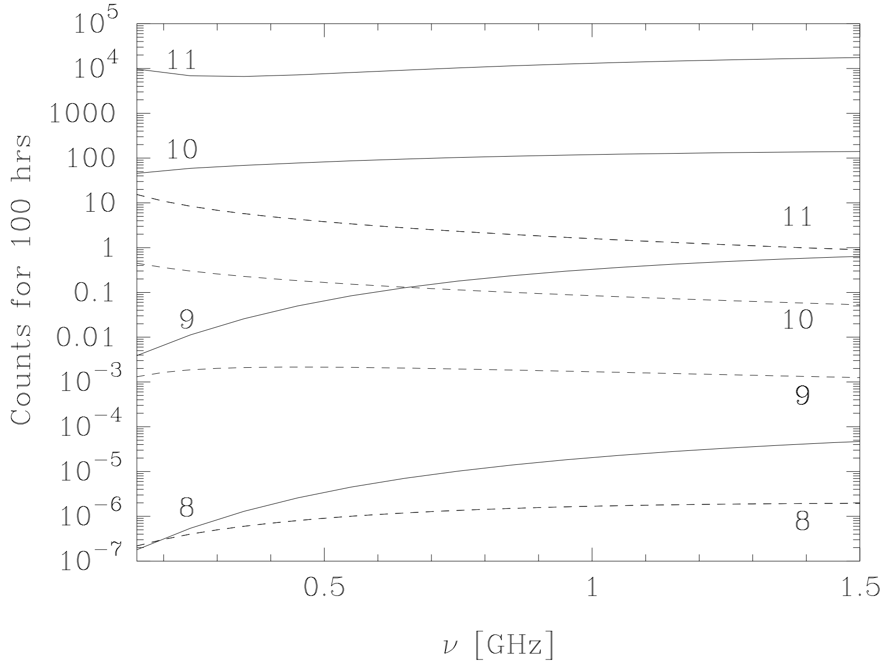

FIG. 3. The number of events observable in 100 hrs, as a function of radio frequency, for neutrino fluxes as predicted by Kotera et al. (dashed) and from cosmic rays (solid) for minimum detectable electric fields of $\varepsilon_{\rm min} = 10^{-n}$ V/m/MHz, $n = 8 - 11$.

The strength of the radio Cherenkov technique observing the Moon is in constraining a diffuse neutrino flux from astrophysical sources. The event rate depends on the neutrino nucleon cross section. In the figure, $S \equiv \sigma_{\nu N}/\sigma_{\nu N}^{SM}$, the ratio of the neutrino cross section to the standard model prediction. We show R, the ratio of the cosmic ray to neutrino event rate for $\phi_\nu = 10^{-8}$ GeV/cm^2/s/sr for $\varepsilon_{min} = 10^{-8}$ V/m/MHz. We also show the minimum value of A such that

$$\phi_\nu = A \times 10^{-8}\ \text{GeV/cm}^2\text{/s/sr} \tag{2}$$

for $A = A_{100}$ yields one event for 100 hrs of viewing. For $\nu = 150$ MHz, even with enhanced neutrino cross sections, 100 hrs of observation yields $A_{100} \simeq 0.2$. Our paper on this work has been recently accepted by *Astroparticle Physics.*

Dark matter in neutron stars

Dark matter, comprising 25% of the matter density in the Universe, may have interesting particle properties that have implications for astrophysical objects. Ultimately, collider physics experiments together with astrophysical constraints will pin down the particle nature of dark matter. We have already looked at signals of dark matter annihilation resulting in neutrino signals in neutrino telescopes in a series of papers, most recently looking at signals from the galactic center (A.E. Erkoca, M. H. Reno and I. Sarcevic, Phys. Rev. D 82, 113006 (2010)). We have turned our attention to other types of constraints.

McDermott, Yu and Zurek (arxiv 1103.5472) have looked at constraints on "asymmetric" dark matter from neutron stars. Asymmetric in this context means the dark matter does not self-annihilate. The constraint explored in their paper is that the dark matter, in this

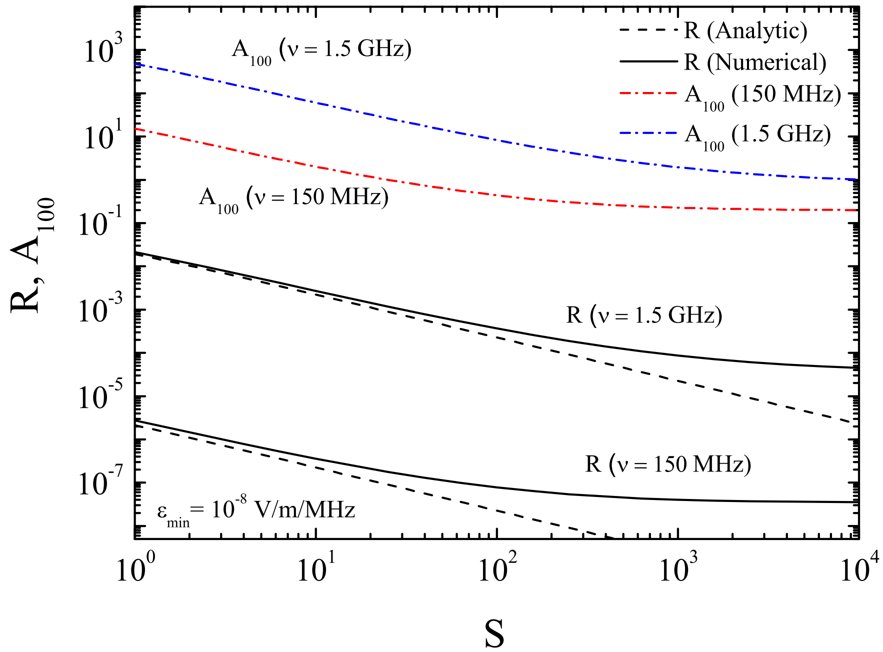

FIG. 4. As a function of $S = \sigma_{\nu N}/\sigma_{\nu N}^{SM}$, the ratio $R = \Gamma_{CR}/\Gamma_\nu$ for A=1 (solid lines) and the values of A such that $A = A_{100}$ produces one neutrino event in 100 hours (dot-dashed), where A is defined in eq. (1) and $\varepsilon_{min} = 10^{-8}$ V/m/MHz.

case, scalar dark matter, can not accumulate so much in the core of the neutron star so as to collapse the neutron star into a black hole. The existence of neutron stars restricts properties of asymmetric scalar dark matter.

With Sarcevic, Erkoca and Guver (all at Arizona), we have considered both fermionic and scalar dark matter, including the effects of self-capture, a feature neglected by McDermott et al. For fermionic dark matter, we find that for $M_{DM} > 100$ GeV, the fermion Chandrasekhar limit is less than the number of fermions required for the fermionic dark matter to be relativistic. Thus for $M_{DM} > 100$ GeV, the minimum number of fermions is governed by the relativistic rather than Chandrasekhar constraint if a black hole is to be formed.

For bosons, there is the added element that bosons can form a BoseEinstein condensate (BEC) in the core of the neutron star. Once the BEC is formed, self capture is not an important feature because the geometric cross section for the dark matter in the core is so mall. For small dark-matter nucleon cross sections, and large dark matter self-interactions, the self interaction can become important. An example, for $M_{DM} = 10$ GeV with $\sigma_{\chi n} = 10^{-55}$ cm^2 and $\sigma_{\chi\chi} = 10^{-24}$ cm^2 is shown in Fig. 3. The lower curve shows the number of bosonic dark matter particles accumulated as a function of time neglecting self interactions, while the upper curve includes self interactions. We are in the process of completing our paper, "On the capture of dark matter by neutron stars," by Guver, Erkoca, Reno and Sarcevic, in which constraints from neutron stars on M_{DM}, $\sigma_{\chi n}$ and $\sigma_{\chi\chi}$ are considered.

Prompt neutrinos from atmospheric charm

Our paper on neutrino fluxes from atmospheric charm (Enberg, Reno and Sarcevic, Phys. Rev. D 78, 043005 (2008)) has received some attention with the developing capability of the IceCube detector to probe neutrino energies where the prompt flux may be significant. With Enberg and Sarcevic, we plan to refine our calculation of the prompt atmospheric neutrino

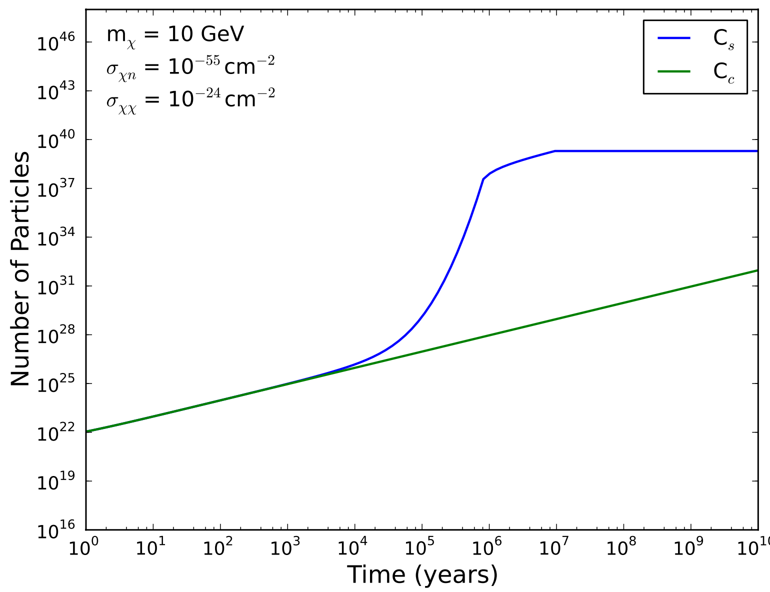

FIG. 5. For dark matter χ mass of 10 GeV, the number of bosonic dark matter particles captured by a "standard neutron star" with $\sigma_{\chi n} = 10^{-55}$ cm^2 neglecting dark matter self interactions (lower curve) and including self interactions with $\sigma_{\chi\chi} = 10^{-24}$ cm^2 (upper curve).

flux. The theoretical uncertainties in the charm production cross section are quite large, due to the relative low "heavy quark" mass of charm, the sensitivity to the factorization and renormalization scales and the small x parton distribution functions. We plan to use the dipole approximation and to re-examine the perturbative QCD calculation of the charm pair cross section and to take into account recent measurements of $\sigma(pp \to c\bar{c}X)$ from the ALICE experiment. This project has already been started. We plan to quantify the minimum and maximum atmospheric prompt fluxes consistent with collider physics results.

Perturbative QCD and improved calculational tools

Professor Yannick Meurice is working with graduate student Haiyuan Zou on improved perturbative techniques. The ultimate goal is to apply the new techniques to collider physics processes. To prepare Mr. Zou for this work, I have been supervising his study of standard next-to-leading order QCD calculations and the implementation of these calculations in computer simulations. As a specfic example, he is looking at NLO W production in pp collisions. I will continue working with Mr. Zou so that he has the standard tools to evaluate W production to compare with the improved perturbative techniques to be developed.

Publications

Papers of Y. Meurice published, submitted or in progress since November 2010. All of these papers acknowledge support of our work by the DOE contract

- A. Bazavov, A. Denbleyker, Daping Du, Yuzhi Liu, Y. Meurice, and Haiyuan Zou, *Fisher's zeros as boundary of RG flows in complex coupling space* arXiv:1011.1675, POS for Lattice 2010.

- Y. Liu and Y. Meurice, *Lines of Fisher's zeros as separatrices for complex renormalization group flows*, Phys. Rev. **D 83** 096008 (2011).

- Y. Meurice and H. Zou, *Complex RG flows for 2D nonlinear O(N) sigma models*, Phys. Rev. **D 83** 056009 (2011).

- Y. Meurice, R. Perry, and S.-W. Tsai, Editors of the theme issue: *New applications of the renormalization group method in physics*, Phil. Trans. R. Soc. **A 369** (2011).

- Y. Meurice, R. Perry, and S.-W. Tsai, *New applications of the renormalization group method in physics, a brief introduction*, Phil. Trans. R. Soc. **A 369** 2602 (2011).

- Y. Meurice, *Dynamical Gauge Fields on Optical Lattices: A Lattice Gauge Theorist Point of View*, Summary of a poster presented at KITP in October 2011, [arXiv:1101.5369 [quant-ph]].

- Daping Du, Carleton Detar, Andreas Kronfeld, John Laiho, Yannick Meurice and Siwei Qiu, *Semileptonic form-factor ratio* $f_0(B \to D)/f_0(B_s \to D_s)$ *and its application to* $BR(B_s \to \mu^+\mu^-)$, submitted to POS for Lattice 2011.

- Yuzhi Liu, Yannick Meurice, and Haiyuan Zou, *Volume Effects in Discrete Beta Functions*, to be submitted to POS for Lattice 2011.

- Yannick Meurice and Haiyuan Zou, *Comparison of improved perturbative methods*, to be submitted to POS for Lattice 2011.

- A. Bazavov, A. Denbleyker, Daping Du, Yuzhi Liu, Y. Meurice, B. Oktay and D. Sinclair, *Fisher's zeros, complex RG flows and confinement in LGT models*, to be submitted to POS for Lattice 2011. A more detailed account is at a first draft stage.

- Yannick Meurice, *QCD calculations with optical lattices?*, to be submitted to POS for Lattice 2011.

- A. Bazavov, B. Berg, Daping Du, and Y. Meurice, *Density of States and Fisher's zeros in* $U(1)$ *pure gauge theory*, preprint at second draft stage.

- Y. Liu and Y. Meurice, *About the continuum limit of discrete RG transformations.*, preprint at first draft stage.

- A. Denbleyker, D. Du, Y. Meurice, and A. Velytsky, *Fishers Zeros of* $SU(2)$ *Lattice Gauge Theory*, preprint at first draft stage.

Summary of recent talks given by Y. Meurice and students

- Y. Meurice, "Fisher's zeros as boundary of RG flows in complex coupling space", 5th ERG Conference, Corfu, September 14, 2010.
- Y. Meurice, "Dynamical Gauge Fields on Optical Lattices : A Lattice Gauge Theorist Point of View", KITP Conference: Frontiers of Ultracold Atoms and Molecules, Oct 11-15, 2010 .
- Y. Meurice, "Fisher's zeros as the Boundary of RG flows in complex coupling space", UCLA, October 15, 2010.
- Y. Meurice, "Fisher's zeros as the Boundary of RG flows in complex coupling space", UC Riverside, October 18, 2010.
- Y. Meurice, "Confinement and Walking Coupling Constants: A Renormalization Group Point of View", Argonne Nat. Lab. (May 2011).
- Y. Meurice, "Confinement, RG flows in the complex coupling plane and Fishers zeros", CAQCD (Minneapolis May 2011),
- Daping Du, "Semileptonic form-factor ratio $f_0(B \to D)/f_0(B_s \to D_s)$ and its application to $BR(B_s \to \mu^+\mu^-)$", Lattice 2011, (July 2011).
- Yuzhi Liu, " Volume Effects in Discrete Beta Functions", Lattice 2011, (July 2011).
- Haiyuan Zou, "Comparison of improved perturbative methods", Lattice 2011.
- Alan Denbleyker, "Fisher's zeros, complex RG flows and confinement in LGT models", Lattice 2011, (July 2011).
- Yannick Meurice, "QCD calculations with optical lattices?", Lattice 2011, (July 2011).
- Y. Meurice, "Fisher's zeros, complex RG flows and confinement in LGT models" , (APS-Prairie, Nov. 2011)
- Y. Liu, "QCD calculations with optical lattices?", (APS-Prairie, Nov. 2011)

Summary of Papers and Proceedings, Mary Hall Reno

Papers published, submitted or in preparation since November 1, 2010 by M. H. Reno. All acknowledge support of our work by the DOE contract.

- A. E. Erkoca, M. H. Reno and I. Sarcevic, "Probing dark matter models with neutrinos from the Galactic center," Phys. Rev. D **82**, 113006 (2010), arXiv:1009.2068 [hep-ph].
- M. H. Reno, "Neutrinos from dark matter," in Cosmic Rays for Particle and Astroparticle Physics, Proceedings of the 12th ICATPP Conference, eds. S. Giani, C. Leroy and P. G. Rancoita, (World Scientific, Singapore, 2011), 603-612.
- Yu Seon Jeong, M. H. Reno and I. Sarcevic, "Radio Cherenkov signals from the Moon: neutrinos and cosmic rays," accepted for publication in Astroparticle Physics, arXiv:1108.2459 [astro-ph].
- M. H. Reno, "Neutrinos from charm production: atmospheric and astrophysical applications," submitted to the Proceedings of the Eleventh Workshop on Non-Perturbative QCD, Paris, France, June 6-10, 2011.
- T. Guver, A. E. Erkoca, M. H. Reno and I. Sarcevic, "On the capture of dark matter by neutron stars," in final draft stage.

Summary of recent talks given by M. H. Reno

- M. H. Reno, "Neutrino signals of dark matter at the galactic center," seminar at AstroParticlue et Cosmologie, Paris, October 5, 2010.
- M. H. Reno, "Neutrinos from dark matter," ICATTP 2010, Centro Volta, Como, Italy, October 2010.
- M. H. Reno, "Cosmic rays and atmospheric leptons: probes of the standard model and beyond," colloquium at the University of Oklahoma, November 4, 2010.
- M. H. Reno, "Neutrinos, nature's messengers," colloquium and ADVANCE lecture at the University of Arizona, December 3, 2010.
- M. H. Reno, "Neutrinos from charm production: atmospheric and astrophysical applications," HEP seminar at Argonne National Laboratory, June 1, 2011.
- M. H. Reno, "Neutrions from charm production: atmospheric and astrophysical applications," at the Eleventh Workshop on Non-Perturbative QCD, l'Institut d'Astrophysique de Paris, France, June 6-10, 2011.
- M. H. Reno, "Velocity of neutrinos," colloquium at the University of Iowa, October 10, 2011.

People Working on Research Activities
Graduate Students working with Y. Meurice

- Daping Du came in fall 2005 and earned his Ph. D. degree in June 2011. He worked with the Fermilab Lattice group with a URA fellowship from January to August 2011 and calculated the fragmentation fractions for the B meson. He is now a postdoc at University of Illinois. He worked on the fits of plaquette distribution, saddle point estimates of the Fisher zeros and interpolations for the density of states in $U(1)$ and $SU(2)$ gauge theories. He developed new algorithms for histogram reweighting and search for zeros. His input was crucial to establish new criteria for confining gauge theories and for preliminary work on 3 light flavors gauge theories. No DOE R. A. support this year.

- Alan Denbleyker came in fall 2006. He works on MC simulations in $SU(2)$ gauge theories with and without adjoint terms and is planning to extend the existing codes for $SU(3)$. He works on histogram reweighting and finite size scaling for finite temperature $SU(2)$ and the adjoint-fundamental critical point. He is the system manager for our cluster and repository. He is supported as a T.A. during the academic year and as a R.A. during summer. He has passed the qualifying exam and will take the comprehensive exam soon. R. A. support from DOE: 2 months in summer 2011.

- Yuzhi Liu came in fall 2006. He has passed the qualifying and comprehensive exams and the T.A. certification. He works on the comparison between discrete renormalization group methods that we have been using and continuous limits of these methods used by other authors. He is now working on multiflavor gauge theories. He has been supported partially as a T.A. and partially as a R.A. He applied for a DOE graduate student fellowship in May 2010 and 2011 but the proposals were not selected. He is now partially supported by the University as a R. A. to work on optical lattice calculations. R. A. support from DOE: 2 months in summer 2011.

- Haiyuan Zou came in fall 2008. He has passed the qualifying exam and the T. A. certification. He has been working on improved perturbation theory and renormalization group flows in nonlinear sigma models. He is learning conventional perturbative methods for W-production with Prof. Reno. He has been supported partially as a T.A. (6.75 months) and partially as a R.A (4.25 months from March 2011 to December 2011, partially from DOE).

Graduate Students working with M. H. Reno

- Yu Seon Jeong, graduate student, PhD July 2011, under the supervision of M.H. Reno. Months of support from DOE: 4.5 months; UI RA support for remainder of the year (March 2010-March 2011). Dr. Jeong is currently a postdoc at Yonsei University in Korea.

- Haiyuan Zou, graduate student primarily supervised by Y. Meurice, but working learning calculational methods of perturbative QCD with M.H. Reno.