

Off-site collaborations as a model for sustainable undergraduate physics research at small colleges

A. Alton, N. Grau, and E. Wells

Department of Physics, Augustana University, Sioux Falls, SD 57197

Abstract: This article presents observations and suggestions from our experiences developing an undergraduate research program based primarily on off-campus collaborations.

Introduction: Augustana University (formerly Augustana College) is a selective, private, residential, comprehensive college located in Sioux Falls, SD. While there are some growing graduate offerings, the central focus of the institution remains undergraduate instruction. The student body consists of approximately 1,840 full and part-time students with an average composite ACT score of 26 and an average high-school GPA of 3.7 on a 4.0 scale. The University has a long tradition of undergraduate research activities, although through the 1980s to the early 2000s this work mainly centered on the Biology and Chemistry departments. While generally well-respected regionally, institutional resources (the current endowment is approximately \$60M) are modest compared to most well-known national liberal arts colleges. Furthermore, South Dakota has historically lacked deep roots in physics research, neutrino experiments in the Homestake gold mine notwithstanding. The state's Board of Regents only recently approved a fledgling Ph.D. program in physics that is shared among the state's public institutions.

The physics department at Augustana University has three full-time tenure-track and one part-time non-tenure-track faculty member. All of the faculty members have been hired since 2003, with startup packages ranging from \$10k-\$25k. The department is housed in approximately 7,000 square feet of the 85,000 square foot Gilbert Science Center, constructed in 1965-66. While the College broke ground in August of 2014 on a \$35M expansion and renovation of the science facility, there is currently no space in the department that is dedicated solely to research activities and so permanent installations of research equipment are not possible.

For fall semester of 2014, we expect 54 physics majors to be enrolled, about half of which are interested in the Dual-Degree (3-2) engineering program. Over the last five years, 30 of the 33 graduates from the Augustana physics program have completed significant research experiences either during the summer or the academic year. At 91%, this number approaches the goal adopted by APS, SPS, CUR, AAPT, and AAS, despite the fact that a research experience is not explicitly required to obtain the physics major at the current time. Two of these 33 students were awarded Goldwater Scholarships and two more received honorable mention from the Goldwater process during this time period. One of our students was also awarded the 2012 LeRoy Apker Award by the American Physical Society.

This article presents the story of how off-site collaborations have enabled this robust undergraduate research activity despite somewhat limited on-campus resources. While our model is probably not unique, we hope that our experience might be useful for other small colleges seeking to enhance their research activity. We also hope to illustrate that the benefits of this model are not one-sided and there are advantages for the larger groups or institutions participating in these collaborations.

In the following narrative, we will introduce the present research activities in the department and how these activities developed, discuss how students are incorporated into the work, and some of the lessons learned about this type collaboration mode during the last decade. In particular, we will outline how students are active while at Augustana rather than the off-site collaboration and the ability to carry this student research into the academic year when student travel is more difficult. We will also discuss the logistical and cultural challenges for faculty operating in this mode and how we have sustained the collaborative activities.

Development of Current Collaborations: Each of the tenure-track faculty members in the Department is active in a different research field. The first group established was the atomic, molecular, and optical physics group, which started with the arrival of Wells in September of 2003. It was immediately apparent that the lack of space and equipment available for physics at Augustana precluded any serious thought of establishing a research program that was exclusively local. Some research work was necessary for professional satisfaction (and for tenure), and therefore, some collaboration was essential. Thus, Wells established a collaboration with colleagues at the J.R. Macdonald Laboratory (JRML) located at Kansas State University (KSU). The KSU campus in Manhattan is a six hour drive from Sioux Falls, not an overwhelming distance in a state where people often drive five hours from Sioux Falls to Rapid City for meetings and events.

Beyond Wells' personal desire to maintain research activity, it seemed evident that department growth, in both quality of program and number of students, required an increased undergraduate research profile. There was also potential for shifting the department strategy through hiring in the coming years. If this collaborative mode of operation was going to evolve from a stop-gap measure to a departmental strategy for undergraduate research, however, it was important to establish both a successful example of a collaborative project and a longer-term plan of operations. Our initial approach, therefore, had shorter and longer-term elements. First, we desired to get a peer-reviewed result as quickly as possible to prove that these sorts of efforts could succeed. The easiest opportunity was a follow-up of an accelerator based experiment¹ done a few years earlier at KSU. This work began in the summer of 2004 with two students and support from Augustana University's internal research fund (ARAF)² and the South Dakota Space Grant. This project was selected because the apparatus was mostly in place and the event-mode data that was generated could easily be analyzed off-site. The preliminary data was used to provide support for a Research Corporation proposal, which was funded for 2005-07. After an additional measurement the next summer, the results of this experiment were published in late 2005³. The article's first five authors were undergraduates.

¹ A.L. Landers, E. Wells, T. Osipov, K.D. Carnes, A.S. Alnaser, J.A. Tanis, J.H. McGuire, I. Ben-Itzhak, and C.L. Cocke, "Interference Effects in Double Ionization of Spatially Aligned Hydrogen Molecules by Fast Highly Charged Ions", Phys. Rev. A **70**, 042702 (2004).

² ARAF stands for Augustana Research and Artist Fund.

³ Nora G. Johnson, R.N. Mello, Michael E. Lundy, J. Kapplinger, Eli Parke, K.D. Carnes, I. Ben-Itzhak, and E. Wells, "Single Ionization of Hydrogen Molecules by Fast Protons as a Function of the Molecular Alignment", Phys. Rev. A **72**, 052711 (2005).

The second goal was sustainability of these research activities. Beyond the Research Corporation grant, it seemed unlikely that an accelerator-based molecular physics program would be a strong candidate for long-term support from funding agencies. As a result, Wells sought to pivot his research activities toward his postdoctoral experience using ultrafast lasers, a move that conveniently followed a similar shift at JRML. To work effectively in this environment, Augustana physics students needed further exposure to more modern laboratory methods (especially optics and lasers), a fact that stimulated work on the intermediate and advanced laboratory sequence in the Physics Department and the physical chemistry laboratory taught in the Chemistry Department. This effort was largely driven by an NSF CCLI grant⁴ although the College contributed a significant amount of matching funds to the award and even more support once the physics program began to grow. Wells joined an existing ultrafast laser project at KSU⁵ that was of interest to him and used the remaining Research Corporation funds to establish an initial set of coherent control experiments at JRML, which have been funded by NSF since 2007 through RUI, EPSCoR RII⁶, and MRI grants as well participation in the “Northern Plains Undergraduate Research Collaboration”, and by the Department of Energy through the JRML award and a mid-scale instrumentation award. This work has produced seven publications since 2009, including a recent article published in Nature Communications⁷. To date, approximately 20 undergraduate students have co-authored papers as part of these collaborations, and a total of 30 high school and undergraduate students have worked in the group, some for multiple years.

The second group established was the particle physics group which started with the arrival of Alton in August of 2006. At the time Alton had decided to move from high energy particle physics (the $D\bar{0}$ experiment at Fermilab) toward underground particle physics (dark matter). Part of the reason Alton was attracted to Augustana University was the substantial effort in the field to form a national underground lab (at the time referred to as DUSEL, and now by the name SURF) in Lead SD, less than a 6 hour drive from Sioux Falls. Alton had substantial experience with collaborative work and the proximity to a lab would reduce travel expenses and might also improve the likelihood of funding. The fact that the state is an EPSCoR state and that Wells had already received external funding gave confidence that

⁴ E. Wells and B.G. Moore, “Instrumentation for Diode-Laser Based Experiments in Physics and Chemistry”, National Science Foundation Course, Curriculum, and Laboratory Improvement program.

⁵ T. Osipov, A.S. Alnaser, S. Voss, M.H. Prior, T. Weber, O. Jagutzki, L. Schmidt, H. Schmidt-Böcking, R. Dörner, A. L. Landers, E. Wells, B. Shan, C. Maharjan, B. Ullrich, P. Ranitovic, X.M. Tong, C.D. Lin and C.L. Cocke, “Photon-Ion Collisions and Molecular Clocks”, J. Modern Optics **52**, 439 (2005); Ali S. Alnaser, Igor Litvinyuk, T. Osipov, B. Ulrich, A. Landers, E. Wells, C.M. Maharjan, P. Ranitovic, I. Bocharova, D. Ray, and C.L. Cocke, “Momentum-imaging investigations of the dissociation of D_2^+ and the isomerization of acetylene to vinylidene by intense short laser pulses”, J. Phys. B: At. Mol. Opt. Phys. **39**, S485 (2006).

⁶ EPSCoR is the Experimental Program to Stimulate Competitive Research. The mission of the multi-agency program is to strengthen research and education in science and engineering throughout the United States and to avoid undue concentration of such research and education. The EPSCoR Research Infrastructure and Improvement award referenced here was a NSF grant to the state of South Dakota to fund research in Photoactive and Nanoscale Systems.

⁷ E. Wells, C.E. Rallis, M. Zohrabi, R. Siemering, B. Jochim, P.R. Andrews, U. Ablikim, B. Gaire, S. De, K.D. Carnes, B. Bergues, R. de Vivie-Riedle, M.F. Kling, and I. Ben-Itzhak, “Adaptive Strong-field Control of Chemical Dynamics Guided by Three-dimensional Momentum Imaging”, Nature Communications **4**:2895 (2013).

an externally funded particle physics group was realistic. On the other hand, the task of changing subfields and the uncertain nature of the underground lab funding both carried risks.

Similar to Wells' case, initial work began on both shorter and longer term paths. To maintain productivity the short term, Alton continued contributing to DØ as a visitor from Augustana University. With an eye to the longer term, Alton developed new collaborations within the state and at the national level. The DØ collaboration has formal requirements for an institution to join but also has a clause where they allow an individual from one institution to be listed as a visitor at an already collaborating institution. We investigated how people at Augustana University would view authorship where the institution was not listed and determined this would not be viewed detrimentally, specifically toward tenure, although some care was needed to explain the situation clearly. The research topic was chosen in an area which Alton had extensive experience and resulted in a publication co-authored with an undergraduate⁸. This project was initially funded by start-up and internal ARAF grants, but Alton subsequently obtained funding from Research Corporation.

The students supported by the Research Corporation award worked mostly on DØ projects, but they did spend some small amount of time (10-20%) working on preliminary work for the longer term projects described below. Even with previous experience in the larger collaboration, it was important for the Augustana participants to work closely with a collaborator that was a strong, year-round member of the DØ group. This link enabled the Augustana efforts not to become lost when the academic year slowed research productivity.

The longer term path was subdivided as well. The activity centered on the underground lab also stimulated interest in creating a Ph.D. physics program within the state. Part of Alton's work included participating in a core group of institutions throughout the state to form a virtual center for underground science.⁹ This virtual center had success in acquiring state funding and provided collaborations to allow pursuit of larger grants. The center was also recently successful in creating a Ph.D. program in the state. The state-supported center provided Alton with some summer support and the home institution matched that by supporting a summer research participant.

The second long term path was in identifying and helping to found a new dark matter collaboration. These efforts have been led by our collaborators at Princeton University¹⁰. In the beginning when there was no substantial data, the Augustana group did more traveling for this effort. As the experiment matured, the amount of travel has declined. During the summers of 2010 and 2011 the Alton group spent 45 days traveling, prototyping parts and constructing infrastructure at Princeton, and helping with a cryogenic distillation column at Fermilab. As the project progressed into reality, its location left the US and landed in Italy, making travel for the entire group much more expensive. In a later summer one student from the group spent over a month at the experiment taking data and doing data analysis. In

⁸ V. M. Abazov et al., "Search for a scalar or vector particle decaying into $Z\gamma$ in p anti-p collisions at $s^{1/2} = 1.96$ -TeV", Phys. Lett. B **671**, 349 (2009).

⁹ CUBED: <http://www.usd.edu/center-for-ultra-low-background-experiments-at-dusel/>

¹⁰ DarkSide: <http://darkside.lngs.infn.it/>

this case of sending a student abroad alone, we were reluctant and only followed this path because the student had worked in the group two previous summers.

Other efforts have focused on improvements to the simulation and data analysis efforts that can mostly be done at Augustana without the need to go to Italy. Again, we note the need to have an engaged person to serve as the Augustana group's interface to the experiment. While the student and professor at Augustana can address the conceptual issues of the research project, it's very helpful to have a liaison who is involved year-round and day-to-day in the experiment and software to help with technical details such as how to check-out, compile, and interpret the simulations or data.

The most recent addition to the Department was the nuclear physics group with the hire of Grau in 2010. Grau came to Augustana as a member of the PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and the ATLAS collaboration at the Large Hadron Collider (LHC) at CERN. Since being involved in both collaborations would be unsustainable, Grau continued as a visiting member of PHENIX through Columbia University where he did his postdoctoral work. Grau was hired as a sabbatical replacement in both 2010 and 2011 and thus did not have immediate access to all resources that were typically available to tenure-track faculty. These included a start-up package, certain institutional awards for research, and the ability to apply for external grants. Despite this, money was obtained by the department (partially by use of indirect funds from earlier grants) and work with undergraduates started in 2010 and has continued since then.

The nuclear physics group's path is similar to the other groups. There were short-term and long-term goals. Two short-term goals were 1) to be as visible as possible in PHENIX to keep Grau "in the loop" and have collaborators continue to see his contributions, and 2) to find a small, well-contained project that an undergraduate could tackle. Grau continued in a high-profile service role for PHENIX, gave a talk at an international conference, and published a phenomenological study with a student¹¹. For the longer term, Grau began working with the subset of collaborators designing and constructing the next generation of the PHENIX detector. These efforts included placing Augustana University in the Letter of Intent for the Department of Energy.

After being hired to a tenure line in 2012, Grau obtained a start-up package and successfully applied for an NSF RUI to fund the research. The proposal included hardware work on a new sub-detector in PHENIX, the MPC-EX, which will be installed in the fall of 2014. The proposal also included software work on the analysis of current data. The longer term goal was to continue to work toward the second generation PHENIX detector with scheduled installation in 2018 and prepare for electron-ion collisions planned at Brookhaven starting in 2022. Grau petitioned and Augustana University was included as a member institution of the PHENIX collaboration beginning in December of 2012.

Grau's expertise is software, which lends itself well to off-site work. Most students who have worked for the group have focused on learning UNIX, C++, and some scripting languages like bash, perl, and python, to analyze current data and to simulate data for data corrections or detector development work. With

¹¹ M. Wussow and N. Grau, "Determination of the quark content of scalar mesons using hydrodynamical flow in heavy ion collisions", Phys. Rev. C 84, 054902 (2011);

the startup and NSF RUI, a cosmic ray test stand has been partially built for use in testing detector components at Augustana. This is useful for both the MPC-EX upgrade and the second generation PHENIX detector work. Students more interested in engineering have been helpful in designing and arranging components.

As a member of a large collaboration, travel to several places besides the laboratory is expected. During the last few years, Grau and his students have participated in workshops and detector assembly projects that have taken them to Brookhaven, Stony Brook, the University of Illinois and the University of Tennessee. These trips have lasted from a few days to over a month depending on the nature of the work. Grau's RUI included approximately one month of travel support to Brookhaven each year. For a 10-week summer program, this means the time at Augustana and at the off-site collaboration roughly balance.

Across the department, students are generally eager to participate in summer research activities, and while initially recruiting was necessary, we now have more applicants than positions every year. Our strategy is to maximize the total number of research experiences for our students. To this end, we encourage participation in off-campus research experiences even at the expense of losing a high performing student for the summer. Talented students are strongly encouraged to apply for a research position after their first year of College so they experience a summer of research at Augustana before becoming good candidates for off-campus programs in later years. In exceptional cases, we have recruited students to join the group while in high school.

As shown in Figs. 1 and 2, the development of our undergraduate research program here at Augustana has coincided with general growth in the department. We do not believe this is coincidental. Our collaborative work and record of publications with students allows us to reasonably claim that we give students access to forefront research while still maintaining the personal interactions between students and faculty that are the signature of the small liberal arts experience.

The host institutions clearly benefit from the collaborations as well. Beyond the normal work done and equipment developed in support of the collaboration as a whole, our partners have access to our student capital. Our partner with the longest duration, KSU, has seen three Augustana students enroll

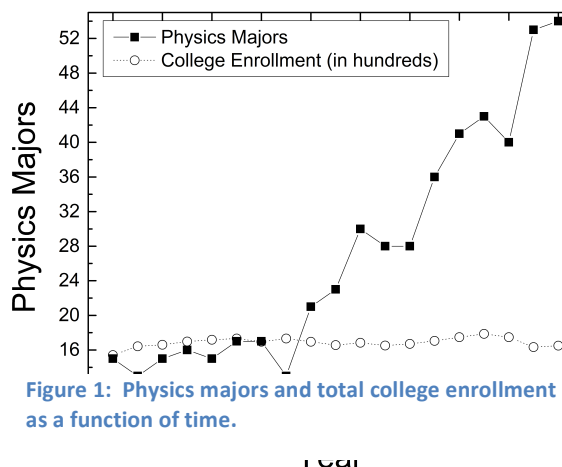


Figure 1: Physics majors and total college enrollment as a function of time.

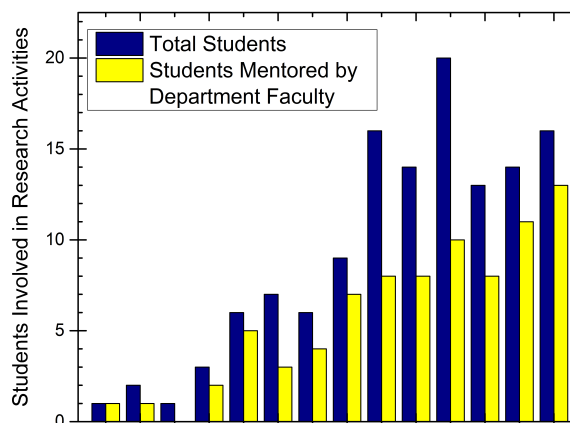


Figure 2: Research students by year. Students mentored within the physics department are reported in yellow, with the total count of physics majors conducting research reported in blue.

there for graduate study and hired one additional former student as a postdoc. More recently, a member of the DARKSIDE collaboration also successfully recruited one of our students for graduate study¹². Even if our students do not directly go on to study at partner institutions, the collaboration members benefit from an increased scope of undergraduate involvement that can be useful in pursuit of funding opportunities that have an educational or workforce development aspect.

Maintaining Student Activity at Augustana: While some research groups have traveled to off-site locations for a month or more per summer, it is important to maintain student research activities when students are on-campus. Ideally, these activities continue during both the summer research period and the academic year. This is perhaps the key challenge to be solved for this collaborative mode of operation.

In this regard an attribute of our work is that each experiment is sophisticated enough that the preparation of the experiment and the data reduction at the end of the experiment usually take far longer than the experiment itself. This is perhaps self-evident for the large-scale particle and nuclear physics activities, but even the coherent control experiments require the development of sophisticated code for computer control and sometimes lengthy analysis of the experimental results.

As a result, there are ample opportunities for computer-based student activities at Augustana. All of the groups have some experience working with event-mode data using such standard packages as ROOT¹³ or SpecTCL¹⁴. In the case of the large experiments, there is considerable time spent in software development. These activities range from analyzing data that has been taken, running simulations of the as-built detector to evaluate corrections and performance of the detector, running simulations and analyzing them in developing and designing a new detector, writing simple toy simulations to understand some physics, and running Monte Carlo event generators and analyzing their output to fully simulate the physics. Most of these activities are done during the production of a published result and can make for self-contained student projects even if the “data” they analyze is simulated. Laser pulse shaping offers students a number of undergraduate-appropriate problems involving transitions of various data from the frequency to the time domain and back again. Our position sensitive detectors generate two-dimensional data that can be “inverted” using the inverse Abel transform to recover a cut (or slice) through the three-dimensional momentum space, and performing these operations and examining the results for physically significant trends can be the basis of a summer research project.

While computer-based activities comprise the bulk of our on-campus work, we have started developing more hands-on activities here at Augustana as our resources have improved. For example, initial testing of our spatial light modulator laser pulse shaper occurred here, as did the building of an imaging spectrometer. More recently, we have developed capabilities to test detector elements for several experiments, including acquiring a small collection of electronics modules and construction of a dark box

¹² Not that all our students matriculate to partner institutions. Recent students have attended graduate school at Arizona State, California-Davis, Colorado, Columbia, Cornell, Iowa State, the Mayo Clinic, Minnesota, Nebraska, North Dakota, Oklahoma, Rice, South Dakota, and Virginia in various fields.

¹³ <http://root.cern.ch/drupal/>

¹⁴ <http://jrm.phys.ksu.edu/Resource/Pubs/SpecTcl/SpecTcl.html>

to test sensitive PMTs. Another recent project is the nearly-completed development of a cosmic ray test stand for use in testing detector components. We look forward to the continued development of these on-campus opportunities as our new facility comes online in 2016. A clear benefit of having additional local, non-computer activities available is it allows us to present a broader array of research options to our students. Many of our more engineering-oriented students, in particular, have gravitated to the more hands-on applications. The summer research program involves students working full time for 10 weeks under the supervision of the faculty either here at Augustana University or at an off-campus location. On some occasions, we have sent experienced students to off-site collaborations without the supervising Augustana faculty, but this is rare. In general, the summer collaboration between students and faculty is quite close. Besides the obvious advantages for the students working on their projects, it is important to remember that the faculty mentors are better able to integrate the students into the larger collaboration. If not for the faculty member being available to shepherd lines of communication, a relatively minor issue (e.g. access to the tunnel server to bypass the firewall) might sidetrack a student for some time. The ten weeks, which often include travel and long hours of work at the collaboration site, tend to be times of intense activity. The faculty mentors frequently comment to each other that it will be nice for the semester to start so things will settle down.

The advantage of working with our own students is the activity can continue through the academic year. It is not unusual for us to make trips to conduct experiments during breaks during the academic year, giving us the ability to follow-up on a summer experiment after some time for analysis. Remarkably, many of our students do not mind spending spring break in the lab rather than the beach. Motivated students are also able to make progress on projects during the academic year while at Augustana – the opportunities are in principle the same as are available in the summer. Often, the activities can be structured so that there is some academic credit involved, such as through a thesis project or an independent study experience. This helps the students to give the research activity a priority. When the academic year work is done well (often combined with a summer project), it offers a significant opportunity for the student to deepen their research experience. Several of our students have used this time to produce publication quality work¹⁵.

Realistically, however, it is difficult for both students and faculty to allocate as much time for research work during the academic year as can happen in the summer. We have found the best practice for successful work during the academic year seems to include (a) reaching a fairly detailed understanding with the student regarding a scope and timeline of the project and (b) following-up with regular meetings between the student and the faculty member.

Even in a semester with limited or no student research activity, it should be recognized that faculty efforts with the collaboration must continue at some level to maintain momentum behind projects and ensure future years of student involvement. This includes not only proposals and reports, but

¹⁵ M. Wussow and N. Grau, “*Determination of the quark content of scalar mesons using hydrodynamical flow in heavy ion collisions*”, Phys. Rev. C 84, 054902 (2011); E. Wells, K.J. Betsch, C.W.S. Conover, D. Pinkham, M.J. DeWitt, and R.R. Jones, “*Closed-Loop Control of Intense-Laser Fragmentation of S_8* ”, Phys. Rev. A 72, 063406 (2005). The two examples noted here were done primarily during the academic year with little or no work during the summer.

sometimes salvaging the projects of struggling students so they still provide a benefit to the larger collaboration.

An additional advantage of research projects during the academic year is to give an opportunity to a student that was unable to participate in the summer research program. Our policy is to restrict the summer program to students that can be funded and not accept volunteer researchers in the summer. This allows us to manage the size of the program and ensures the quality of the experience by maintaining a reasonable student to faculty mentor ratio. Several students that have not otherwise participated in research were able to complete a project using the senior thesis or independent study mechanisms during the academic year. As the number of international students in our program has increased, the non-summer research experience is becoming more important, since the funding sources for international students are more limited than sources for domestic students.

In summary, it is not difficult to keep our students occupied with meaningful research activities while at the home institution rather than the collaboration site. In fact, it is common for some of us to have projects in which the students never visit the site of the experiment, although we consider it best practice to go to the remote location if possible. Obviously, travel to Kansas is somewhat easier to manage than travel to Italy. Even so, it should be pointed out that the local hands-on activities are not, in and of themselves, sufficient to build a research program around. Each of the projects depends upon the ability to collaborate with the off-campus site as motivation for the work done locally at Augustana.

Observations and Suggestions: In this section we will outline some observations about how this collaborative mode of undergraduate research works, and some suggestions of items to consider when implementing similar approaches. We understand that every situation is different and that we might be, in some cases, stating the obvious¹⁶. The issues range from the philosophical to the mundane. Perhaps this might serve as a checklist for faculty members considering how undergraduates might be incorporated into off-site research work. We break these items into some broad categories.

Before you start...

- Identify what unique ability you bring to the collaboration. To solicit funding you may need to be able to differentiate your intellectual pursuit from what the host group is already doing. The answer could be technical (we are the simulation experts in the group) or it could be that you use similar equipment to pursue a different set of experiments. Ultimately, however, standing out within the larger collaboration is likely essential for a sustainable program. The answer may change with time, but it is important to be able to provide an initial answer to this question.
- Department (institutional) culture matters. If your department (or institution) does nearly everything in-house and off-site collaboration is new, we suggest discussing with colleagues how the off-site work will be viewed vis-à-vis the tenure and promotion process. Have students ever been involved in off-site work? Are there policies for how this works?

¹⁶ We are also all experimentalists, and so we will have nothing to say about the issues that might be specific to theoretical collaborations.

- How open is the collaborative institution to this sort of work (with undergraduates)? This can vary widely. Some operations, such as large high-energy physics experiments, are collaborative by default. Even so, is there a standard way visiting undergraduates are handled? Smaller lab groups may have little or no experience in collaborative work at all, let alone with undergraduates. This need not be a barrier – just communicate clearly about the expectations from each side of the collaboration.
- If the collaboration is large, you may need to formally apply for membership. What does this entail, and can you participate as required (e.g. can you “sit shift” X days per year)?
- It helps for the faculty to have some experience with the off-site location and people before the students arrive. If the collaboration is new, consider having the faculty member make a reconnaissance visit before the students arrive.
- Is there specific grant support available for these sorts of activities? The Department of Energy, for example, sometimes has grant opportunities for collaborations with National Labs.
- What support can your institution or collaboration partner provide for travel? Is there cheap housing for visiting scientists? Hotels can make funds disappear quickly.

Student issues:

- There is always a balance to be struck between having a 10-week summer goal for a student and meeting the longer term needs of the collaboration. We find the balance to be difficult at times, but it helps to talk to students about the overall project and how their project fits into the whole. It also helps to have students listen and participate in collaboration meetings as appropriate to help facilitate student understanding of the overall experimental goal.
- Training (formal or informal) is often required upon arrival at the off-site locations. Formally, this could include safety and computer training required of everyone working at the facility. Informally, this is simply the process of bringing the new student “up to speed” so they can contribute to the group. Large labs and institutions often have a structure for these activities. Smaller labs might not. Who will handle the training in this case? Will the training be done by the visiting faculty member, a graduate student from the host lab, or some other method?
- Beyond training, who supervises the undergraduate students at the host laboratory? For the most part, we have found it works best to have the faculty from the undergraduate institution directly involved, at least initially.
- How will the undergraduate work be recognized? Can deserving students co-author papers? Is there a formal procedure for this decision?
- Getting students up to speed on specialized computer data analysis tools is sometimes challenging and cannot be allowed to take too long. Alton and Grau have had success in organizing a “ROOT boot-camp” the first few days of research.
- It is helpful to construct your group of students to include some experienced and some new students each year. If things work out, this strategy can provide continuity for the project, with the experienced students helping to train the new students each summer. This influences our choice of students, and it is therefore rare for students here to hop from one research group to

another in multiple years. A few (10-20%) of our students have worked for a particular group for three summers during their undergraduate years. These are generally strong students who, in later summers, are able to take a leadership role in the group. Many of our students will spend a summer or two working for us early in their undergraduate careers and then participate in an off-campus program after their junior years. About 1/3 of our students work for us for a single summer or during a single academic year.

Faculty issues:

- Understand, up-front, if you can plan to leave during the academic term for collaborative work and, if so, how long is reasonable.
- Recognize how much time will be devoted to grants, collaborative meetings, and administrative details during the school year.
- Recognize that on larger experiments you won't be able to attend every phone meeting or collaboration meeting and prioritize them.
- Talk to colleagues in your department to make sure there are people who can cover classes for you, and make sure you pay them back so that they don't feel abused.
- Set realistic expectations for yourself and your students. You will not be as productive with undergraduates as you were as a postdoc or graduate student. Your students are learning about new physics, new software, new detectors, etc. without likely first seeing the experiment itself. That poses a unique intellectual challenge. Do you have enough students with the capabilities to sustain the research program you want to do?
- If and when applications outnumber positions it is wise to judiciously choose the students. While even some incoming freshman have succeeded in our program, we find that freshman with lower scores in introductory physics sequence are likely to struggle with the research experience, often producing only marginal results. Even among the selected students, it is desirable to think about (a) how to best match student skills with project needs and (b) which projects have the highest priority for the collaboration.

Collaboration issues:

- Both sides of the collaboration should understand the likely work-flow from the undergraduate institution. Consistent progress can be expected in the summer, while work during the academic year may be more sporadic. This depends on the teaching and administrative load of the faculty (and students) in question, but recognizing this initially is preferable to tension arising when a project stalls mid-semester.
- If not already available, invest in decent hardware and software for web-based meetings. Participate in as many weekly group meetings as possible.
- It is a good idea to form a strong relationship with a non-local collaborator that is intimately aware of the efforts of your group and also involved in the day-to-day operations who can possibly take on some of your group's projects when the school year begins if necessary.

Items for Department/Institutional Leadership:

- The hiring process often represents the opportunity where the department or institution can play the most direct role in advocating for a collaborative approach to undergraduate research. If you are considering this as a potential method for stimulating undergraduate research, make it clear this is an option in your recruiting material. In our case, during the department's 2006 and 2011 searches, we asked that the common "research statement" include specific details about how undergraduates were to be involved in the work. If a candidate made the short list, we made sure they had some knowledge of what to expect locally, and made it clear that collaborative work had been successful here in the past.
- Although Augustana is an institution that values teaching highly, we feel that mentoring undergraduate research is one of our most important teaching functions. In hiring, therefore, strong research credentials were a primary criteria for selection. We felt that without postdoctoral experience, it would be unlikely that a candidate would be able to initiate a substantial collaborative effort with an outside partner. On the other hand, we felt that given suitable baseline communication skills and a desire to develop teaching ability, there were many local resources that could help the candidate evolve into a strong instructor. For us, this strategy has been successful.
- In partial contradiction to the two points above, changing to a collaborative style may of course be initiated by an existing faculty without much input by the local college administration. If this occurs, we would encourage the administration to give faculty the freedom to pursue this research route.
- If not already structured this way, consider making startup funds flexible so they may be used not just for equipment but also for travel and initial collaborative work.
- Endeavor to understand this mode of operation early in the tenure-track and have a clear understanding of what a successful collaborative venture looks like. In larger institutions, tenure is often decided mainly by the department, which generally has a reasonable idea of how to benchmark the candidate with regard to other peers in physics. At smaller institutions, it is possible for this to be much more complicated since the department might have relatively little to say in the tenure process. "Professor X from the ATLAS collaboration co-authored 50 papers last year. What does this mean?" is a question to be understood and answered long before the final meeting of the tenure committee.
- Does your institution have a fund for faculty travel to conferences? Might it be used for collaborative travel?
- Does your institution have a fund for undergraduate research? Could it also fund travel?
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Funding Issues

- Obtaining funding for a collaborative situation is largely the same as for independent work. You still need to keep the basic review criteria in mind and plan your proposal appropriately. In an independent proposal, focus on the science you want to do and how the collaboration helps you do this. In a collaborative proposal, make your contribution to the proposal explicit.

- Identify all sources of funding, both internal and external. Even a small award can provide some travel funds that can initiate collaboration.
- Are you going to seek funding as a single institution or as a collaborative project with other institutions? (Or both depending on the situation?) Does it matter to your home institution which option you choose?
- In a collaborative proposal, understand how the indirect costs (if applicable) are distributed between the institutions.
- Does your institution have anyone to help with grant submission, such as from a sponsored research office? Will the “grants person” at the collaborating institution help you with your portion of the grant?
- Seek out someone to advise you on funding using the NSF-RUI route. Getting advice from collaborators at a large research institution has its place (especially about the scientific portions of the proposal), but you should attempt to find an experienced colleague at a primarily undergraduate institution that can advise you as well. In a large collaboration, there might be another person on the collaboration with a RUI award. Talk to them.

Summary: The last decade of work here at Augustana University has demonstrated that a robust undergraduate research program can be developed based around collaborative work with partner institutions. While this operational style may not work for everyone, the potential to limit initial costs and the lack of permanent space requirements are attractive in certain situations. It can also expose undergraduates to highly specialized facilities and give access to leading scientists at partner institutions. From the host institution perspective, the brief but repeated exposure to the collaborating institution can make it more attractive for graduate school when the undergraduates reach that stage. We feel that this mode of operation is perhaps not considered as an option as much as it might be, especially in fields that commonly operate in small groups or single-investigator labs. Careful planning can make this collaborative undergraduate research experience fruitful for all concerned.

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