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Summary Report
Topical Group on Physics Education
Community Engagement Frontier
Snowmass 2021

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ABSTRACT

Companion to the development and advancement of the field of Particle Physics is a strong program in physics education at all levels, that can attract entry level students across the full demographic spectrum and provide them with the education, training and skills needed to advance to successful careers in Science, Technology, Engineering and Mathematics (STEM) and other fields. This report summarizes the work of several investigative teams that have reviewed and assessed current opportunities in physics education across K-12, undergraduate, graduate and postdoctoral domains, including national and international linkages. From these assessments, recommendations have been put forward aimed to innovate educationally in strategic ways to strengthen ties between the research community and teachers, between the academic community and the private sector, and through both domestic and international connections.

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1 Introduction

To have in place the needed educated and trained workforce for currently planned and future experiments in high energy particle physics and ancillary fields, the attraction to and education of students for a broad range of careers in STEM is both necessary and essential. Traditional STEM educational efforts have provided a high-quality workforce, but with rather highly selective demographics. And if left unchanged, the character of the workforce will likely remain generally discouraging to the participation of women and those from underrepresented groups. The Snowmass2021 Process, with its 10-year planning and 20-year vision, offers a creative opportunity to assess the challenges, build on what is currently working very well, and frame a structure a broader opportunity for young researchers to join the exciting particle physics field through an expanded range of educational opportunities.

To identify what is working and the shortfalls and to recommend actions to be taken, the Community Engagement Frontier Topical Group on Physics Education has viewed the physics education process in a systemic way and indicated schematically in Figure 1, considering K-12 education, undergraduate and graduate education, postdoctoral and faculty education, and connections with international linkages. A very large and demographically

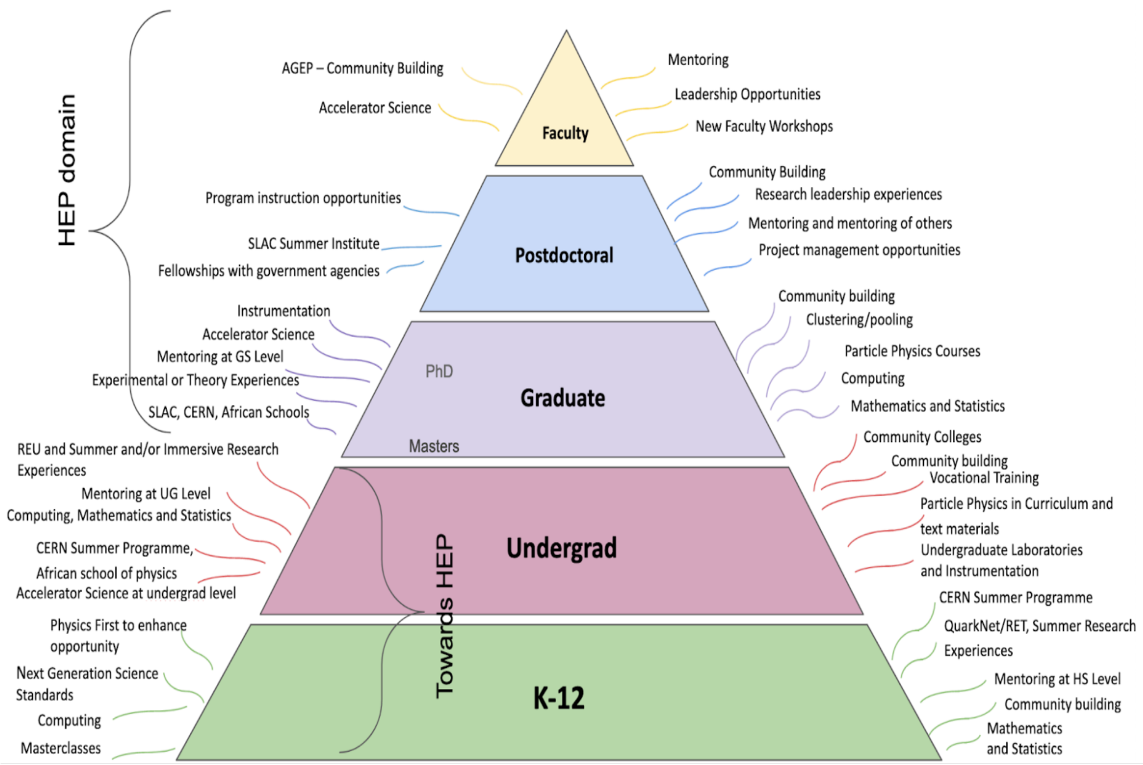

Figure 1: A Schematic Representation of Particle Physics Education

diverse population of students who might consider and potentially enter STEM fields enters at the base of the pyramid. For a variety of reasons, educational, cultural and societal, the fraction of students that choose STEM careers and are able proceed upward to research careers becomes reduced at each step. To assess these issues, the Physics Education Topical Grouo formed four Working groups, organized by community interest, all of which have submitted contributed papers and included: *Group 1. Broadening the Scope of Education, Career and Open Science in HEP* [1]; *Group 2. Opportunities for Particle Physics Engagement in k-12 Schools and Undergraduate Education* [2]; *Group 3. Transforming U.S. Particle Physics Education: A Snowmass 2021 Study* [3]; and *Group 4. The Necessity of International Particle Physics Opportunities for American Education* [4]. In this Topical Group Summary Report, we highlight briefly the efforts of each group including key questions addressed, summarize crucial findings and associated recommendations, and follow the schematic flow up the Pyramid of Figure 1. The process arises naturally at the K/12 and undergraduate levels where the challenge is to attract and engage young students to interest in STEM and physics, and then to hold and enrich their interest and provide the needed scaffolding to help sustain their upward path to research careers. Greater depth and insight will be found in each of the associated and referenced Contributed Papers indicated above [1, 2, 3, 4]. It all begins at the K/12 level...

2 Opportunities for Particle Physics Engagement in K/12 Schools and Undergraduate Education

While many (particularly young) students might show an early interest and aptitude for science and mathematics at the elementary level, the structures are not necessarily in place to capture, nurture and develop such nascent interests. Recommendations to encourage and strengthen such interest are given in [2].

This contributed paper [2] advocates the formation of local collaborative communities (”fora”) of academics of all backgrounds (physicists, engineers, technicians etc.) and K-12 teachers. Such fora can only be created and sustained if a minimal amount of funding for coordination and logistic support is made available. For the sustainability, it is important to have a steady source for this funding, which can come from baseline support by universities or institutes, but could for example also come from or be supplemented by a fixed small part designated for outreach in research grants. Another important ingredient for sustainable fora is that the efforts of the participants are appropriately and regularly recognised.

2.1 Selected Findings

- Joint activities of academia and K-12 educators and pupils should focus on how scientists develop knowledge and the essence of the knowledge acquired so far. It should connect to sister STEM fields, to their successful outreach programs and with an emphasis of a holistic view on STEM.
- It is important that K-12 activities address all students and teachers, adapting to the appropriate level of scientific literacy, and be mindful of biases in program designs that might filter student participation by race, gender, or socioeconomic background.

2.2 Recommendations

- HEP should form a K-12 particle physics outreach community with a "forum" for networking and sharing resources and open to physicists, engineers, technicians, computer scientists and secondary school educators. The community can discuss ideas and issues and work collaboratively to help develop understanding appropriate for secondary school about how scientists develop knowledge.
- Individuals can form local collaborative communities by Identifying a few teachers to hold an assessment session to determine the needs and interests of teachers. Then, the physicists can find ways to meet needs such as helping teachers strengthen their scientific background and/or providing support to use instructional materials.
- K-12 programs should prioritize exposing all students to age appropriate STEM topics to create scientifically literate citizens and be mindful of bias in program designs that might filter student participation by race, gender, or socioeconomic background.
- K-12 particle physics programs should engage with sister STEM fields with successful outreach programs to the same ages and participate in interdisciplinary discussions on best practices in science communication.
- Funding agencies should provide funding for these outreach activities including compensation for those who organize and run them.
- The community, universities, labs, and institutes should acknowledge and reward those who participate in this important work.

3 Educational Opportunities at the Graduate and Postdoctoral Level

This critical time domain for the development and pursuit of careers in particle physics and ancillary fields has traditionally been the purview of university and laboratory groups in the US and abroad. In the words of the engaged group of young researchers working on this topic: "Graduate school (and undergraduate school to a lesser extent) is where researchers learn most of the technical skills required for research, develop scientific problem solving abilities, learn how to establish themselves in their field, and begin developing their career. It is unfortunate, then, that the skills gained by physicists during their formal education are often mismatched with the skills actually required for a successful career in physics.

3.1 Transforming U.S. Particle Physics Education: A Snowmass 2021 Study

The group performed a survey of the U.S. particle physics community to determine the missing elements of graduate and undergraduate education and to gauge how to bridge these gaps." Given the extent of the group's summary document [3], we highlight here the high-level findings and recommendations.

3.1.1 Selected Findings and Recommendations

- Finding: Survey respondents are mostly satisfied with their graduate education and feel relatively well-prepared for careers in academia or in laboratories. However, perceived preparation is moderate for careers in industry and worse for K/12 education, including among those who intend on these non-academic careers.
- Recommendation: Graduate programs in particle physics should normalize training for industry positions via encouragement of industry partnerships (such as summer research internships) and formal development of skills in-demand beyond academia (such as computer programming, team/project management, and effective communication).
- Comment: See Sections 3.2 and 4 below for further discussion related to this topic.
- Finding:Survey respondents were most likely to be interested in academic careers when starting graduate school, though a sizeable number have since changed career intention to laboratory, industry, or other careers. Furthermore, a sizeable number of survey respondents report changing intention from HEP theory to HEP experiment. Lack of positions and/or funding were often cited as the reason for this.
- Recommendation: Universities should provide undergraduate students with a more complete picture of what particle physicists do beyond classroom discussion of physics theory, such as increased opportunities for learning about research (e.g. seminars). They should also provide a more realistic view of common career paths post-PhD in particle physics, including the breakdown of theory and experimental academic positions as well as the commonality of shifting to a non-academic career (e.g. through job panels). This could help students make a more informed decision about what to study in graduate school and whether such a choice aligns with their goals.
- Finding: Professional skills, such as technical presentations and scientific writing, are considered important for one's career and are more strongly correlated with reported career preparation than technical skills such as computer programming. However, they are very frequently gained through self-teaching rather than through any sort of training, including peer learning or mentoring; this self-taught mode is largely disfavored by respondents, while alternative modes such as university courses are more highly-rated. There is some evidence that physicists are being more formally trained in these skills over time, though this effect is small.
- Recommendation: Graduate programs in particle physics should support more formal modes of training for those skills where self-teaching is inadequate. Many of these professional skills are equally useful throughout physics disciplines or even other scientific and non-scientific fields, this could take many forms such as university-wide workshops, one-on-one coaching sessions, or shared online resources. It is critical for

advisors or program coordinators to make their students aware of such resources and to actively encourage their use as part of their graduate training (and not a "free time" activity).

- Finding: Despite receiving high career importance ratings, computer programming and statistics remain somewhat likely to be learned through self-teaching or peer learning. Among theorists, theoretical mathematical skills were also somewhat commonly received through these methods. There is evidence that these methods are poorly rated, especially for statistics, while learning through a university course is rated well.
- Recommendation: Physics departments should consider making a course in statistics a standard part of the undergraduate physics curriculum, as well as providing avenues for formally training graduate students in statistics for particle physics. More formal training opportunities should also be made available for advanced theoretical skills, including opportunities outside of the classroom such as virtual workshops which are free to attend.
- Finding: Only a small subset of survey respondents were undergraduates. We were unable to provide deeper analyses of undergraduate course preparation and career paths due to lack of survey participants.
- Recommendation: Funding agencies and professional societies should develop connections and networking opportunities - including student oriented conferences - to help undergraduate students remain connected in the HEPA community. Develop a mass communication system to reach undergraduates in the future. Community members should actively plan to perform this survey again in the future for undergraduate data once the communication barriers listed in other findings are rectified.
- Finding: None of the survey respondents who self-identified as undergraduates reported research experience in an REU or DOE sponsored lab internship. Most undergraduates participating in this survey came from R1 research institutions.
- Recommendation: Funding agencies and national labs should compile a list of contact information for recent undergrad students in internship and REU programs. Create a central mass communication system for physics departments across a variety of college or university types.

3.2 A New View of the Masters Degree

As noted in several of the recommendations derived from the comprehensive survey cited above and detailed in the Contributed Paper [3] a potentially important level of academic achievement, that of the Masters Degree, is often overlooked or ignored by the physics community which tends to be "Ph D" driven. However the Masters level has several important attributes worthy of community consideration. (1) It is a level where more extensive cross-disciplinary (elective) course work is possible, providing potential branches to applied math, statistics, computer science, engineering and nuclear medicine. (2) It is a level of potential participation by students from the private sector who enroll for technical advancement with support from their companies. This nexus can provide a bridge between students following an academic path with those already in commercial applications sectors, opening up dialog and potential career opportunities that might otherwise be missed. (3) The Masters Level is an intermediate (and potentially achievable) target for students from groups traditionally underrepresented in physics and for whom a PhD in physics might seem an unlikely goal. And (4) enriched programs at the Masters Level can lead to collaborative opportunities across academia, which is the central topic of the next section.

4 Collaborative Opportunities Across Academia

Review the challenges and develop strategies to correct the disparities to help transform the particle physics field into a stronger and more diverse ecosystem of talent and expertise, with the expectation of long-lasting scientific and societal benefits.

- Finding: Trends in education and career opportunities in HEP have been highly selective and generally exclusionary of participation by underrepresented minority and female students. Measures must be taken to strengthen our academic workforce by tapping significant pool of students and faculty at Predominantly Undergraduate Institutions (PUIs) and Community Colleges (CC) that provide access to a broader geographic and demographic base of students
- Recommendations:
  - Investigate Creative ways to engage faculties and at PUIs and CCs in front-line particle physics research
  - Conduct an analysis to assess the needs of faculty at undergraduate institutions in order for them to be successful in developing vibrant research programs, whilst maintaining a significant teaching load characteristic of such institutions.
  - Survey institutional collaborations of PUI and CC faculty with R1 and laboratory groups that have proven successful so far, to assess lessons learned.
  - Conduct a study of new models of collaboration or cooperation that would allow PUI/CC faculty and their students to collaborate in demonstrably effective ways in experiments, and for faculty to be effective leader rather than regarded as secondary.
  - Conduct a survey of R1 institutions and research laboratory physicists who might share an interest in collaborating with PUI and CC faculty.
  - Identify and inventory past and present activities by PUI and CC faculty engaged in HEP or related activities such as experiment design, construction, installation, and maintenance.
  - To bridge the academic preparation gap have more dedicated funding in HEP experiments for students (who lag behind their peers at R1) from PUIs and

CCs to participate in software and hardware training activities and national lab internships in HEP
  - More funding for Open Science activities to bring accessibility to everyone and everywhere. The HEP community should define, with cogent arguments, what should be the scope of making our data and resources publicly available, and the hardware, software and person- power costs associated with such implementation

- Finding: Machine Learning (ML) is becoming an integral part of physics research. Many critical HEP algorithms for triggering, reconstruction, and analysis rely on ML and there are entire conferences and summer schools dedicated to this crosscutting field. Despite the relevance and importance of this research, pursuing a career at the intersection of these fields remains tenuous and undefined endeavor. Current mindset in the field is that highly specialized skills such as software and firmware development and instrumentation development are not broadly recognized as "physics" work, and thus the perception of what it means to 'be a physicist' must be challenged else it will continue to be an impediment. Confronting and addressing these issues would encourage an influx of new workforce into the field, help retain those who are in the field, and equip those who might seek careers outside of HEP

- Recommendations:
  - Finding ways to better support academic and career development at the intersection of physics and ML, and ensure that we can continue to benefit from and contribute to state-of-the-art ML.
  - The view of what constitutes significant contribution to the physics must be reexamined, expanded and rewarded

    item HEP faculty jobs should solely not be based only Physics Analyses but must expand to be base also solely on computing, software or hardware contributions

5 The Necessity of International Particle Physics Opportunities for American Education

Particle physics is an international endeavor. No one institution or nation can assemble the resources or expertise needed to explore the frontiers of the field. The diversity of national, social and cultural backgrounds present in the experiments and labs enriches the pool of intellectual thought and solidifies the validity of their scientific findings. This line of thought has been worked out in the contributed paper [4] from which the findings and recommendations are listed the following, ordered by topic.

5.1 Selected Findings and Recommendations by topic

QuarkNet is a collaboration between Fermilab and the University of Notre Dame that brings particle physics research into the classroom and empowers teachers by developing their skills.

- *Finding:* QuarkNet is at the center of international pre-university particle physics international collaboration.

- *Recommendation:* QuarkNet and other U.S. outreach programs in particle physics should expand ties to international partners, particularly in the developing world.

- *Recommendation:* International education and outreach efforts such as International Masterclasses and various cosmic ray projects should expand and U.S. institutions should support and participate in them at increasing levels.

The *International Particle Physics Outreach Group (PPOG)* is a global collaboration, currently including 32 member countries, six experiments and CERN (Geneva Switzerland), while DESY and GSI (both in Germany) are associated members, known for the organisation of international Master Classes for secondary education. IPPOG also governs an extensive data base with particle physics resources for high school education. There are close links between QuarkNet and IPPOG.

- *Finding:* Associate membership in IPPOG by large national laboratories in the U.S. is a great benefit to particle physics education. In addition to Fermilab, other national laboratories should seek IPPOG associate membership.

- *Finding:* International Masterclasses are an excellent model of international physics collaboration for high school students and teachers. Increased promotion of and participation in IMC by particle physics experimental groups in the U.S. would benefit the particle physics community.

Cosmic Rays allow for low-cost direct detection of sub-atomic particles and therefore provide are excellent demonstration experiments for high school students and others. The *Global Cosmics portal* provides access to (the construction of) cosmic ray detectors and data. QuarkNet has similar activities and is in close contact with the Global Cosmics portal.

- *Finding:* Development and distribution of affordable, maintainable cosmic ray devices for classroom use internationally and in the U.S. have increased collaboration in cosmic ray studies. This should be expanded.

CERN organises the *Beamline for Schools (BL4S)* competition in which high school teams propose experiments to be executed in particle beams at CERN and other accelerator laboratories.

- *Finding:* The U.S. particle physics community can encourage participation in Beamline for Schools by arranging for a number of U.S. teams that do not win to carry out their experiments in U.S. facilities. They can expand these benefits to more students by creating an international research competition to complement Beamline for Schools at one or more U.S. laboratories; this will also highlight U.S. research to students and the public.

- *Recommendation:* Continue to support efforts by U.S. teams in Beamline for Schools and provide analogous opportunities within the U.S.

Two types of international schools can be distinguished: *International Graduate Schools*, where advanced topics are taught for students working on their PhD thesis and *International Secondary schools*, to educate particle physic at high school level. Specific version of these schools play an important role in making advanced particle physics knowledge available to pupils and students from less privileged countries. QuarkNet has particularly good relations to International Secondary schools.

- *Finding:* The masterclass introductory sessions pioneered in international meetings and schools build interest in not only masterclasses but particle physics education and outreach when carried to graduate student and young physicist settings in the U.S. and abroad.

- *Finding:* The QuarkNet relationship with the African School of Fundamental Physics and Applications should become a permanent feature; QuarkNet should also seek collaboration with other relevant initiatives from developing nations or regions.

Several opportunities exist for U.S. students to participate in global Summer Schools and exchange programs. The NSF Research Experience for Undergraduates (REU) program funds participation of U.S. students in the CERN Summer Student program. Also some universities provide opportunities to take part in the CERN Summer student program, e.g. through a semester-long program sponsored by the University of Michigan. The DoE-INFN summer student exchange program is a two-way exchange of students between the U.S. and Italy. INFN and the University of Pisa run a two-moth summer training programme for Italian students at Fermilab. In 2019 this program was extended to also include a two-month training program at BNL.

- *Finding:* The particle physics community should make every effort to seek out participation in the CERN, Fermilab, and other international summer and semester programs by U.S. applicants from underserved communities, including minorities and those of lower income families. Additional support could come from dedicated NSF, APS and State Department. Programs. Expansion of these programs would benefit all students and the wider community.

- *Recommendation:* U.S. institutions should expand and more fully support international student research and learning opportunities for both students coming to the U.S. and U.S. students going abroad.

International exchange of students and teachers raise the mutual understanding between nations and cultures. They also allow for emancipation of economically less favoured parts of the world.

- *Finding:* Education and outreach programs of mutual benefit help form strong collaborations by theoretical particle physicists or institutions in the U.S. with developing nations and should be encouraged.

In conclusion, the following observation was made on a complementary particle physics school dedicated to it high school teachers:

- *Finding:* An international particle physics summer school for teachers in the U.S. with a strong but accessible content orientation, along with emphasis on physics education reform, would be a unique contribution to education while complementing other international efforts.

with as a final recommendation:

- *Recommendation:* Establish, with international partners, an International Particle Physics Summer School for Teachers.

6 Interconnections and Synergy with Frontiers and Topical Groups

New text here based upon Workshop Discussions

6.1 Selected Findings

6.2 Associated Recommendations

7 Conclusions

To support a compelling program of scientific discovery, a robust Physics Education program is an essential companion. Such a program should provide students across the demographic spectrum ample basis of opportunity to enter particle physics and ancillary fields to engage in and benefit from the science. The ten-year program and twenty-year vision of Snowmass 2021 affords a strategic time window within which both the science and the education process can evolve holistically and constructively and requires Community Engagement at all educational levels. This is an opportunity that should not be missed.

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