The LHC Theory Initiative:
From the Standard Model to the Terascale

Project Summary

The ultimate goal of particle physics is to identify the fundamental principles that govern matter, energy, space and time. The Standard Model (SM) of particle physics provides a thoroughly tested quantitative description of the matter particles (quarks and leptons) together with the mediators of the strong and electroweak interactions (gluon, photon, W and Z bosons). An accumulating body of evidence suggests that the SM is not complete, and that it is merely the low-energy limit of a more fundamental theory.

In 2007, the Large Hadron Collider (LHC) at CERN will begin operation. With its unprecedented energy and luminosity, the LHC promises to revolutionize particle physics. It will unveil the mechanism of electroweak symmetry breaking and shed light on how matter acquires mass. It might well discover the dark matter that makes up so much of the Universe. The LHC will open the physics of the Terascale, named for the Teraelectron volts of energy necessary to access it.

Accurate theoretical predictions are needed for the LHC to realize its full potential. Many of the most important signatures at the LHC are complex. For example, because of the LHC's high luminosity, it can be difficult to separate signal from background. The lowest-order predictions for such processes exhibit significant uncertainties which can be reduced by including higher orders in perturbation theory. Also, it is essential to explore discovery signatures and strategies in depth to make the most of the new discoveries, and to fully exploit the physics potential of this magnificent new experimental facility.

The **intellectual merit** of the activities proposed here is to provide calculational tools and theoretical results necessary to fully extract physics from the LHC. Proposed activities include calculations of higher-order QCD and electroweak corrections in the SM and beyond-the-SM models, as well as the development of new, improved, shower algorithms. Also important is the development of robust and well-tested Monte Carlo tools to confront with data theoretical models. Much remains to be done in these areas.

The **broader impact** of the proposed activities is to facilitate the development in the United States of a world-class program in LHC-related theory. To stimulate research in this area, a network of nationwide postdoctoral and graduate student fellowships is being proposed. The fellows will provide a nucleus of a vital US LHC theory community over the projected twenty-year lifetime of the LHC. Two annual meetings will be held to facilitate collaborative research and personal links between the fellows, their sponsors, and the LHC experimental collaborations. The continuity of these links will be insured through the use of regularly-scheduled video conferences. Professional development of the fellows will be an integral part of the program with the expectation that they will become leaders of the field.

The proposed activities will be pursued within the framework of the LHC Theory Initiative, a nationwide community effort to promote LHC-related theoretical research connecting the model building and phenomenology theory communities. The tools developed will be made publicly available and will help the experimental high-energy physics community to fully exploit the potential of the LHC. Scientific results will be published in peer-reviewed journals, via the World Wide Web, and will be presented at national and international conferences. Finally, the meetings of the fellows will be open to the US particle theory community, and will provide a backbone for a nationwide collaborative theory network, making it possible for physicists from isolated groups and smaller institutions to participate and focus their efforts on projects that are directly relevant to the LHC.

Project Description

1 Introduction and Motivation

In 2007, the CERN Large Hadron Collider (LHC) will begin operation. The LHC will collide protons at a center-of-mass energy of $\sqrt{s} = 14$ TeV with a design luminosity of $\mathcal{L} = 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. This represents an increase of a factor of seven in energy and a factor of 100 in luminosity over the Fermilab Tevatron. With its unprecedented energy and luminosity, the LHC promises to revolutionize particle physics. It will unveil the mechanism of electroweak symmetry breaking (EWSB) and shed light on the physical processes that are responsible for the origin of mass. The LHC holds the potential to make dark matter in the laboratory and perhaps even to reveal extra dimensions of space. Its reach for uncovering new phenomena is dramatically higher than that of all previous accelerators. The LHC truly will be a discovery machine.

To uncover the mechanism of EWSB and discover new physics, it is necessary to have accurate theoretical calculations of Standard Model (SM) processes and new physics signatures. The final states of many processes are quite complex at the LHC. The lowest-order (LO) predictions for many SM processes exhibit a significant dependence on the unphysical renormalization and factorization scales that can be traced to the truncation of the perturbation series. The scale dependence can be reduced by calculating observables to higher order in perturbation theory. Higher-order QCD and, in some cases, electroweak (EW) radiative corrections are needed for accurate SM predictions. For new physics scenarios, it is also important to devise unique signatures to characterize the models.

Calculating higher-order corrections and devising robust signals is necessary but not sufficient for discovering new phenomena at the LHC. In order to arrive at realistic predictions that can be used by the experimental community, matrix-element based theoretical calculations must be integrated into Monte Carlo (MC) event generators – a process which, especially at higher order in perturbation theory, is not yet well understood.

While there has been much progress during the last few years towards more precise calculations of SM processes, along with a better understanding of new physics signatures, much work remains to be done (see Secs. 2 and 3). Substantial work can be accomplished in a timely fashion with a modest increase in the number of postdocs and graduate students in the US working on LHC-related theory. To stimulate more LHC-related theory research — a goal endorsed by the recent P5 Particle Physics Roadmap — and to build and strengthen the network of LHC-related theorists in the US, we propose to establish graduate student and postdoctoral LHC fellowships, which we describe in some detail in Sec. 4. The proposed LHC fellows would form the nucleus of a virtual LHC theory institute, a center without walls. If fully funded, these fellowships will cost (in years 2 through 5 of this proposal) approximately \$875k per year. This a significant but important investment in the LHC, necessary to extract full value from the LHC investment made to date. It is necessary to realize the high expectations of the worldwide physics community and the American public for this magnificent new facility.

2 Precision Calculations of Standard Model Cross Sections

The first LHC physics run will take place in 2008. SM processes offer the potential for important measurements and are backgrounds to signals of new physics. A productive program at the LHC will require a detailed understanding of SM processes in general, and of QCD, in particular.

To obtain reliable predictions for SM processes at the LHC, (NLO) QCD corrections must be calculated. Higher-order QCD corrections reduce the dependence on the unphysical factorization and renormalization scales. In some cases, such as W and Z production [1], the effect is dramatic. Controlling EW radiative corrections [2–5] and obtaining precise knowledge of the parton distribution functions (PDFs) are also essential (see Sec. 2.1).

Processes for which the NLO QCD corrections will be needed include those that are relevant to top quark [6–11], Higgs boson [10, 12–16] and supersymmetry (SUSY) studies [17–19] (see Sec. 2.2). To arrive at realistic predictions, the theoretical calculations then need to be integrated into MC event generators. At higher orders, this remains a difficult task (see Sec. 2.4).

In the remainder of this section we describe some of the SM physics projects that the LHC Theory Initiative (LHC-TI) believes are important to pursue. The priority of a project is determined by the integrated luminosity needed for the process to become relevant (see Sec. 2.5). More details on the calculations described here can be found in the LHC-TI whitepaper [20]. The list presented here is meant to be illustrative – not exhaustive.

2.1 Parton Distribution Functions and NNLO QCD Corrections

Parton Distribution Functions (PDFs) are essential for nearly every measurement planned for the LHC. While NLO accuracy was sufficient at the Tevatron, NNLO precision will be needed to reach the LHC goals. The NNLO evolution kernels [21–24] are currently being incorporated into the various evolution programs. Additional work is still needed to integrate these programs and to standardize the interface to the NNLO PDF evolution routines. Furthermore, the NNLO kernels must be matched with NNLO calculations. The necessary NNLO ingredients are available for the DIS structure functions [23–25] and the Drell-Yan process [26]. However, for the other sub-processes used in the global analysis, significant challenges remain [27].

Specifically, work is needed on jet, direct photon, and heavy quark production. For many of these processes, the NNLO matrix elements have been computed [28, 29]; however, they need to be combined with real emission diagrams, properly accounting for soft and collinear subtractions. Several promising techniques [30–32] can be pursued to accomplish this non-trivial task.

There are other PDF related issues that need to be investigated:

Gluon Distribution. The gluon PDF has larger uncertainties than the corresponding quark distribution functions. Tevatron jet production data play a crucial role in constraining the gluon PDFs, particularly in the large x region. Since accurate knowledge of the gluon PDF is required for Higgs and top-quark production channels, this is an important issue to resolve.

Heavy Quark PDFs. The data in current global PDF analyses place no constraints on charm and bottom quark distributions. Even the strange quark distribution is only weakly constrained. Dedicated efforts are needed to address this problem, using recent high statistics neutrino scattering data [33] and new Tevatron data on W/Z production in association with c- and b-quarks [34].

PDF Uncertainties and Validity of the DGLAP Picture. The release of PDFs with uncertainties [35, 36] represents a significant advance in performing quantitative estimates for the errors associated with a particular observable. However, the treatment of PDF uncertainties needs to be improved. For the LHC, one also has to ask about limitations of the DGLAP picture, and whether an alternative framework (see eg. Refs. [37, 38]) is needed in part of the LHC phase space.

2.2 Standard Model Predictions

There are a host of SM processes for which more accurate predictions are needed at the LHC:

Full NLO QCD Corrections to $pp \to t\bar{t} \to b\bar{b} + 4f$. Top quark pairs will provide both a calibration and a copious background source at the LHC. Therefore QCD corrections must be under control. Existing NLO QCD calculations of $pp \to t\bar{t} \to b\bar{b} + 4f$ ($f = \ell$, ν, q) do not include non-factorizable contributions [39]. Since non-resonant contributions to $t\bar{t}$ production are known to be important [40], especially with cuts imposed, the non-factorizable QCD corrections to this process are likely also to be relevant. Thanks to recent advances [41], a calculation of the full NLO QCD corrections for $pp \to t\bar{t} \to b\bar{b} + 4f$ is feasible, but has not yet been done.

NLO QCD Corrections to $t\bar{t}V$ ($V = \gamma$, Z) and $t\bar{t}j$ Production. $t\bar{t}V$ production makes it possible to probe the ttV couplings. The achievable accuracy depends on the uncertainty of the SM $t\bar{t}V$ cross sections [6], which so far are known to LO only. $t\bar{t}j$ production is, together with $\mathcal{O}(\alpha^4)$ $WWjj$ production, the dominant background to $qq' \to qq'H \to qq'WW^{(*)}$, which is a major discovery mode for a light Higgs boson (with $10 - 30$ fb^{-1}) [42]. The calculation of the NLO QCD corrections to $t\bar{t}j$ production is very important.

Resummed QCD Corrections to $qq' \to qq'H$. To identify $H \to WW^{(*)}$ in vector boson fusion (VBF) events, one relies on $WW^{(*)} \to 2\ell + 2\nu$ decays, tagging on the two forward jets, and vetoing on a jet in the central rapidity region [42]. The central jet veto requires a detailed understanding of the jet activity in $qq' \to qq'H$ events. This is best achieved by calculating the resummed QCD corrections to $qq' \to qq'H$.

NLO QCD Corrections to $t\bar{t}b\bar{b}$ and $t\bar{t}jj$ Production. These processes are the main backgrounds for $pp \to t\bar{t}H$ with $H \to b\bar{b}$, which offers the possibility to probe the top Yukawa coupling [9, 11, 16] if the background can be controlled. Both $t\bar{t}b\bar{b}$ and $t\bar{t}jj$ production are currently known only to leading order. Since information on the background shape relies on theoretical calculations [11], and $pp \to t\bar{t}H \to t\bar{t}b\bar{b}$ will be observable for 30 fb^{-1}, calculations of the NLO QCD corrections for these processes are very important.

$pp \to t\bar{t}Wjj$ at LO. For m_H between 150 and 200 GeV, $pp \to t\bar{t}H(\to W^+W^-)$ promises a top Yukawa coupling measurement with $15 - 25\%$ precision for 30 fb^{-1} of data [8]. This channel's largest background, $t\bar{t}Wjj$ production, was only approximated in Ref. [8] due its complexity. A full tree-level calculation of $t\bar{t}Wjj$ should be feasible with current GRID resources.

NLO QCD Corrections to HH, $t\bar{t}W$ and $WWWjj$ Production. Higgs pair production will make it possible to probe the Higgs self-coupling, λ_{HHH}. For $m_H > 140$ GeV, $pp \to HH \to \ell^\pm\ell'^\pm + 4j$ offers the best prospect [12] (see Sec. 5). To measure λ_{HHH}, the cross sections of the SM signal and the most important backgrounds, $t\bar{t}j$, $t\bar{t}W$ and $WWWjj$ production, must be known to NLO precision. The NLO QCD corrections for $gg \to HH$ are currently available in the $m_t \to \infty$ limit [43], which is not sufficient for predicting differential cross sections [12]. While computing the full NLO QCD corrections to HH and $t\bar{t}W$ production appears feasible, it requires the calculation of seven-point functions for $pp \to WWWjj$, which has never been done before.

NLO QCD Corrections to $HH \to b\bar{b}\gamma\gamma$ Background Processes. For $m_H < 140$ GeV, $HH \to b\bar{b}\gamma\gamma$ offers the best chance to probe the Higgs self-coupling [14]. The NLO QCD corrections to the main background sources for this final state, 4 jet, $\gamma + 3$ jet, $\gamma\gamma jj$, $Q\bar{Q}\gamma j$, and $Q\bar{Q}\gamma\gamma$ ($Q = b, c$) production, have yet to be calculated.

NLO QCD Corrections to SUSY Background Processes. If R-parity is conserved, the most powerful and model-independent signature for SUSY is multi-jet plus missing transverse energy production. The main backgrounds in these channels are QCD multijet events, $t\bar{t}$, $W+$ jets, and $Z(\to \bar{\nu}\nu)+$ jets production. The LO multi-jet and $W/Z+ > 2j$ cross sections depend strongly on the factorization and renormalization scales. The calculation of the NLO QCD corrections to $W/Z + 3j$ production involves six-point functions and should be feasible. For $W/Z + 4j$ production one faces the same obstacles as for $pp \to WWWjj$.

EW Radiative Corrections to Drell-Yan Production. These corrections become large and negative at large di-lepton invariant masses [2, 3] because of Sudakov-like logarithms. It is necessary to resum these terms for new physics searches at the LHC.

2.3 Automatic Tools and Analytical Properties of QCD Amplitudes

Most calculations proposed in Sec. 2.2 involve one-loop QCD diagrams. To achieve the goals of this project in a timely fashion, automatic or semi-automatic tools must be used. However, there is no fully automatic program for calculating one-loop QCD corrections[1]. Recently a new approach, `Samper`, has been started [47–49]. Processes calculated using this method will be included in `MCFM` [50], a generator that already contains a number of processes at NLO that are of interest for data analysis at the LHC.

Recent progress in the analytical computation of tree-level [51] and massless one-loop [52] gauge theory amplitudes provides a promising alternative to `Samper`. This work, including new methods based on twistor-space string theories [53], has led to compact expressions and recursion relations that promise a faster numerical evaluation of differential cross sections. The next steps in bringing this approach to fruition are to generalize the results for massless one-loop diagrams to the massive case, and to build parton-level MC programs for processes of interest.

2.4 Interface of QCD Calculations with Parton Showers

Parton shower MC programs form the bridge between hard-scattering fixed-order calculations and observed final states. Most shower MC programs are based on angular/energy ordered $1 \to 2$ branching. But QCD gluon radiation has a dipole structure (i.e. $2 \to 3$ branching), so improved shower algorithms are needed. One new algorithm [54], `Vincia`, is based on $2 \to 3$ branching and promises to exactly match fixed-order calculations (NLO as well as LO), with full phase space coverage and a better description of hadronic radiation outside of a jet cone. It is important to integrate `Vincia` with `MCFM/Samper` to provide the same functionality as `MC@NLO` [55].

Even with an improved shower MC program available, `Pythia` [56], `Herwig` [57], and `Sherpa` [58] will still play important roles in LHC data analysis. Standard parton showers are based on the leading-log approximation, and must be supplemented with matrix-element (ME) corrections to accurately predict large p_T emissions. Several approaches [59–61] have been developed to systematically merge ME calculations with shower MC programs. So far, they have been applied to the production of QCD singlets plus jets (W and Z bosons [61], WW pairs [62], etc.), or pure jet production. Other, more complicated final states must also be considered, particularly those including heavy quarks.

Alternatively, one can try to directly combine NLO QCD calculations and parton showers. So far, this has only been done for `Herwig` [55]. It is desirable to extend this approach to other event generators. Current applications include the production of EW singlets and heavy quarks, but not pure jet production. It is not currently known how to generalize this approach beyond NLO.

2.5 Prioritized List of Projects

From the discussion in the previous sections, we prioritize the SM projects listed above as follows:

1. Needed at LHC startup (2008 – 2009):
   (a) Calculation of full NNLO PDFs, complete $pp \to jj$, γj at NNLO, and improved global PDF analyses.
   (b) Application of `MCFM/Samper/Vincia` to $4j$ and $W/Z + 3$ jet production at NLO, and pursuit of other new calculational techniques, such as those based on twistors.
   (c) Resummation of EW Sudakov logarithms in high-mass Drell-Yan production.

[1] Several semi-automatic tools are available [44, 45], and work on extending the automatic program `Grace` to include QCD corrections has begun [46].

(d) Interface of $t\bar{t} + n$ jet matrix elements, including off-shell effects, with `Pythia` and `Herwig`.

2. For $10 - 30$ fb^{-1} (2009 – 2010):

   (a) Calculation of full NLO QCD corrections to $pp \to t\bar{t} \to b\bar{b} + 4f$.
   (b) Calculation of full tree-level $t\bar{t}Wjj$ production.
   (c) Calculation of NLO QCD corrections to $t\bar{t}j$, $t\bar{t}\gamma$, $t\bar{t}b\bar{b}$, and $t\bar{t}jj$ production.
   (d) Resummation of QCD corrections to $qq' \to qq'H$.
   (e) Interface of $H + n$ jet matrix elements with `Pythia` and `Herwig`.

3. For 300 fb^{-1} (2012 – 2013):

   Calculation of NLO QCD corrections to $gg \to HH$, $t\bar{t}W$ and $t\bar{t}Z$ production.

4. For 3000 fb^{-1} (> 2015):

   Calculation of NLO QCD corrections to $WWWjj$, $jj\gamma\gamma$ and $Q\bar{Q}\gamma j$ production.

3 Signatures of New Phenomena at the LHC

The LHC will revolutionize particle physics by opening the TeV energy region to direct experimental exploration. It will certainly reveal the origin of EWSB. But beyond that, it will probe a variety of possible extensions to the Standard Model – supersymmetry, large or small extra dimensions, strong gravity, technicolor, composite and Little Higgs – with a large number of models in each category. These models share a handful of signals that will be the focus of early LHC searches. Generic signatures of new physics models include nonstandard top physics, top partners [SUSY, composite and Little Higgs (LH), Randall-Sundrum (RS), universal extra dimension (UED), technicolor (TC), and topcolor models], missing energy signals with or without cascades [SUSY, composite and LH with T parity, UED], W' and Z' bosons [composite and LH, RS, TC, UED, string-inspired SUSY models], and non-standard Higgs sectors [SUSY, composite and LH, TC, UED, and RS models]. Below we discuss some representative models and propose specific calculations that are needed. The list presented is meant to be illustrative – not exhaustive. For more details, we refer to Ref. [20].

3.1 Supersymmetry

SUSY, if it exists, is likely to be found rather quickly after the LHC begins taking data [17]. After the discovery of a potential SUSY signal, the emphasis will shift to determining the masses, spins and couplings of supersymmetric particles, together with their decay modes and branching fractions [63].

The masses of supersymmetric particles can be reconstructed from edges and thresholds in cascade decays [64]. Most such analyses involve jets; hence understanding the jet activity in SUSY events is critical. Existing studies [64] have used `Pythia` [65] or `Herwig` [66]. But a recent study [67] shows that the p_T distributions of jets from a matrix-element-based calculation [68] and `Pythia` can be very different. This indicates the need for a full NLO SUSY-QCD MC generator for squark and gluino production and decay (and spin correlations where appropriate). SUSY-QCD corrections for many SUSY production [69] and decay [63] processes are already known. Using these building blocks, together with `Vincia`, the development of a full NLO SUSY-QCD MC generator, including cascade decays, should be feasible.

Studies of how to measure the spin and the couplings of SUSY particles are very important. The spin of sleptons can be determined using lepton charge asymmetries [70], but there are no similar studies for the spins of other SUSY particles. Likewise, whether and how the couplings of SUSY particles can be measured at the LHC remains unknown, except for the weak squark gauge coupling [71].

Other SUSY issues need to be addressed before the LHC reaches its design luminosity. For example, CP-violating phases must be included in non-Higgs related SUSY production and decay processes. Various versions of the NMSSM, and R-parity violating SUSY production processes, must be incorporated in event generators. NLO QCD corrections in Higgs radiation off bottom and top quarks [72, 73] and via VBF also need to be calculated.

A great deal of work has been devoted to developing "semi-realistic" string constructions[2] that contain the gauge group and particles of the SM or the MSSM. So far, no construction is fully complete. One major issue involves supersymmetry breaking and its mediation. Almost all existing constructions suggest new TeV scale physics beyond the MSSM. For these reasons, physics at the LHC could well be much more complicated than the SM or the MSSM. It is important to work out a variety of examples of likely new scenarios, together with their signatures, and then to implement the physics in event generators.

3.2 Models of Electroweak Symmetry Breaking

Motivated by precision measurements, theorists have developed many other intriguing models for EWSB. One of the most promising new approaches is the "Little Higgs" (LH) mechanism [81], in which the Higgs field is a pseudo-Goldstone boson associated with the spontaneous breaking of a global symmetry. In such models, new particles with the same spin cancel the one-loop quadratically divergent contributions to the Higgs mass. Some of the predicted new particles should be observable at the LHC [82, 83]. Cancellation of the quadratic divergences implies a sum rule, which can in principle be tested at the LHC, but it is currently not known how well. Other aspects of LH models also warrant more detailed investigation. For example, recently proposed models with T-parity [84], supersymmetry [85], and the phenomenology of pseudo-axions in LH models [86], have yet to be studied in detail. Moreover, LH models have to be incorporated into standard MC packages in a systematic way before the LHC turns on.

Extra-dimensional theories represent another promising direction. In Higgsless models, EWSB occurs via the boundary conditions of gauge fields, without the appearance of a physical Higgs boson [87]. These models predict a Kaluza-Klein (KK) tower for both the SM gauge bosons and the SM fermions. Some phenomenological aspects of the KK excitations of the SM gauge bosons have been studied in Ref. [88]. However, many properties of Higgsless models have not been explored. For example, the couplings of the new vector bosons are supposed to fulfill certain model-independent sum rules. They are expected to hold at the few percent level and can be tested at the LHC. Furthermore, no LHC studies have been performed for the RS Higgsless model or the version with gauge-Higgs unification [89].

String theory suggests that extra spatial dimensions may be the price for unifying the SM with gravity. The fact that string theory requires new non-perturbative soliton-like objects has opened new avenues for model building. Several classes of such extra dimension (ED) models have been developed [90–93]. Remarkably, the so-called universal extra dimension (UED) models [93] have many of the same discovery signatures as SUSY, which makes it difficult to discriminate between the two possibilities [94]. Although much work on ED models has already been done [95], there are a number of issues which need to be addressed before the LHC begins operation. In particular, the implementation of ED models in event generators has to be completed; constraints on the ED parameter space from

[2] See, for example, Refs. [74–77]; for reviews, see Refs. [78–80].

current data have to be determined; representative ED benchmark points have to be developed; and more in-depth studies have to be performed to answer how well UED and SUSY can be discriminated. Additional tasks are listed in Sec. 3.4.

3.3 Flavor Physics

LHC-b will produce an astonishing 10^{12} bottom quark pairs a year, with which it will be possible to test the CKM sector of the SM in extremely rare channels that have branching ratios of $\mathcal{O}(10^{-9} - 10^{-10})$ [96]. Of particular interest is the B_s meson, whose decays are sensitive to multiple CKM parameters. The extraction of these parameters in heretofore unstudied modes will allow for strong consistency checks whose violation would signal new physics. Exact priorities for research will depend on forthcoming results from the B factories at SLAC and KEK.

3.4 Prioritized List of Projects

Based on the previous discussion, we prioritize the new physics projects listed above as follows:

1. Needed at LHC startup (2008 – 2009):

   (a) Studies of jet activity in cascade events, and determinations of how the spins and couplings of SUSY particles can be measured. Studies of CP-violating phases in supersymmetric production and decay processes.

   (b) Studies of how well the sum rules of Little Higgs and Higgsless models can be tested.

   (c) Incorporation of ED models in MC generators; calculations of the search reach for UED.

   (d) Establishment of benchmark points for ED models and determination of the parameter space that is consistent with existing data.

   (e) Studies of the discovery reach of the LHC in Higgsless models with gauge-Higgs unification and Randall-Sundrum type models.

   (f) Determination of strategies to discriminate SUSY and UED.

2. For $10 - 30$ fb^{-1} (2009 – 2010):

   (a) Implementation of a full NLO SUSY QCD event generator and calculation of SUSY QCD corrections to Higgs production in association with t- and b-quarks.

   (b) Implementation of branon production [97] and transplanckian effects [98] in MC generators.

   (c) More complete studies of the phenomenology of new particles in Little Higgs and Higgsless models.

   (d) Incorporation of new physics from string constructions in event generators.

   (e) Development of techniques to distinguish KK gauge boson excitations from heavy Z' production in GUT theories.

3. For 300 fb^{-1} (2012 – 2013):

   Calculation of NLO QCD corrections for processes in models with extra dimensions.

Of course, the priorities will be adjusted in light of LHC results. Note that the overall program targets both phenomenology and model-building because of the close interconnections between the two fields. Indeed, the postdoctoral and graduate student fellows will build bridges between the two communities. A tighter coupling would work to the benefit of each.

4 Fellowships

To stimulate work on LHC-related theory, and in particular, on the questions raised in the previous sections, we propose a program of national postdoctoral and graduate student LHC fellowships. (See Sec. 4.2 for an explanation of the nomination and selection procedure.) By awarding fellowships through a nationwide competition, it will be possible to support the best qualified individuals at any US institution working on the highest priority LHC issues. By focusing on student and postdoctoral support, we will attract more highly qualified young particle theorists to collider physics, and facilitate the development of a world-class program in collider theory in the United States. Finally, by encouraging nominations for LHC fellowships from all institutions engaged in elementary particle physics research, we will create a higher profile for LHC-related physics nationwide — not just at those institutions already emphasizing collider physics.

The fellowships are meant to help create and sustain a vital LHC theory community in the United States, with the fellows eventually pursuing a career path as tenure-track faculty. There is proof that this approach can succeed: Out of the twenty SSC Postdoctoral Fellowships awarded by the Texas National Research Laboratory Commission to theorists from 1990-93, thirteen led to tenured positions at research universities or national laboratories. These theorists have formed a nucleus of the US collider theory community over the last decade – indeed, two are members of the LHC-TI Steering Committee.[3] Similarly, we expect that the graduate and postdoctoral LHC fellows will become attractive candidates for tenure-track faculty positions and that they will help sustain a vital US LHC theory community over the projected twenty-year lifetime of the LHC.

Each fellow will receive funds to be spent as specified in an initial nomination. The funds can be used for full or partial salary support. The funds can also be used for research expenses – something that will enable the fellows to be more independent than ordinary postdocs or graduate students. The research funds will allow the fellows to play highly visible roles in conferences or workshops. They will also help to cover the computing needs of the fellowship projects, enable the fellows to invite collaborators for visits, or visit other institutions for collaborative purposes.

Two meetings will be held each year to stimulate collaborative research and build personal links between the fellows, their sponsors, and the LHC experimental collaborations. These meetings will include practical training sessions run by the postdoctoral fellows and guest lecturers, and are meant to expose fellows to the broad array of LHC-related physics topics. They will incorporate feedback from the experimental collaborations on issues arising from experimental analyses, and provide advice on professional development (such as advice on applying and interviewing for faculty positions, writing grants, giving seminars or colloquia, and participating in public outreach). These meetings could be hosted by National Laboratories or other institutions, such as KITP or the Aspen Center for Physics. They could also be held in parallel with the CERN-Fermilab LHC Summer School, where the postdoctoral fellows could play a role in the school, for example as discussion leaders (see the attached support letter by Jeff Appel and Bogdan Dobrescu).

The links between the fellows, and between the fellows and the theoretical or experimental community at large, will be further strengthened through the creation of theoretical working groups similar to the physics working groups of the Tevatron and LHC experiments. The LHC fellows, with the help and guidance of their faculty sponsors and senior members of the US theory community, will take leadership roles in these working groups. In this way the fellows will provide the backbone of this nationwide collaborative theory network. In addition to smaller gatherings, the groups will be encouraged to have regularly-scheduled video conferences. Videoconferenced meetings will facilitate the participation of physicists from isolated groups and smaller institutions – making it possible for them to collaborate

[3] Giele and Orr are former SSC Postdoctoral Fellows. For an exposition of Steering Committee's role, see Sec. 4.3.

with others and coherently focus their efforts on projects that are directly relevant to LHC physics.

This fellowship proposal is the result of a collaborative community effort, the LHC Theory Initiative. The structure arose out of a series of community workshops.[4] One idea that arose during deliberations was the possibility of creating RIKEN-like junior faculty fellowships, which would fund 50% of the salary of a junior faculty member for the five-year probationary period of a tenure-track appointment. Given the scope of resources at NSF, the RIKEN model was judged to be prohibitively expensive. Another suggestions was to use fellowship funds to free junior faculty from their teaching commitments. However, NSF guidelines do not allow for funds to be used to pay academic-year salary to faculty.

4.1 Fellowship Details

The fellowships would formally be structured as subawards from Johns Hopkins University to the institutions hosting successful nominations. Details of the proposed LHC fellowships include:

- Each LHC postdoctoral fellowship would total $150K to be spent over two or three years. A fellowship could be awarded to an existing postdoc, or to a new postdoc whose position would be made possible by the award. The funds could be used for salary support (including fringe benefits), research support (of at least $4K per year), together with an administrative fee of up to $10K. The precise distribution of funds would be left to the nominator, but the allocation must be specified in the nominating proposal. Two examples of the possible distribution of fellowship funds are given in Table 1.
- Each LHC graduate fellowship would total $40K for one year. The funds could be used to provide a graduate stipend (including fringe benefits), research support (of at least $4K), tuition support, and an administrative fee of up to $5K. The fellowship would free the student from other responsibilities, allowing full-time effort on LHC research. The precise distribution of funds is left to the nominator, but the allocation must be specified in the nominating proposal. An example of the possible distribution of fellowship funds is given in Table 1. Individuals are eligible for a total of two graduate fellowships, thereby deriving support for two years, but must be renominated for a second year of support. Re-nominations will be considered in the selection process (see Sec. 4.2), in competition with other graduate student nominations.
- The number of postdoctoral and graduate LHC fellowships may vary from year to year based on the pool of applicants and the availability of funds. The budget included with this proposal anticipates the award of 2 postdoctoral and 3 graduate LHC fellowships the first year, and 4 postdoctoral and 6 graduate fellowships in each of years two through five. The proposed budget, then, would support a total of 18 postdoctoral fellows and 27 graduate fellows – providing a substantial impact in the number and profile of young physicists working in LHC-related theory in the United States.[5] Note that the budget ramps up to mitigate impact on the overall NSF theory budget. The program is designed so that it can be scaled based on the availability of funds.
- Postdoctoral awards are intended to begin in September each year, to coincide with the usual particle theory postdoctoral appointments, while graduate awards may cover any year-long period as proposed in the nomination letter.
- To avoid an excessive concentration of fellows, each institution may host only one new postdoctoral and one new graduate student fellow every other year.

[4] A timeline and cumulative set of documents developed during this process may be found at the LHC-TI website, `http://www.pas.rochester.edu/~orr/LHC-TI.html`.

[5] By way of comparison, as noted above, a total of 20 SSC Postdoctoral Fellowships were awarded to particle theorists during the four-year period from 1990-1993.

	Postdoctoral Fellowship		Graduate Fellowship
	Example 1 (2-year)	Example 2 (3-year)	
salary/stipend	\$50K+\$50K	\$55K+\$15K+\$15K	\$21K
fringe benefits	\$15.5K+\$15.5K	\$17K+\$4.7K+\$4.7K	\$2.3K
tuition			\$6K
research funds	\$9K	\$28.6K	\$5.7K
adm. fee	\$10K	\$10K	\$5K
total	\$150K	\$150K	\$40K

Table 1: An illustration of the possible distribution of award funds for a two- or three-year postdoctoral fellowship and a graduate fellowship. Note that in the three-year scenario, the fellowship provides only partial salary support in the second and third years. Fringe benefits are assumed to be 31% (11%) for postdoctoral (graduate student) fellowships.

- For a given individual, only one fellowship nomination would be accepted per year and there is a lifetime limit of two graduate fellowships and one postdoctoral fellowship per individual.
- Nominees need not currently be resident at the nominating institution, although in most cases graduate nominees will be continuing students. Fellowship awards will be made the December prior to the beginning of the fellowship year, so as to coordinate with the annual postdoctoral hiring cycle.

Johns Hopkins University has agreed to administer the overall grant for a flat administrative fee of \$3K per postdoctoral fellowship and \$2K per graduate student fellowship (plus off-campus F&A on advertising and Screening Committee expenses; see Sec. 4.2). Each subaward would be limited to \$10K or \$5K of administrative expenses. We expect recipient universities would accept this arrangement because of the prestige and visibility that such a fellow would bring. Indeed, this is the model behind the very successful Hubble Fellowships in Astronomy, and the recently initiated Astronomy and Astrophysics Postdoctoral Fellowships at NSF. At the end of this proposal, we have attached letters from a variety of institutions (including the US ATLAS and CMS collaborations), demonstrating broad-based support for the fellowship program.

The yearly cost of the fellowship program is \$445K for 2 postdoctoral and 3 graduate fellowships in year 1, and \$865K for 4 postdoctoral and 6 student fellowships in years 2 through 5. In addition we anticipate a nominal amount (\$8K per year) of administrative expenses to support advertising the fellowship and the travel expenses of the Screening Committee (see Sec. 4.2).

4.2 Fellowship Nomination and Selection

LHC postdoctoral and graduate fellowships would be advertised in the summer, proposed in the early autumn, and selected by early December, in line with the annual postdoctoral hiring cycle. The fellowships would be awarded in an open nationwide competition:

- The institution proposing to host an LHC fellow would submit a nomination for a specific individual to the LHC-TI Steering Committee (see Sec. 4.3). The nomination would have to include:
    1. A nomination letter from a faculty member or other eligible scientific staff member who would serve as the fellow's faculty sponsor and scientific mentor. The letter would briefly describe the fellowship project, its relation to existing or planned theoretical collaborations, the nominee's qualifications, and the mentoring activities that the sponsor plans on behalf

of the nominee. Each faculty sponsor may nominate at most one graduate fellow and one postdoctoral fellow in a given year of institutional eligibility.

2. An institutional endorsement letter specifying the financial and other support being committed by the host institution to ensure the success of the fellow's research, along with a budget explaining how the fellowship funds would be spent over the period of the award (two or three years for postdoctoral fellowships and one year for graduate fellowships). The faculty sponsor would serve as Principal Investigator for the fellowship subaward.
3. For a postdoctoral fellowship nomination, a short research plan (of no more than five pages) written by the nominee, and two additional letters of recommendation. For a graduate fellowship, only one additional letter of recommendation is necessary, and a research plan is not required.
4. Graduate fellowship nominations should specify the start-date of the award.
5. Collaborative nominations from two institutions are encouraged, in which case the nomination should include institutional endorsements from both institutions.

- The fellowship announcement would encourage the nomination of women, members of underrepresented minority groups, and persons with disabilities. The announcement would be distributed widely to reach these groups – e.g. by using the WIPHYS e-mail list.

- Nominations would be screened by a committee with seven members chosen by the LHC-TI Steering Committee (see Sec. 4.3), and to ensure fairness, subsequently vetted by the cognizant NSF Program Officer (currently Dr. Fred Cooper, fcooper@nsf.gov):

  1. Members of the Screening Committee would serve for one or two years; the Screening Committee would be representative of the US particle theory community in LHC-related physics, and would include representatives from U.S. CMS and ATLAS. To avoid conflicts of interest, members of the Screening Committee would not be eligible to nominate a fellow during the time of their service on the committee.
  2. The Screening Committee would produce a rank-ordered list of all nominations, and a recommendation of the number of postdoctoral and graduate fellowships to be awarded. These recommendations and all nomination materials would be forwarded to NSF as a reallocation request involving a "change of scope" (see sections 311.1 and 322b of the NSF Grant Policy Manual, NSF-05-131).
  3. The cognizant NSF Program Officer would review the screening process. Dr. Fred Cooper, the current program officer for particle theory, has stated his intention to convene an NSF panel to review the Screening Committee's recommendations and make the final award determinations, should the proposal be funded.
  4. This information would be returned to the LHC-TI Steering Committee, and the final (sub-)awards would be processed by Johns Hopkins University.

- The following criteria would be used by the Screening Committee to rank nominations:

  1. Quality of the candidate.
  2. Quality of the fellowship project.
  3. Relevance of the proposed work to the LHC, using the projects listed in Secs. 2.5 and 3.4 as updated appropriately, as guidelines.
  4. Support committed by the recipient's institution, in particular the synergy between the proposed work and the theoretical and experimental groups at the sponsoring institution, as well as the availability of students, postdocs and faculty for collaboration.

5. Potential for impact on the recipient institution as a center of excellence for LHC-related theoretical research.
6. Potential for the proposed project to nucleate an active theoretical working group.

- In order to ensure the full consideration of women, members of underrepresented minority groups, and persons with disabilities, the Screening Committee would apply the best practices developed for the unbiased review of applicants.[6] The Screening Committee would also, to the best of its ability, keep track of the diversity of the nomination pool, and two members of the Screening Committee would be specifically charged to provide a report to the Steering Committee on the status of the nominations of women, underrepresented minorities, and people with disabilities.
- If a postdoctoral (graduate) fellow is hired into a junior faculty (postdoctoral) position during the fellowship period, the balance of funds would stay with the fellow to continue the support of his or her project.

The most important selection criteria would be the strength of the candidate and the relevance of the project to the LHC. If this proposal is funded, the details of the nomination and selection process would be finalized through negotiations with NSF.

4.3 Management Structure

As with all grant proposals, formal scientific management rests with the PI and co-PIs. However, in order for the LHC fellowship program to be responsive to the array of issues discussed in the previous sections, it is crucial that there be broad-based community input. A broad-based Steering Committee, including representatives of US ATLAS and CMS, as well as the model building and string theory communities, was formed to oversee the LHC-TI process.

The LHC-TI Steering Committee, chaired by Paul Langacker, would serve as the Steering Committee for the LHC fellowship program described here. The Steering Committee will make sure that the LHC fellowship program is "done right." The current members of the Steering Committee are:

Jonathan Bagger*† (Johns Hopkins)
R. Sekhar Chivukula*† (MSU)
Robin Erbacher (UC Davis)
JoAnne Hewett† (SLAC)
Paul Langacker [*Chair*] (IAS, Princeton)
Steve Mrenna (Fermilab)
Lynne Orr*† (Rochester)
Martin Schmaltz† (Boston)
Ulrich Baur*† (SUNY Buffalo)
Sarah Eno (Maryland)
Walter Giele (Fermilab)
Ian Hinchliffe† (LBNL)
Tom LeCompte (ANL)
Fred Olness (SMU)
John Parsons (Columbia)
Carlos Wagner (Argonne and Chicago)
Edward Witten (IAS, Princeton)

* (co-)PI of this proposal
† Executive Committee member

All members of the LHC-TI Steering Committee have agreed to serve for at least one more year. The role of the Steering Committee would be to construct the fellowship Screening Committee and advise on any policy issues not specified in this proposal.

[6] See, for example, `http://wiseli.engr.wisc.edu/initiatives/hiring/Bias.pdf`.

In addition, a smaller Executive Committee would be needed to handle the details of the execution of the fellowship program – for example, constructing and distributing a suitable fellowship solicitation, ensuring that fellowship meetings are scheduled and that programs are arranged, etc. The Executive Committee would be a subset of the Steering Committee of about 7 members. The current Executive Committee members are indicated by a dagger. Lynne Orr and Ulrich Baur have agreed to serve as co-chairs of the Executive Committee. The (co)-PIs of the proposal (who are indicated by an asterisk) are committed to serve on the Executive Committee for the duration of the grant. The additional members have agreed to serve through at least the first two years of awards. The LHC-TI Steering Committee would have overall oversight responsibility for this group.

Finally, as replacements on the Executive or Steering Committees are needed, the LHC-TI Steering Committee would solicit and endorse replacement members – while maintaining broad-based representation on the committees in terms of research interests and diversity.

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SUMMARY PROPOSAL BUDGET
YEAR 1

ORGANIZATION **Johns Hopkins University**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Jonathan A Bagger**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jonathan A Bagger - none	0.00	0.00	0.00	$ 0	$
2. Ulrich J Baur - none	0.00	0.00	0.00	0	
3. R. Sekhar Chivukula - none	0.00	0.00	0.00	0	
4. Lynne H Orr - none	0.00	0.00	0.00	0	
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,250	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				400	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				420,000	
6. OTHER				12,000	
TOTAL OTHER DIRECT COSTS				434,900	
H. TOTAL DIRECT COSTS (A THROUGH G)				440,150	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) F&A (Rate: 26.0000, Base: 8150)					
TOTAL INDIRECT COSTS (F&A)				2,119	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				442,269	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 442,269	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME **Jonathan A Bagger**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Nancy Kerner**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET — YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **Johns Hopkins University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Jonathan A Bagger**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jonathan A Bagger - none	0.00	0.00	0.00	$ 0	$
2. Ulrich J Baur - none	0.00	0.00	0.00	0	
3. R. Sekhar Chivukula - none	0.00	0.00	0.00	0	
4. Lynne H Orr - none	0.00	0.00	0.00	0	
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,250	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				400	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				840,000	
6. OTHER				24,000	
TOTAL OTHER DIRECT COSTS				866,900	
H. TOTAL DIRECT COSTS (A THROUGH G)				872,150	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) F&A (Rate: 26.0000, Base: 8150)					
TOTAL INDIRECT COSTS (F&A)				2,119	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				874,269	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 874,269	$

M. COST SHARING PROPOSED LEVEL $ 0 — AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Jonathan A Bagger**

ORG. REP. NAME*: **Nancy Kerner**

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION: **Johns Hopkins University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Jonathan A Bagger**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jonathan A Bagger - none	0.00	0.00	0.00	$ 0	$
2. Ulrich J Baur - none	0.00	0.00	0.00	0	
3. R. Sekhar Chivukula - none	0.00	0.00	0.00	0	
4. Lynne H Orr - none	0.00	0.00	0.00	0	
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,250	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				400	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				840,000	
6. OTHER				24,000	
TOTAL OTHER DIRECT COSTS				866,900	
H. TOTAL DIRECT COSTS (A THROUGH G)				872,150	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) F&A (Rate: 26.0000, Base: 8150)					
TOTAL INDIRECT COSTS (F&A)				2,119	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				874,269	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 874,269	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Jonathan A Bagger**

ORG. REP. NAME*: **Nancy Kerner**

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 4

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: Johns Hopkins University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Jonathan A Bagger

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jonathan A Bagger - none	0.00	0.00	0.00	$ 0	$
2. Ulrich J Baur - none	0.00	0.00	0.00	0	
3. R. Sekhar Chivukula - none	0.00	0.00	0.00	0	
4. Lynne H Orr - none	0.00	0.00	0.00	0	
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,250	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				400	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				840,000	
6. OTHER				24,000	
TOTAL OTHER DIRECT COSTS				866,900	
H. TOTAL DIRECT COSTS (A THROUGH G)				872,150	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) F&A (Rate: 26.0000, Base: 8150)					
TOTAL INDIRECT COSTS (F&A)				2,119	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				874,269	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 874,269	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME: Jonathan A Bagger

ORG. REP. NAME*: Nancy Kerner

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 5

ORGANIZATION **Johns Hopkins University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Jonathan A Bagger**				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. **Jonathan A Bagger - none**	0.00	0.00	0.00	$ 0	$	
2. **Ulrich J Baur - none**	0.00	0.00	0.00	0		
3. **R. Sekhar Chivukula - none**	0.00	0.00	0.00	0		
4. **Lynne H Orr - none**	0.00	0.00	0.00	0		
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (0) GRADUATE STUDENTS				0		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				0		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,250		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS $ 0						
2. TRAVEL 0						
3. SUBSISTENCE 0						
4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				400		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,500		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				840,000		
6. OTHER				24,000		
TOTAL OTHER DIRECT COSTS				866,900		
H. TOTAL DIRECT COSTS (A THROUGH G)				872,150		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **F&A (Rate: 26.0000, Base: 8150)**						
TOTAL INDIRECT COSTS (F&A)				2,119		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				874,269		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 874,269	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD NAME **Jonathan A Bagger**				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Nancy Kerner**				Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION Johns Hopkins University	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jonathan A Bagger	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jonathan A Bagger - none	0.00	0.00	0.00	$ 0	$
2. Ulrich J Baur - none	0.00	0.00	0.00	0	
3. R. Sekhar Chivukula - none	0.00	0.00	0.00	0	
4. Lynne H Orr - none	0.00	0.00	0.00	0	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				26,250	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				12,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				3,780,000	
6. OTHER				108,000	
TOTAL OTHER DIRECT COSTS				3,902,500	
H. TOTAL DIRECT COSTS (A THROUGH G)				3,928,750	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				10,595	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				3,939,345	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 3,939,345	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME Jonathan A Bagger	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Nancy Kerner	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

BUDGET JUSTIFICATION/EXPLANATION PAGE - FIRST YEAR

E.1. The seven members of the Screening Committee are to meet once each year in person to select the postdoctoral and graduate student fellows. The funds listed here ($5,250) are to cover the expenses for this trip, estimated at $750 per person.

G.1. $400 for printing and mailing posters to announce LHC fellowships

G.2. $2,500 to place advertisements for LHC fellowships in *Physics Today*, *CERN Courier*, and other printed and online publications

G.5. $420,000 for two postdoctoral LHC fellowships (each at $150,000) and three graduate student LHC fellowships (each at $40,000)

G.6. JHU has agreed to waive its standard F&A charges on the subcontracts in lieu of an administrative fee of $3,000 per postdoctoral fellowship, and $2,000 per graduate student fellowship.

I.1. JHU has approved an off-campus F&A rate (26%) for travel, advertising and printing.

BUDGET JUSTIFICATION/EXPLANATION PAGE - SECOND YEAR

E.1. The seven members of the Screening Committee are to meet once each year in person to select the postdoctoral and graduate student fellows. The funds listed here ($5,250) are to cover the expenses for this trip, estimated at $750 per person.

G.1. $400 for printing and mailing posters to announce LHC fellowships

G.2. $2,500 to place advertisements for LHC fellowships in *Physics Today, CERN Courier*, and other printed and online publications

G.5. $840,000 for four postdoctoral LHC fellowships (each at $150,000) and six graduate student LHC fellowships (each at $40,000)

G.6. JHU has agreed to waive its standard F&A charges on the subcontracts in lieu of an administrative fee of $3,000 per postdoctoral fellowship, and $2,000 per graduate student fellowship.

I.1. JHU has approved an off-campus F&A rate (26%) for travel, advertising and printing.

BUDGET JUSTIFICATION/EXPLANATION PAGE - THIRD YEAR

E.1. The seven members of the Screening Committee are to meet once each year in person to select the postdoctoral and graduate student fellows. The funds listed here ($5,250) are to cover the expenses for this trip, estimated at $750 per person.

G.1. $400 for printing and mailing posters to announce LHC fellowships

G.2. $2,500 to place advertisements for LHC fellowships in *Physics Today*, *CERN Courier*, and other printed and online publications

G.5. $840,000 for four postdoctoral LHC fellowships (each at $150,000) and six graduate student LHC fellowships (each at $40,000)

G.6. JHU has agreed to waive its standard F&A charges on the subcontracts in lieu of an administrative fee of $3,000 per postdoctoral fellowship, and $2,000 per graduate student fellowship.

I.1. JHU has approved an off-campus F&A rate (26%) for travel, advertising and printing.

BUDGET JUSTIFICATION/EXPLANATION PAGE - FOURTH YEAR

E.1. The seven members of the Screening Committee are to meet once each year in person to select the postdoctoral and graduate student fellows. The funds listed here ($5,250) are to cover the expenses for this trip, estimated at $750 per person.

G.1. $400 for printing and mailing posters to announce LHC fellowships

G.2. $2,500 to place advertisements for LHC fellowships in *Physics Today*, *CERN Courier*, and other printed and online publications

G.5. $840,000 for four postdoctoral LHC fellowships (each at $150,000) and six graduate student LHC fellowships (each at $40,000)

G.6. JHU has agreed to waive its standard F&A charges on the subcontracts in lieu of an administrative fee of $3,000 per postdoctoral fellowship, and $2,000 per graduate student fellowship.

I.1. JHU has approved an off-campus F&A rate (26%) for travel, advertising and printing.

BUDGET JUSTIFICATION/EXPLANATION PAGE - FIFTH YEAR

E.1. The seven members of the Screening Committee are to meet once each year in person to select the postdoctoral and graduate student fellows. The funds listed here ($5,250) are to cover the expenses for this trip, estimated at $750 per person.

G.1. $400 for printing and mailing posters to announce LHC fellowships

G.2. $2,500 to place advertisements for LHC fellowships in *Physics Today*, *CERN Courier*, and other printed and online publications

G.5. $840,000 for four postdoctoral LHC fellowships (each at $150,000) and six graduate student LHC fellowships (each at $40,000)

G.6. JHU has agreed to waive its standard F&A charges on the subcontracts in lieu of an administrative fee of $3,000 per postdoctoral fellowship, and $2,000 per graduate student fellowship.

I.1. JHU has approved an off-campus F&A rate (26%) for travel, advertising and printing.

SUPPLEMENTARY DOCUMENTS

The LHC fellowship program has been endorsed by a wide variety of US universities and national laboratories, as well as by the US ATLAS and US CMS management. A representative sample of letters is attached: US ATLAS, US CMS, Berkeley, Florida, Florida State (CTEQ), Harvard, Oklahoma State, Stony Brook, William & Mary, Wisconsin, Yale, Argonne, Brookhaven, and Fermilab.

The LHC fellowship program has also been endorsed by the members of the Steering Committee, representing in addition: Boston, Buffalo, Chicago, Columbia, Davis, IAS Princeton, Johns Hopkins, LBNL, Maryland, Michigan State, Rochester, SLAC, and Southern Methodist.

Columbia University *in the City of New York*

Prof. P. Michael Tuts
Mail Code 5214
Physics Department
538 W 120th St
New York, NY 10027
tel. (212) 854-3263
FAX (212) 854-3379
tuts@nevis.columbia.edu

Prof. U Baur
239 Fronczak Hall
Department of Physics
SUNY Buffalo
Buffalo, NY 14260-1500

October 17, 2006

Dear Prof. Baur,

I am writing this letter in enthusiastic support of the LHC Theory Initiative. As the Research Program Manager for U.S. ATLAS I am keenly aware that we must fully exploit the unique LHC physics opportunities that lie ahead of us. Experiment and theory must work hand in hand to fully realize those opportunities. The U.S. has made a large investment in the ATLAS and CMS experiments and the LHC accelerator, and it is important to make appropriate investments on the theory side.

The LHC Theory Initiative is an excellent opportunity to do just that. In 2008 we will have the experimental tools to probe the energy frontier at 14 TeV with luminosities that will ultimately reach 10^{34} $cm^{-2}s^{-1}$. We anticipate exploring, at the TeV scale, the source of electroweak symmetry breaking, be it related to the Standard Model Higgs, to Supersymmetry, to the possible existence of additional spacetime dimensions, or to other sources of new physics beyond the SM. Just as we experimentalists must carefully calibrate our detector and understand instrumental backgrounds, our theoretical colleagues must help us to understand the physics backgrounds and signal signatures. Some of the signals will be difficult to observe and a more complete understanding of the background will be critical to fully exploit the physics program. The LHC Theory Initiative lays out a sensible prioritized program of work that is closely coupled with the anticipated data taking program at LHC. The proposed mechanism of prestigious fellowships is one that will likely have an impact beyond the specific individuals that will be supported – it draws attention to the remarkable discoveries that await us over the next decade and the exciting program of work that needs theoretical attention; I suspect this initiative will be a catalyst to attract additional theoretical focus on these important topics.

This initiative will help to assure a world class U.S. program in collider physics and will be an invaluable complement to the existing LHC experimental program. I strongly endorse this initiative.

Sincerely

Philip Michael Tuts

Michael Tuts
Professor of Physics
US ATLAS Research Program Manager

Fermilab

Fermi National Accelerator Laboratory
Particle Physics Division - CMS Project
P.O.Box 500 • MS205
Batavia, IL • 60510• Fax: 630-840-2194

October 5, 2006

Professor Ulrich Baur
The Department of Physics
University at Buffalo
State University of New York
Buffalo, N.Y.

To: Whom it may concern

Re: Support of the LHC Theory Initiative

The Large Hadron Collider (LHC) experiments will soon start operation at a new frontier of greatly expanded energy and luminosity. The energy will be a factor of seven higher and the event rate a factor of about one hundred larger than our currently operating hadron colliders. In turn, this implies the probability of new discoveries and the certainly of a flood of new data.

Because the LHC experiments will be prepared to perform data analyses opening up new discoveries, the theoretical preparation for the new data should proceed apace. The new physics to be mined at the LHC occurs in rather rare processes; about one in ten billion proton-proton reactions may be of fundamental interest.

Therefore, the much larger background reactions must be predicted and understood theoretically to an exquisite precision. The new physics is expected to truly be a needle in a haystack, and we must understand the haystack very, very well. In addition, the signals themselves will likely be complex and possess non-trivial topologies. Hence, the experiments will need precise predictions of the defining characteristics of the signal processes.

Indeed, the signatures for the new processes must have robust predictions so that the nature of the discoveries can be carefully unraveled. For example, supersymmetry (SUSY) can possess rather intricate cascade decays which then appear in the detectors. The ability to reconstruct and interpret these decays depends both on the detector properties and the correct theoretical guidance within the context of specific models.

The LHC experiments need to be armed with the best and most predictive tools. The basic inelastic interactions are important in that each logged reaction contains, in addition, about twenty of these reactions as background at design luminosity. Therefore, the trigger strategy and reconstruction algorithms are both dependent on the details of these interactions.

There are large QCD backgrounds in multi-jet reactions which are required for background estimates. Basically, at the LHC the experiments will study vector boson – vector boson scattering. Thus, backgrounds to those scatters, from top-anti-top pairs or weakly produced vector boson pairs or boson plus jets, must be accurately predicted.

Finally, the signals must be well modeled. Those predictions must be run through the specific detector simulations, trigger strategies, and reconstruction algorithms so as to fully understand the signals which are found at the experiments. In any discovery, new questions arise. What are the masses, couplings and quantum numbers of any new state which is found? Here, theoretical guidance is crucial.

Obviously, the proposed program of work will be of great importance to the full realization of the potential of the LHC experiments. The US has invested 531 M$ in the detectors and interaction region magnet. Therefore, a modest investment by the US to further understand the products of these detectors seems very appropriate. Clearly, there will be a close collaboration between experimenters and theorists as all strive to understand the discoveries that will be made at the LHC. The proposed program of fellowships will help to ensure that the US realizes the major investment it has made in the LHC physics program. I recommend this proposal to you most strongly.

Sincerely,

Dan Green
US CMS Program Manager

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO

SANTA BARBARA • SANTA CRUZ

SHAPIRO
CHAIR

DEPARTMENT OF PHYSICS
BERKELEY, CALIFORNIA 94720-7300

October 28, 2006

National Science Foundation
Washington DC

To Whom It May Concern:

I would like to express my continued strong support for the proposal for the NSF to fund an LHC Fellowship program for theorists interesting in phenomenological issues related to the LHC. As an experimentalist working in the LHC program (I am a member of the ATLAS collaboration), I understand how many difficult theoretical issues remain and how few US theorists are currently working in this area. The Fellowship program could have a major impact on the US contributions to understanding and interpreting the experimental data that will become available in the next decade.

The model presented in this proposal is quite similar to that of the SSC Fellowships awarded by the Texas National Research Council. I served as a member of the selection committee for the SSC Fellowships and can attest to the high quality of the applicants. Given the fact that the LHC will be taking physics-quality data in 2008 and that the potential for observing beyond-the-standard-model physics in early data is good, I expect even stronger applicants for the proposed LHC Fellowships. These applicants are likely to cover a broad range of theoretical work from precision measurements of Standard Model processes through the elucidation of Beyond the Standard Model phenomena.

I believe the organization suggested in the proposal is an excellent one. By limiting the Fellowships to at most one postdoc and one student per institution, by including two annual meetings for all recipients and by providing adequate research support (including funds that can be used for travel to conferences), this organization insures that the recipients of the Fellowships will significant scientific exposure and, I hope, a broad impact on the LHC program. Because the administrative costs for the grant would be exceptionally low, the proposal allows a large number of postdocs and students to benefit. I believe that the use of such fellowships to support post-docs and students is a more cost effective approach than funding a smaller number of junior faculty salaries would be. In addition, the proposed fellowship selection committee will insure that the chosen fellows are of high quality and working on relevant problems.

The LHC era will be an exciting one of particle physics, with the potential to profoundly change our world iew. The US has made significant contributions to the experimental program at the LHC. This proposal would insure that the US theoretical community has the resources to contribute successfully to LHC physics and to reap the rewards of the experimental community's work. I urge you to approve this proposal expeditiously and to fund it at the requested level.

Sincerely,

Marjorie Shapiro

Marjorie Shapiro
Chair, Physics

PHONE: (510) 642-3316 FAX: (510) 643-8497 E-MAIL: chair@physics.berkeley.edu

UF | UNIVERSITY of FLORIDA

Department of Physics
Alan T. Dorsey
Professor and Chairman
chair@phys.ufl.edu

P.O. Box 118440
Gainesville, Florida 32611-8440
(352) 392-0521
Fax (352) 392-0524

October 4, 2006

Professor J. Bagger
Department of Physics and Astronomy
The Johns Hopkins University
Baltimore, MD

Dear Professor Bagger:

The High Energy Theory Group at the University of Florida strongly supports the creation of Postdoctoral and Graduate Fellowships, as outlined in the "LHC Initiative" white paper. These new positions, devoted to data analysis at the LHC, are much needed and long overdue. Our department's high energy groups (theory and experiment) play a significant role in the CMS detector, with several theorists who are intimately concerned with the analysis of the signatures of new physics at LHC energies.

In response to their strong endorsement of the proposals in the White Paper, I have sought and obtained approval from our "Division of Sponsored Research", which determines overhead and benefit rates, to agree to limit the administrative costs on the postdoc fellowships to $10K/year, and on the graduate fellowships to $5K/year, as outlined in the White Paper.

We look forward to our participation in this important initiative.

Sincerely,

Alan T. Dorsey

Alan T. Dorsey
Professor and Chairman
Department of Physics

Department of Physics
315 Keen Building
Florida State University, Tallahassee, FL 32306–4350

URL: http://www.hep.fsu.edu/~owens/ *(850) 644-4765*
Email: owens@hep.fsu.edu *FAX: (850) 644-6735*

September 21, 2006

Dear Colleagues,

The CTEQ collaboration (www.cteq.org) strongly supports the LHC Theory Initiative (LHC-TI). CTEQ is a multi-institutional collaboration devoted to a broad program of research projects emphasizing close cooperation and interaction between theorists and experimentalists. We believe the LHC-TI is an essential component of a strong US physics program for the following reasons.

The LHC will extend our energy reach by an order of magnitude and open an unexplored kinematic regime. It will provide marvelous new discoveries, impart a new perspective on the fundamental forces of nature, and be the high-energy focus of our field for the coming decade.

Physics is an experimental science. Data can lead to revolutionary new insights, as we have witnessed in the past few decades. Moreover, confronting theoretical expectations with data is essential for advancing our base of knowledge. Toward this goal, it is important to continue to foster close interaction between the theoretical and experimental communities. The LHC-TI contributes to this objective by encouraging and supporting physicists whose efforts are directed toward the experiment/theory interface.

The LHC-TI will provide tools, training, and talent to support more effort in the US physics community to match precision theoretical calculations with LHC data. The proposed LHC-TI budget, a small fraction of the resources the US has committed to the LHC, will help ensure maximum benefit from LHC data and assist in the development of US leadership in the international LHC physics endeavor.

We support the aims of the LHC TI with urgent priority.

Sincerely,

Steve Kuhlmann and Jeff Owens
on behalf of the CTEQ collaboration

HARVARD UNIVERSITY

THE PHYSICS LABORATORIES
17 OXFORD STREET
CAMBRIDGE, MA 02138

HOWARD GEORGI
EMAIL: georgi@physics.harvard.edu
TEL: 617–496–8293

Oct. 28, 2006

Prof. Sekhar Chivukula
Prof. Jonathan Bagger

Dear Sekhar and Jon,

I write in very strong support of the LHC Theory Initiative. I believe that the proposal represents a relatively small investment that will pay big dividends in the LHC era and beyond. We are already seeing an upswing in interest in collider phenomenology in several top graduate programs. It is very important to keep up this momentum for the next few critical years.

Sincerely,

Howard Georgi
Mallinckrodt Professor of Physics
The Physics Laboratories
Harvard University
Cambridge, MA 02138 USA

OKLAHOMA STATE UNIVERSIT

OSU

Department of Physics
145 Physical Sciences
Stillwater, Oklahoma 74078-3072
405-744-5796
Fax 405-744-6811

October 4, 2006

Dr. Ulrich Baur
Department of Physics
239 Fronczak Hall
State University of New York at Buffalo
Buffalo, NY 14260-1500

Dear Dr. Baur:

I am in strong support of the LHC Theory Initiative and its request for funding from NSF for nationwide postdoctoral and graduate student fellowships. At Oklahoma State University, we have a small but strong theoretical high energy physics program. Our high energy theory group consists of two outstanding professors, one postdoctoral research fellow and eight graduate students, and is involved in many aspects of LHC physics research. Several of these students are being supported by teaching assistants, which is a strain on Departmental resources. In addition, teaching assistantship is scarce in the summer, and it is not possible to support HEP theory students during the summer. The possibility of postdoctoral and graduate fellowships will be of tremendous assistance for both our high energy physics program and the Department.

OSU Physics Department will be very happy to host postdoctoral fellows, and/or graduate student fellows supported through this initiative. Enhancing our research program through such graduate student fellowships and postdoctoral fellowships is one of the goals in our Department's strategic plan, and will match very well with our long term vision.

Sincerely,

James P. Wicksted

Dr. James P. Wicksted, Professor and Head
Department of Physics

STONY BROOK

C.N. Yang Institute for Theoretical Physics
Stony Brook University
Stony Brook, NY 11794-3840
voice: (631) 632-7967
fax: (631) 632-7954
email: sterman@insti.physics.sunysb.edu

October 23, 2006

Profs. Ulrich Baur and Lynne Orr
LHC-TI Steering Committee

Dear Uli and Lynne,

I am writing to express my support for the program of postdoctoral and graduate fellowships outlined in the LHC white paper prepared by the LHC-TI Sterring Committee. I believe that special thanks are due to you for your untiring initiative in this project.

Such fellowships would strengthen U.S. participation in the theory that supports the Large Hadron Collider. This would lead to a more rapid exploitation of LHC data in the search for physics beyond the standard model, including some of the fundamental contemporary questions of particle physics, many of which have impact as well in cosmology. It would also broaden the set of youthful voices within the U.S. available to interpret and to communicate the excitement of new experimental results to the wider public.

The example of SSC Fellowships of the early nineties, which helped the careers of a large number of then-junior and now prominent phenomenologists, shows that such a program can have a very positive effect. The C.N. Yang Institute for Theoretical Physics at Stony Brook University would be delighted for the opportunity to nominate candidates for graduate and/or postdoctoral LHC Fellowships. The guidelines for indirect costs seem reasonable, and should not present an obstacle at Stony Brook.

Sincerely,

George Sterman

George Sterman
Distinguished Professor
Director

GS/dm

The College Of WILLIAM & MARY

Keith A. Griffioen, Chair
Department of Physics
griff@physics.wm.edu

P.O. Box 8795
Williamsburg, VA 23187-8795
757/221-3537, Fax 757/221-3540

October 27, 2006

Prof. Lynne H. Orr
Department of Physics and Astronomy
University of Rochester
Rochester, NY 14627-0171

Dear Prof. Orr,

I am writing to strongly support the proposal for theoretical graduate and post-doctoral fellowships for the LHC in the "LHC Theory Initiative: from the Standard Model to New Physics" being prepared for the National Science Foundation. The College of William & Mary, through its theoretical particle physics faculty, is eager to participate in such a fellowship program.

Should the College of William & Mary receive a post-doctoral award or graduate student award, it agrees to accept an administrative fee of $10,000 for each post-doctoral award and $5,000 for each graduate student award in lieu of indirect costs.

I understand that each institution involved in this project is being asked to abide by these same terms. Should the overall terms change, our terms would change also.

Sincerely,

Keith Griff

Keith A. Griffioen
Professor and Chair
Department of Physics

October 23, 2006

Dr. Fred Cooper
Mathematical and Physical Sciences (MPS)
The National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

Dear Dr. Cooper:

We are writing this letter in enthusiastic support of the ***LHC Theory Initiative proposal*** being submitted by the members of the LHC-TI Steering Committee.

In 2007, the LHC at CERN will begin operation. It will collide proton beams at an energy of 14 TeV, a factor of 7 beyond the energy scale we have currently explored. It will accumulate a factor of 100 more data than the Fermilab Tevatron, the current energy frontier machine. Using LHC data, we will uncover the origin of the masses of fundamental particles, and search for drastic modifications of nature such as the presence of unseen extra dimensions. The potential of the LHC for increasing our understanding of fundamental physics is unprecedented.

The proposed LHC Theory Initiative addresses a serious need for theoretical input to the experimental program. In order to fully utilize the potential of the LHC, accurate predictions for expected signals and backgrounds are needed. These predictions require very precise calculations of processes in Quantum Chromodynamics, the theory of the strong interactions. Many of these calculations cannot be performed with current computational techniques, and have stimulated the development of new mathematical and algorithmic ideas in quantum field theory. We strongly believe that the activities suggested in this proposal should be pursued, both for their importance to the experimental program and for their own intellectual merit.

Department of Physics
Susan N. Coppersmith, Department Chair, Professor of Physics

Department Office: 2320A Chamberlin Hall 1150 University Avenue Madison, Wisconsin 53706-1390
Telephone: (608) 263-3279 e-mail: snc@physics.wisc.edu Fax: (608) 262-3077

We are especially excited about the possibility of the University of Wisconsin-Madison hosting graduate and postdoctoral Fellows sponsored by the LHC Theory Initiative. UW-Madison has a strong tradition in connecting particle physics theory with experiment. We are the home of the Phenomenology Institute, the first institute founded in the United States devoted to the theoretical explanation of phenomena in high energy experiments. Our experimental group is a leader in both the ATLAS and CMS experiments at the LHC, and works in close collaboration with the Phenomenology group.

In May 2006, members of the high energy physics community met at UW-Madison to discuss the LHC-TI proposal. The support for this effort was unanimous and remarkably enthusiastic. The meeting stimulated many discussions to identify relevant physics scenarios that should be addressed by the LHC-TI proposal. As a result of this activity, the UW-Madison Phenomenology Institute will host a web site to categorize and summarize research directions vital to the high energy experimental program.

We strongly endorse the LHC Theory Initiative proposal, and look forward to UW-Madison's participation in this program.

Sincerely,

Susan N. Coppersmith, Chair
Professor of Physics

Vernon Barger
Vilas Research Professor

Tao Han
H. I. Romnes Faculty Fellow

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October 17, 2006

Prof. Sekhar Chivukula

Dear Sekhar,

Thank you for contacting me again this year about the LHC-TI initiative. I continue to agree strongly with you and your colleagues that it is important to increase the support of LHC related theory in the U.S as we approach the beginning of the LHC era.

A postdoctoral and graduate fellowship program such as the one described in your proposal would be an excellent step in this direction. One can already see a shift toward physics more directly relevant to the LHC on the part of some faculty members in university groups, creating an opportunity for the education and training of a new generation of young physicists. If university groups continue to increase appointments in LHC-related areas, then these opportunities will increase even more.

With ever constricting budgets, however, the support of graduate students and postdoctoral fellows is becoming increasingly difficult in theory groups, and this fellowship program would directly address this pressing need. At the same time, it would stimulate more interest in the LHC on the part of current faculty members and help to insure a vibrant theoretical community in the future. As I understand your proposal, a mechanism would be in place so that the number of these fellowships in any one institution would be limited. I think this is very important for the broad health of the field.

I strongly endorse your proposal and I hope very much that the National Science Foundation will be able to support it.

Sincerely,

Tom

Thomas Appelquist

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October 23, 2006

ToWhom It May Concern:

This is a letter in enthusiastic support of the proposal to the National Science Foundation, with the title: "The LHC Theory Inititative." Let me start by saying that this is an excellent proposal, at the right time and addressing a critical need for a successful LHC physics program in the US.

In the Tevatron hadron collider program with Dzero, I learned that to extract meaningful physics from such a program requires both experimental and theoretical physicists. To simulate the standard and possible new physics signals in detectors, accurate simulations are needed, with correct parton distributions of the proton derived with the best possible perturbative QCD descriptions. This is a critical ingredient to determine acceptances and efficiencies for all processes to be studied. The next stage is to compare standard model measurements at the LHC (*jet, W,Z, top*, etc production) with accurate theory predictions. Once this has been established one can start looking for new physic signatures. This program requires all kind of physicists: detector experts, analysis experts(provided by experiments) and theorists (not provided automatically) to interpret the results from these complicated experiments. Some time theory will be leading experiment and in other cases experiment will guide theory. We went through this process when we explored the new energy regime of the Tevatron and we need to do it again at the LHC. For the Tevatron the CTEQ collaboration played a critical role and it was successful, because it included theorists and experimentalists. Experimenters were easy to identify. It was harder for young theorists to participate, because of a lack of funding for phenomenology.

This proposal addresses this problem head-on with a support program for theorists/phenomenologist at an early stage of their career, allowing them to work within the LHC program, without other constraints. This is critical, because it is exactly this group that is needed to complement the experimenters. I very much look forward to this intense interaction between LHC data and theory in the near future at Argonne, where we will have the people to do this. I would also enthusiastically welcome a Fellow, described in this proposal, because I am convinced LHC physics output would be greatly enhanced by the presence of the Fellow. This program will also be a key and critical ingredient for a successful US role in the worldwide LHC physics arena. It is a component which is lacking currently in the US, compared to Europe.

If I can be of any further assistance please let me know.

Sincerely

H. Weerts

Hendrik Weerts
Professor of Physics &
Director of HEP Division
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October 4, 2006

Dear Sir or Madam:

I am writing to strongly support the proposal for an LHC-Theory Initiative.

During the next decade, the energy frontier will reside at the CERN Large Hadron Collider. With its unprecedented energy, this accelerator is certain to produce many experimental results and lead to new insights into the interactions of particles and the forces that govern these interactions.

Understanding the nature and implications of the LHC results will require close connections between theorists and experimentalists. The data will have to be interpreted in terms of a Standard Model interpretation or perhaps a possible discovery of something new. In order to interpret data in terms of the Standard Model, complicated calculations of higher order corrections are required. These calculations take a dedicated, long term effort, which can be provided by the LHC-Theory fellows. There are many calculations of this nature which do not yet exist—we know how to perform the calculations, but there has not been sufficient theoretical manpower devoted to the effort. Similarly, before we can claim discovery of some new phenomena, further complex theoretical calculations are necessary.

In the past, the US theory community has not supported phenomenology efforts adequately. This must change if we are to fully reap the benefits of the LHC data. There is no doubt in my mind that a theory initiative such at the one proposed is crucial for maximizing the physics output of the LHC.

I hope that BNL will be able to participate actively in the LHC-Theory Initiative, perhaps by sponsoring a fellow or one of the meetings of the LHC theory fellows.

Sincerely,

S Dawson

Dr. Sally Dawson
Chair, BNL Physics Department

Fermilab

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October 10, 2006

Professors Jon Bagger,
Sekhar Chivukula, Lynne Orr,
and Ulrich Baur
LHC-Theory Initiative Steering Committee

Dear Colleagues:

On behalf of the Fermilab Theoretical Physics Department I wish, again, to strongly endorse the LHC Theory Initiative. It is clear that the LHC will be the main thrust of our field by the end of this decade, and well into the next. We expect revolutionary discoveries from this machine, ranging from the possibility of the establishment of supersymmetry as a basic physical principle, to bosonic extra dimensions and/or new dynamical phenomena. The success of the LHC experimental program will determine the long-range future of our entire field, including the viability of the aspiration for the next U.S. led effort, the ILC.

The challenge to successfully conduct the LHC physics program in a timely and effective manner is daunting. The event structures will be ferocious. The detailed behavior of new phenomena could prove enigmatic. The application of QCD to this energy scale with a full understanding of all elements of a given physical process is an almost overwhelming theoretical problem.

The U.S. must contribute to this program in an energetic and fundamental way if it is to be a success. The LHC-TI represents a very important effort, coming from and focused largely within the university community. The LHT-TI concept of Fellowships, that are patterned after the successful SSC Fellows program, is an excellent way to encourage young people and to stimulate the development of the research base needed for the U.S. LHC program. When I first heard of this initiative I realized that we must all work together to ensure the kind of success of this program that we all want to see.

Fermilab, and especially the Theory Group, can provide a unique environment to further enhance the LHC-TI effort. We are primarily a phenomenologically oriented theory group, with special expertise in perturbative QCD and Beyond-the-Standard-Model physics, as well as neutrino and flavor physics. Our own initiatives, in conjunction with the Fermilab LHC Physics Analysis Center (LPC), are beginning to take shape. This includes the Theory Group sponsored Academic Lectures, the Joint Fermilab-CERN Summer School, and the general LHC focused theoretical activities. We have a significant overlap with much of the U.S. experimental community, and will continue to staff our group with people having expertise relevant to the energy frontier research program.

We can help in many ways, to host and to nurture the LHC-TI. We can support LHT-TI Fellows as well as our own post-Docs, and our Frontier Fellows program allows senior researchers to take time away from teaching to come to an active research center. The LHC Theory Initiative is proposing to hold joint meetings of the LHC-TI fellows and the CERN-Fermilab Summer School and to involve the LHC-TI fellows in the activities of the Summer School, for example as discussion group leaders, and both students and LHC-TI fellows would greatly benefit from this. I foresee the possibility that Fermilab could work with the LHC-TI team to coordinate these activities. We can focus our Summer Visitors Program on the LHC in conjunction with the Fermilab-CERN Summer School. In addition, we look forward to an expanded Latin Visitors Program, and guest lecturers from the general community in conjunction with our Frontier fellows Program.

I look forward to considerable conjoining of these various efforts in the future. I hope that the LHC Theory Initiative can become a maximal success, and enhance the success of the LHC program and the long term future of accelerator based elementary particle physics.

Sincerely,

Christopher T. Hill
Head, Theoretical Physics Department
(hill@fnal.gov)

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October 6, 2006

Professors Jon Bagger, Sekhar Chivukula, Lynne Orr, and Ulrich Baur
LHC-Theory Initiative Steering Committee

Dear Colleagues:

We are writing in support of your "LHC Theory Initiative" proposal to the NSF. As Co-Directors of the First CERN-Fermilab Hadron Collider Physics Summer School, we have, perhaps, a unique perspective on a part of what you propose to do.

First, let us note from our experience with the Summer School that community interest in hadron collider physics is, understandably, very intense. We had very nearly 300 applicants to our school, which was announced and planned initially to accommodate only 100 students. While the interest in hadron collider physics is driven by both the increasing amount of data from the Tevatron Collider and anticipation of the higher-energy data from the LHC, the LHC is central to exploring new physics in the future.

It is also clear from our experience that there is a large community of young people who want to and would benefit from concentrating their research in the area of hadron collider physics, not to mention the benefit to the development of the field. Helping to create a sense of shared community and interest among these young people is one of the anticipated outcomes of approval of your proposal.

Had the group of postdoctoral LHC-IT fellows existed at the time of our school, as you propose to have in the future, we could easily have taken advantage of that for our school. There are a number of ways that they could have participated, for example as discussion leaders. Your proposal also speaks of having a parallel gathering of these people at the time of future such schools. Thus, they could also benefit themselves from the open lectures as well.

For all these reasons we are strongly in support of your proposal.

Sincerely,

Jeffrey A. Appel and Bogdan A. Dobrescu
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