Virtual Snowmass Town Hall Meeting: Open Mic Session

5:30 pm – 7:00 pm EDT

Community Voices: Questions, Suggestions, Comments, Statements, …

1. **Daniel Hayden** (danhayden0@gmail.com)

"For the last snowmass process a critical part of its success was to have access to large (10's of millions of events per sample) centralised Monte Carlo samples, prepared under different future collider scenarios such as 14, 27, 100 TeV collider, with 50, 100, 200 collisions per bunch crossing, etc. We also had an ATLAS-like, CMS-like, and future-ideal detector simulation, with recommendations and guidance for people on how to create and document your own signal samples for studies, beyond the mainly SM processes that were provided centrally (Neutral-Current and Charge-Current Drell-Yan, ttbar, dijet, etc).

My question is: How will this be handled for the current Snowmass effort?"

Best Regards,
Dan

Response from Energy Frontier conveners:

The Energy Frontier conveners recognize the importance of helping the community carry out studies which are impactful and define the future vision of the EF HEP community. One of us (Narain) was extremely involved in the MC production for Snowmass 2013 effort and hence providing MC samples (to some reasonable extent) for Snowmass 2021 studies is an integral part of the planning process for the EF. Since Snowmass 2013, the landscape for Monte Carlo simulations for future colliders has changed, and many efforts have generated samples and have a good software foundation which the community could possibly use.

Hence, the EF conveners are in the process of organizing a "MC task force" to assess the needs for MC samples for studies by each Energy Frontier topical group. The "task force" is tasked to survey existing frameworks for MC generation and analysis for future colliders. In the event the EF group has to mount a production of a large set of samples for Standard Model backgrounds and other samples, they will develop a plan for 1) a common framework, 2) the samples needed to be produced as a central production, 3) the scale of CPU resources needed for sample generation, 4) the projected size of storage required for production and long term storage of the samples. The OSG has kindly agreed to support the MC generation for EF, and will provide both computing resources and storage on the OSG Data Federation.

After this plan is developed, it will be discussed during the July EF workshop. An MC production team will be established around the end of June to set up the technical infrastructure in collaboration with the OSG to produce the samples. At that time (~July), we will send out a call for volunteers to help this team, and would welcome effort from the community in joining the "EF production team". We encourage the members of the community to provide their input on the samples needed, motivated by their interests, to the respective EF topical group conveners. Please keep in mind that this is a community-based volunteer effort, with limited resources, and hence some choices may need to be made! We will try to do our best.

2. Josh Barrow (jbarrow3@vols.utk.edu)

ESS NNBAR Collaboration Snowmass Townhall Statement

J. L. Barrow, for the NNBAR Collaboration

April 10th, 2020

The baryon asymmetry of the universe remains unexplained, requiring a beyond Standard Model (BSM) generation mechanism likely stemming from B − L violation. An attractive feature of (post-sphaleron) baryogenesis theories is the presence of B − L violating processes at experimentally observable energies, such as ΔB = 2 neutron-antineutron transformations ($n \rightarrow \bar{n}$). Large volume underground experiments such as DUNE and Hyper-Kamiokande promise excellent BSM sensitivities via parasitic searches over long observation times, but their capabilities are limited for identification of intranuclear ΔB = 2 signals due to nuclear effects and atmospheric neutrino backgrounds. Free neutron beams offer unique, backgroundless, complementary ΔB = 2 search potential. The forthcoming European Spallation Source (ESS) and its ANNI/HIBEAM and Large Beamport beamlines will provide exquisite neutron brightness and flux capabilities. With modern neutron optics and particle detector technologies, the ESS offers the opportunity for a 1000-fold improvement in $n \rightarrow \bar{n}$ sensitivity. Over the next decade, we advocate for R&D funding to pursue searches for this and related B − L violating processes as part of a staged experimental program using neutrons at Oak Ridge National Laboratory and the ESS. We invite the broader US high energy community to participate and provide leadership as part of the NNBAR Collaboration, an international group including scientists from the high-energy, neutron science, fundamental symmetries, and nuclear physics communities. This proposed program of experimental and theoretical work is critical for understanding the baryon asymmetry, a question of paramount importance to experimental particle physics and cosmology.

Response from Rare Processes & Precision Measurements Frontier conveners:

Thank you for your comment! Neutron-antineutron oscillations is a topic we address in our frontier, in particular in the "Baryon and lepton number violating processes" topical group (please see our wiki page https://snowmass21.org/rare/). We invite you to submit a white paper describing the NNbar experiment and work with us on our Frontier's activities.

3. **Sven Vahsen** (sevahsen@hawaii.edu)

Belle II: The critical role of Flavor Physics and CPV in the quark sector

Flavor physics and CP violation in the quark sector has an unparalleled physics to cost ratio and provides an exciting road to New Physics complementary to the high-luminosity LHC.

The predecessor B-factory experiments, Belle at KEKB and BaBar at PEP-II, discovered large CP-violation in the quark sector leading to the 2008 Physics Nobel Prize for Kobayashi and Maskawa. We expect similar impact from Belle II and its explorations of lepton universality violation, new CPV phases, precision electroweak measurements, and the dark sector.

Belle II/SuperKEKB aim to produce 55 billion B-meson pairs, 46 billion tau pairs, and 65 billion charm-quark pairs, with branching fraction sensitivity down to $O(10^{-9})$. The resulting broad physics program is described in *The Belle II Physics Book*, Prog. Theor. Exp. Phys. (2019), 654 pages.

The Belle II experiment has been proceeding well since 2019. SuperKEKB has verified the nano-beam scheme and already reached an instantaneous luminosity of 1.5×10^{34} /cm^2/s – beyond PEP-II and approaching that of KEKB.

The US has been leading Belle II detector upgrades, physics, computing, and accelerator background commissioning. Given the broad and ambitious program, it may be surprising that the entire US Belle II DOE construction project cost only $15M. Belle II has about 120 US collaborators. It is important for the US community to leverage its Belle II investment over the next decade.

SuperKEKB is the world's highest-luminosity electron-positron collider, and literally the intensity frontier. Belle II/SuperKEKB and their upgrade programs should be treated as leading priorities in the Snowmass plan.

Response from Rare Processes & Precision Measurements Frontier conveners:

Thank you for these comments! We definitely agree that flavor physics represents an important tool in studying New Physics. This is why B/D/K-decays, flavor oscillations, and other relevant topics are included as topics in the Rare Processes & Precision Measurements Frontier (please see our wiki page https://snowmass21.org/rare/). We hope all the experiments in flavor physics work together in our Frontier and participate in Frontier activities. We invite all experiments in the field to submit white papers describing their future activities and any upgrade plans.

4. Zelimir Djurcic (zdjurcic@anl.gov)

I will say a few words about physics of the neutrino mass. Now more than ever in the past we have opportunities to learn more science from multiple research frontiers.

Explaining why particles have mass is a fundamental ingredient in how we understand physics. In particular the properties of neutrinos that may explain abundance of matter in the universe make the quest for the absolute value of the neutrino mass among of the most urgent questions of nuclear and particle physics.

Neutrino physics is currently separated into two different DOE offices, HEP and Physics. Within the HEP neutrino physics topics are further separated into Intensity Frontier and Cosmic Frontier. This separation appears to be one the pressing issues in the development of our field.

We would need a coherent effort to explore the synergies, including cosmology (sum of neutrino masses), NLDBD (Majorana mass search) and beta decay (effective neutrino mass) searches, long-baseline oscillation measurements (delta_m's), and to look for alternatives to discover Majorana neutrinos.

These opportunities should be summarized. Our Snowmass input to the community should outline the benefits of the cross-cut efforts. As a follow-up the DOE and other agencies could react on these science opportunities with targeted funding announcements. A support would go to labs and university groups to combine measurements and neutrino mass constraints from different research areas. The Snowmass infrastructure could seed a national and international leadership for correlating different efforts to make rapid progress on neutrino physics. We need to agree on where to look next.

Reply from Neutrino Frontier conveners:

Thanks for this excellent comment. Neutrino mass, NLDBD and related topics are in the purview of the “Neutrino Properties” working group, and conveners have been selected with different funding-agency backgrounds in mind. Furthermore, we are in the process of selecting a liaison with the Cosmic Frontier with expertise on connections of neutrino properties to cosmological data.

We completely agree that these topics in particular often suffer from “stovepiping” between DOE offices and even between frontiers within HEP (and they are not the only such topics-- for example, topics related to cross sections sometimes fall between the cracks, too.) As a community, rather than as a funding-agency-driven, effort, the Snowmass process presents an opportunity to encourage the agencies to find ways to join forces to optimize science efforts. We fully intend to address this with the Neutrino Frontier activities.

5. Anders Ryd (anders.ryd@cornell.edu)

Comment on HL-LHC

The United States has made a fruitful, sustained investment in the energy frontier via its program at the Large Hadron Collider. Our scientists have made leading contributions in the discovery of the Higgs boson, extended the restrictions on possibilities for dark matter, greatly expanded our constraints on possible extensions to the standard model, and have performed a wide variety of searches for rare decays and precision measurements of the strong and weak forces. We have begun to characterize the Higgs boson, with the first measurement of all major decay modes. The idea of jet substructure and its combination with machine learning have opened new search channels, previously though infeasible, at hadron colliders. The upgrade of the LHC machine and detectors for high luminosity, a major recommendation of Snowmass 2013 and the 2014 P5 report, is underway. Results from HL-LHC, probing the coupling of the Higgs to an unprecedented level that start to reach loop-level for some couplings, may change the landscape of precision physics and also to some extent for the discovery of rare low cross section processes. Many studies of the extraordinary physics reach allowed by this run have been performed. However, since extending our knowledge of the physics potential of this run is essential to our understanding of its impact on our physics knowledge and to our planning process, we encourage the LHC community to find time to make a strong involvement in the snowmass 2021 process.

Sarah Eno (Maryland)
Dan Marlow (Princeton)
Gordon Watts (University of Washington)
Hal Evans (Indiana University)
Steve Nahn (FNAL)
Anders Ryd (Cornell)
Lothar Bauerdick (FNAL)
Harvey Newman (CalTech)

Response from Energy Frontier conveners:

We thank you for your excellent comment in highlighting the strong impact and continued importance of HL-LHC results in forming the vision of the future colliders for EF. The HL-LHC studies provide a baseline for expected performance of future colliders. As the studies on the potential of HL-LHC program develop in the near future and during Run 3, they will inform the final Snowmass report. We welcome strong participation from the LHC community to participate in developing a global picture and the future roadmap for Energy Frontier within US HEP. This large community has the necessary expertise and the knowledge base, and is the training bed for the next-generation of stellar collider physicists. The contributions and engagement of this community, especially the young scientists, is essential for the success of the Snowmass process.

6. **Sarah Eno** (eno@umd.edu)

Comment on future machines (FCC-xx, ILC, etc)

Energy frontier colliders provide a versatile facility for probing forces and fields, providing access to new massive particles and high intensity sources of the known particles. The United States has always been a leader in energy frontier physics. We have recently played leading roles in the transformative physics enabled by high energy (e.g. in the discovery of the top quark at the FNAL Tevatron and the Higgs boson at the LHC). The HEP community, especially outside the US, is progressing on investigating and documenting the physics case and technological requirements for a new era in the energy frontier, examining possible future hadron and electron-positron colliders. So far, while there has been strong engagement from the US theory community, contributions by US experimentalists on detailed studies of the reach using realistic background estimation techniques, and contributions towards the possible designs of detectors that can satisfy the demanding requirements of the physics programs at these machines, has been limited due to the lack of funding, restrictions on allowed research and work, and frankly effort conflict with the wealth of physics studies available with the LHC data. We encourage those interested in the energy frontier, especially our younger members, to have strong participation in Snowmass 2021. Without strong participation we will be unable to make the case for the importance of this program in the future of US particle physics.

Gordon Watts (University of Washington)
Sarah Eno (Maryland)
Steve Nahn (FNAL)
Anders Ryd (Cornell)
Michael Peskin (SLAC)
Harvey Newman (CalTech)

Response from Energy Frontier conveners:

The EF conveners fully share your view and wholeheartedly endorse the call for participation in the Snowmass 2021 community exercise. They recognize and emphasize the need for a broad and strong community participation in exploring existing and new ideas for future HEP facilities and will aim at promoting their study in the context of the EF physics program. They are committed to promote and continuously monitor participation of the US HEP community to the work of the EF during Snowmass 2021 and will strongly encourage the participation of younger members of the community throughout the process. They also encourage the funding agencies to accelerate facilitation and promote the involvement of the community in the EF and Snowmass process at large.

7. Jure Zupan (zupanje@UCMAIL.UC.EDU)

Given the null results of new physics searches at the LHC, the flavor physics program has become crucial for the advancement of the field. This includes both the experimental program as well as theory. We have a wide range of observables in kaon physics, charm physics, B physics, both CP-violating and CP-conserving, as well as other CP-violating observables such as electron and neutron dipole moments, and observables in the lepton sector such as rare muon decays, mu to e conversion and rare tau decays, as well as flavor violating Higgs decays. All these transitions probe effective scales that, assuming O(1) couplings, are much higher than the direct reach at colliders. If, instead, a minimal flavor-violating pattern of couplings is assumed, the reaches of flavor probes and direct searches are comparable. It is thus clear that the flavor physics and the direct searches programs are complementary.

In order to interpret the experimental data, the theoretical input is indispensable. On the one hand, these are the perturbative calculations, very important for instance in the precise predictions of epsilon_K, and the interpretations of recent hints of anomalies in b-> s l+ l- and b-> c tau nu decays, including model building. On the other hand, these are the non-perturbative methods such as lattice QCD. Finally, I would like to stress the importance for creative model building that can lead to novel experimental signatures. The support for these theory efforts is crucial in order to take full advantage of the experimental program.

Response from Frontier conveners:

Rare/precision: Thank you for your comments! Theory computations are very important, if not essential, for interpreting flavor experiments. We invite you to contribute to our Frontier and participate in our Frontier's activities. As you point out, theory calculations touch all of our frontiers and in addition to working with each topical group, perhaps a separate theory White Paper contribution would be an appropriate input to our Frontier's activities.

Theory: Thank you for highlighting the key role of the flavor physics program in probing physics within and beyond the Standard Model. Theory plays an invaluable role in interpreting data from current and future flavor experiments, and we look forward to articulating the vibrancy of the flavor theory program during the Snowmass process. We anticipate the flavor theory program to be highlighted in a number of topics across the Theory Frontier, most notably TF02 (EFT techniques), TF05 (lattice gauge theory), TF06 (theory techniques for precision physics), TF07 (collider phenomenology), and TF08 (BSM model-building). In addition, we have selected a co-convener in TF06 (theory techniques for precision physics) specializing in flavor theory, and will liaise directly with Rare Events & Precision Frontier convener Alexey Petrov to ensure coordination of flavor-related efforts in both theory and experiment across the Snowmass frontiers. We hope that you will consider providing further input into the process in the form of a white paper and by attending our meetings, as we will need the entire theory community to come together around this process and experts like you in particular helping us.

8. Sergei Chekanov (chekanov@anl.gov)

The electron-ion collider (EIC), the only colliding experiment in the USA, will be built in the context of nuclear physics (NP). This experiment can study topics which are traditional to the energy frontier (proton PDF, particle production, heavy flavor, fragmentation functions, etc.). In the past, the DOE office of HEP participated in HERA (very similar to EIC) by building HERA detectors and by contributing to HERA physics. Currently, energy-frontier scientists are involved in the LHC detector operation during heavy-ion runs for nuclear science. They have much experience in running collider experiments and designing detectors for such experiments. So, historically, HEP and Nuclear Science offices know how to cooperate and share common accelerator resources. Do you think it is useful if Snowmass21 will explore traditional HEP topics, and some new physics opportunities at the EIC collider, which can be beneficial to HEP and nuclear science, in a hope that this may lay a common ground for close cooperation between HEP and NP DOE offices?

Response from Energy Frontier conveners:

The Energy Frontier group is planning to study the impact of physics from all future colliders, including the EIC, can have on HEP and specifically in the EF. The study of physics opportunities related to EF, which are expected to emerge from the EIC and other future NP experiments, are an integral part of the EF topical group structure. In particular, EF07 is dedicated to the heavy ion physics and its impact on the EF, for example jet production in vacuum, heavy flavor meson production in heavy ion collisions, PDF in nucleons and nuclei as well as new particle searches in heavy ion collisions. Topical group EF06 ("Hadronic structure and forward QCD") will include studies that overlap with heavy ion physics, for example PDFs in nucleons, nuclei, pions, kaons, photons, the transition to the non-perturbative QCD regime at low Q, BFKL, saturation, color glass condensate etc. Members of the community are invited to join these EF topical groups to contribute and highlight the impact of EIC on HEP, and Energy Frontier.

9. **Carlos A. Argüelles** (caad@mit.edu)

Fundamental physics with high-energy cosmic neutrinos

A plethora of new and upcoming laboratory experiments search for the physics beyond the Standard Model in an effort to understand flavor mixing and the generation of neutrino mass. Answers to these questions typically require the introduction of a new high-energy scale, new particles, or both. Thus, neutrinos provide a principal portal to search for new physics signatures.

While ideal messengers from the extreme universe, cosmic neutrinos also provide a beam for particle physics. They provide a unique opportunity to test fundamental symmetries and to search for physics beyond the Standard Model: with a spectrum extending beyond 10,000 TeV, they provide the highest neutrino energies; they travel the longest baseline from production to detection; they only interact via the weak force allowing to probe very feeble phenomena; and they have a quantum number not shared by other cosmic messengers: flavor.

IceCube's discovery of a cosmic neutrino flux with a relatively high intensity has opened new opportunities probing the fundamental properties of the neutrino. With an energy resolution of 10%, current observations have already yielded some of the most stringent constraints on new physics in the neutrino sector. The precision of these measurements will improve as the current neutrino telescope facilities are being upgraded and, soon, enhanced by additional detectors. This will allow for better reconstruction of the observed events and improved statistics.

Like the observation of neutrinos from SN1987, high-energy cosmic neutrinos represent an unprecedented portal to physics beyond the Standard Model.

Best,
Carlos A. Argüelles, Francis Halzen, Ali Kheirandish, and Aaron C. Vincent

Response from Cosmic Frontier conveners:

We thank you for this important point, which we agree with entirely. High energy cosmic neutrinos are a crucial portal to the Universe, and may provide key insights into Physics Beyond the Standard Model. Exploring their potential future impact is a key part of the mission of CF7: Cosmic Probes of Fundamental Physics.

10. Jonathan Paley (jpaley@fnal.gov)

Neutrino Scattering Theory Experiment Collaboration (NuSTEC) Statement on the relevance of neutrino interactions for the future of Neutrino Physics Research.

To reach the full potential of the neutrino-physics program, in which the US plays a vital role, a better understanding of neutrino interactions with matter is crucial. The precision goals of the oscillation program can only be achieved with a realistic modeling of neutrino-nucleus scattering dynamics, based on solid theory and comprehensive measurements.

NuSTEC is a collaboration of theorists and experimentalists focused on the circular dependency of the collection and analysis of data, model development and tuning, and incorporation of these models in neutrino event generators. NuSTEC fosters communication and collaboration between experiments and theory groups through working groups, workshops, schools and white papers (eg, seehttp://www.sciencedirect.com/science/article/pii/S0146641018300061.)

Progress in this field cannot wait until the next generation of neutrino measurements becomes limited by systematic uncertainties. The process of collecting and analyzing new measurements, developing and tuning models based on those data, and incorporating these models in generators can take many years. In addition, neutrino-nucleus scattering measurements expected in coming years will cover only a fraction of the phase space and nuclear targets needed to make real progress. Therefore NuSTEC will continue to pursue and advocate for increased support for neutrino-related HEP, nuclear theory and lattice QCD efforts, neutrino event generator development, new precision neutrino-H2/D2/He4 scattering measurements, complementary electron scattering experiments and other topics that can lead to improvement in neutrino-nucleus scattering physics. Considerable impact is expected for the precise determination of neutrino properties but also in supernova, beyond the Standard Model, hadronic and nuclear physics.

Thank you,

Jonathan Paley
NuSTEC Co-spokesperson
Fermilab

Response from Neutrino Frontier conveners:

Thanks for this comment. We look forward to contributions on this topic. This is mostly within the purview of the "Cross Sections" topical group, but there are overlaps with other topical groups as well. We note also the importance of cross-Frontier and cross-funding-agency efforts on this topic.

11. Jonathan Paley (jpaley@fnal.gov)

Statement on the important of support for small-scale projects and test beam facilities

Small-scale HEP experiments play a critical role in providing important data that are of significant benefit to the large-scale experiments, an excellent training ground for early-career scientists, and enable early-adaptation or proof-of-concept of new technologies. This was recognized in the 2014 P5 Report, which recommended that we "maintain a program of all scales", and that the "research program should provide the flexibility to support new ideas and developments."

As a prime example, the EMPHATIC Collaboration proposes a novel table-top-sized fixed-target spectrometer capable of high-rate data collection to measure hadron production cross sections that are particularly relevant to neutrino flux predictions [https://arxiv.org/abs/1912.08841]. The spectrometer would be placed in the Fermilab Test Beam Facility, enabling measurements of hadron scattering and production cross sections at beam energies that have yet to be measured well. The new measurements proposed by EMPHATIC can reduce the current neutrino flux uncertainties by a factor of two and be of benefit to the HEP and Nuclear communities as well.

Experiments such as EMPHATIC rely heavily on the infrastructure provided by test beam facilities. There are now very few such facilities in the US, and those that do exist are not very well funded. As we pursue new large-scale experiments aimed at precision measurements or searches for rare processes, we must increase funding for the kinds of measurements that test beam facilities enable and that EMPHATIC is pursuing. Investments in these facilities as well in small-scale experiments is an investment in the long-term success of our field.

Thank you,

Jonathan Paley
EMPHATIC Co-spokesperson

Response from Neutrino Frontier conveners:

Thanks for this comment. We look forward to contributions on this topic also. This is mostly within the purview of the "Artificial Neutrino Sources" topical group (which includes neutrino production in beams), but there are overlaps with other topical groups as well.

We agree also on the importance of support for smaller-scale efforts, including test beams, and expect to address this in discussions.

12. Gordon Watts (gwatts@uw.edu)

The Computing Frontier, Snowmass, and the Future of Particle Physics

Particle physics and computing have been intertwined for decades. With the dramatically increased computing needs of the HL-LHC, new nuclear experiments with computing requirements like particle physics, and large astronomy observatories with data storage and processing requirements that rival a modern collider experiment, this is not likely to change. Each new advance in computing enables new types of physics. Column-wise ntuples revolutionized data processing in the FORTRAN/PAW days. C++ and toolkits like ROOT allowed us to create massive applications capable of simulating and reconstructing data in detectors with many millions of readout channels and 10s of millions of different material volumes. The GRID was central to the discovery of the Higgs and every result currently produced by the EF and has spread to science outside of physics via the Open Science Grid and other similar efforts. The field is just getting acquainted with new techniques, like array programming, machine learning, and differentiable programming as well as new hardware like GPU's and FPGA coprocessors. How can we make sure that the Snowmass process does its best to identify potentially new physics that can be attacked with new tools, that the various groups understand the new tool opportunities, and that the CF knows the challenges and where R&D is most required to maximize the field's physics impact?
Gordon Watts (U. Washington)

Response from Computing Frontier conveners:

The keys to ensuring that the Snowmass process is able to identify potentially new physics that can be attacked with new tools, that various groups understand the new tool opportunities, and that the Computing Frontier knows the challenges and where R&D is most required to maximize the field's physics impact are three fold. The first key is to identify and recruit knowledgeable, curious, enthusiastic, and intelligent frontier and topical group leaders and members. We will leave it to the community to decide if the steering committee has accomplished that for the frontier leaders. We believe that we have found an excellent set of topical group leaders for the Computing Frontier, and we are currently starting to recruit members to our topical groups. We encourage people to volunteer for a group for which they have expertise and interest. The second key is to organize our groups in a way that maximizes cross frontier interactions. In 2013, we had topical groups organized around frontier needs. Now we have a different organization arranged by functional aspects of computing. This will require that all the stakeholders are represented in each topical group. The third key is to maintain communication with the other Frontiers. To this end, we have begun appointing liaisons between the Computing Frontier and almost all of the other Frontiers. We plan to fully integrate the liaisons into our meetings with the topical group conveners. We also will soon be working on joint meetings and workshops with the other Frontiers to activate the entire community regarding computing topics.

Thank you for your comment, and we hope this addresses your concerns.
Ben Nachman, Oli Gutsche, and Steve Gottlieb (Computing Frontier co-conveners)

13. Sergey Pereverzev (pereverzev1@llnl.gov)

Effects of energy accumulation on the performance of low energy threshold detectors.

From time to time, dark matter particles, neutrinos and similar particles induce discrete and very small (meV to keV) energy depositions deep inside our most sensitive superconducting, solid state and noble liquid detectors. Alongside these occasional and interesting punctuations, a slow trickle of unwanted ionizing radiation, whether cosmogenic or residual in materials, causes a gradual accumulation of energy, in form of trapped positive and negative charges and other long-living excitations (excitons, localized states and others). These excitations can be de-excited through numerous mechanisms: an every-day example is the thermoluminescence underlying personal dosimeters. More generally, from a condensed matter perspective, our favorite dark matter target media, (such as noble liquids, germanium, sodium iodide) and quantum devices (SQUIDs, qubits and others) can be described as non-equilibrium systems, in which energy slowly accumulates and suddenly (but still rarely) discharges. In such systems, energy releases often take form of avalanches – a dynamic called self-organized criticality (SOC). The phenomenon can generate a spectrum of events, depending on the detector type, which is nearly indistinguishable from expected dark matter, neutrino and similar rare low-energy interactions, or power noise spectrum close to 1/f, frequent in superconducting devises. Our work aims to characterize and even suppress these SOC mechanisms in diverse media. Improved understanding and suppression of this oft-neglected source of noise will help dark matter detectors, superconducting devices and other low threshold instruments reach their fundamental physical limits of sensitivity, possibly down to the single information carrier level (photon, electron or phonon).

Response from Instrumentation conveners:

Thank you very much for these remarks. This is indeed very important work that should be addressed in several of the topical working groups within the Instrumentation Frontier, namely Calorimetry, Quantum Detectors, Photo Detectors, Noble Elements and possibly also Electronics. For further information on these groups please visit https://snowmass21.org/instrumentation/start . Feel free to contact the relevant conveners of the topical subgroups to learn how to get involved. We are looking forward to working with you in the future.

Jinlong Zhang, Phil Barbeau, Petra Merkel (Instrumentation Frontier conveners)

14. Harry Nelson (hnn@charm.physics.ucsb.edu)

I've searched for dark matter direct interactions since 1981, although I did some accelerator experiments interspersed with those searches.

For "high-mass" (greater than fraction of the Higgs mass) WIMPs, many techniques have achieved much. Liquid detectors, particularly of nobles, and have succeeded beyond what we imagined when I helped organize the 2001 Snowmass WIMP sessions.

The science of high-mass WIMPs is as compelling as ever... the "WIMP miracle" was always a clue, not a proof; it is independent from, but has a possible connection to, SUSY; and it might prove to be in the progression of stunners from the weak interaction: particle-antiparticle mixing, parity and CP violation, neutrino mass, and the Higgs.

The 2014 Strategic Plan ("Building for Discovery") had a Recommendation #20 to support a G3 direct dark matter experiment, which hasn't yet been executed. I suggest that the current Snowmass process support and flesh out the execution of Recommendation #20.

Among the challenges for G3 that I hope the new Snowmass process for G3 will address:

1. Development and coordination of the relationships of HEP with Nuclear Physics, which is also exploring a noble liquid program, and between the Cosmic Frontier and the Intensity Frontier. An experimental hall from the DUNE excavation might be useable for G3.
2. Organization G3 program portions that fall best in the national lab system, and of those that fall best in the university program.
3. Development of a process and/or organization to foster and manage international coordination.

Harry Nelson / UCSB

Response from Cosmic Frontier conveners:

Thank you for making these points, which we agree with. The work you propose falls squarely in the mandate of CF1: Dark Matter: Particle-like, and we hope that you and others in this area will help make a strong and effective argument there.

15. Leah Broussard (broussardlj@ornl.gov)

Understanding the particle nature of dark matter demands that we explore new ideas and use our scientific infrastructure to its fullest potential. Mirror matter, a hidden sector dark matter candidate, can be sought experimentally through searches for neutron oscillations to a mirror state. Ultracold neutron experiments have placed strong limits on neutron-to-mirror neutron oscillations (n-n') under the assumption of zero energy splitting between the neutron and mirror neutron states, though anomalous findings remain when this assumption is relaxed. The comparatively higher flux of cold neutron beams enables possibilities to search for disappearance and regeneration; the latter is a more robust experimental test, but requires low ambient backgrounds and long and large area beamlines. With these requirements in mind, we have initiated a new program of searches for neutron oscillations using Oak Ridge National Laboratory's cold neutron scattering facilities: the Spallation Neutron Source and High Flux Isotope Reactor. With modest investments, existing instruments can be used for sensitive searches for these apparent $\mathcal{B}-\mathcal{L}$ violating modes, which in turn could illuminate the mystery of dark matter and resolve or clarify other long-standing experimental problems, one being the neutron lifetime anomaly. This program also includes the possibility of a search for a recently proposed mechanism of driven, regenerative neutron oscillations into antineutrons through the mirror sector; this mechanism opens the door for near-term R&D work for a future high sensitivity search (NNBAR at ESS) for neutron-antineutron oscillations (n-nbar), a $\mathcal{B}-\mathcal{L}$ violating process that would provide compelling implications for the baryon asymmetry of the universe.

Response from Rare Processes & Precision Measurements Frontier conveners:

Thank you for this second opportunity to comment on nnbar oscillation experiments and pointing out the wide range of important physics questions these experiments address. Please also see our reply to Comment 2.

16. Cameron Geddes (cgrgeddes@lbl.gov)

Advanced Accelerator Concepts could revolutionize the cost and capability of future accelerators for frontier High Energy Physics. The capacity for orders of magnitude higher acceleration gradient than conventional systems could enable new types of high energy colliders including energies at and beyond TeV, as well as intermediate applications. Concepts include plasmas driven by lasers and particle beams, and advanced structures (metallic, dielectric, and others).

There is need for focus on the concepts that are being developed, the new physics capabilities that could be enabled, the major challenges that need to be addressed to enable physics machines using these new concepts, and the development time and cost scales. This should include consideration of intermediate applications which will develop these technologies on the path to a potential future collider. Ultimately, future colliders for High Energy Physics are the most demanding applications and require development of particle acceleration, generation, and focusing methods.

We encourage members of the advanced accelerator community to engage strongly in the Snowmass process. We also encourage strong engagement of the broad Snowmass community on the challenges and capability gaps that new particle acceleration methods could address. How and with what groups can we engage in the Snowmass process to understand the needs for future HEP experiments and to develop and communicate the possibilities that could be enabled by advanced accelerator concepts?

17. John Carlstrom (jc@astro.uchicago.edu)

Cosmic Microwave Background Stage IV experiment, CMB-S4

CMB-S4 will probe the origin of the Universe and provide insights into the quantum gravity, while exploring physics at 10^16 GeV. CMB-S4 was conceived at Snowmass 2013 as a CMB experiment to cross critical science thresholds. These include the detection of the B-mode polarization signal of primordial gravitational waves as predicted from single field, slow roll inflationary models, light relics particles frozen out before the QCD transition, the mass scale of the neutrinos, and much more. The potential for fundamental discoveries offered by CMB-S4 is enormous.

CMB-S4 exploits the technology developed over the last two decades and the two premier sites in the world, the South Pole and high Chilean Atacama Plateau. CMB-S4 requires an increase of scale over prior experiments by roughly two orders of magnitude. Since P5, the collaboration has been established and the project achieved DOE CD-0 in 2019. DOE CD-1 and NSF PDR are scheduled for Spring 2021, after the Astro2020 Decadal Survey report. In a nutshell, CMB-S4 requires 500,000 superconducting detectors and will use two high throughput 6-m telescopes in Chile for conducting a deep wide-area survey of roughly 70% of the sky necessary to achieve the light relics constraint, and a single 6-m telescope and 18 small aperture 0.5-m telescopes deployed initially at the South Pole for conducting an ultra-deep survey of a small fraction of the sky (~3%) to achieve the primordial gravitational wave constraint. The construction project is expected to be complete in 2028, followed by seven years of operations.

18. Bob Zwaska (zwaska@fnal.gov)

Multi-Megawatt target stations will be a prime component to future HEP experiments and only be enabled by development of targetry technology. Multiple particle accelerators will be able to produce high-power, high-energy beams of protons and other particles that will be able to support multiple experiments at once; this beam power must be put to use. The number of high-power target facility in the world is quite small and the expertise has been developed at a small number of labs and universities. This discipline risks falling in the gap between particle and accelerator physics.

The push for a multi-megawatt beam to DUNE is well known. There is also a demand for high-power short baseline neutrino beams for oscillations and cross sections, as well as to explore sterile neutrinos and coherent neutrino scattering. Similar beams can be used in searches for dark matter, axions, and other hypothetical particles. Charged lepton flavor violation ask for high-power beams of an entirely different flavor. Proposals for kaons, etas, and other particles are also being proposed. Each of these target stations will have unique challenges, using unique materials and employ unique particle production/focusing technology.

A nascent international collaboration network exists to study the issues related to high-power targetry, mostly for the current generation of neutrino superbeams. Only with sustained support and the introduction of new talent will the future experimental program be realized. We will study these issues at Snowmass and invite collaboration.

19. Yu-Dai Tsai (ytsai@fnal.gov)

As we wait for the LHC upgrade to further explore the energy frontier, it is beneficial to look back at the existing facilities in the US (and the rest of the world) to see if cost-efficient experimental setups can facilitate the searches of new physics beyond the standard model.

The proton fixed-target experiments have long been powerful probes of dark-sector particles (including neutrinos!), given their ability to probe new physics produced in intermediate energy (with 100 to 400 GeV beams) and high-intensity environment.

With the existing beams already constructed to study neutrino and other standard model physics, low-cost repurpose and add-on detectors provide excellent opportunities in exploring exotic long-lived (e.g., mediators) and stable particles (e.g., dark matter and millicharged particles).

The on-going efforts of such studies include DarkQuest, which is a proposed repurpose of the SeaQuest experiment to study long-lived particles, and LongQuest, a long-term plan to add multiple detectors to the SeaQuest facility and construct a multi-purpose dark-sector machine. For the study of stable exotic particles, FerMINI is an example of such efforts that plan to search for millicharged particles in a fixed-target setup, that is directly inspired by the milliQan experiment proposed at LHC.

I would like to briefly highlight these ongoing efforts that are happening at Fermilab in this town hall meeting.

Comments and Questions from Frontier / Topical Group Conveners

1. Tor Raubenheimer (tor@slac.stanford.edu)

Accelerator Frontier

I would like to discuss and request feedback on the focus of the Accelerator Frontier working group. Snowmass is a process to help the HEP community think about future opportunities. To this end, we have created 7 topical groups as discussed by Steve Gourlay and listed on the website which will need to establish clear communication with the other accelerator-based HEP groups. In addition, we have asked each of these groups to address five questions:

1. What is needed to advance the physics?
2. What is currently available (state of the art) around the world?
3. What new accelerator facilities could be available on the next decade (or next next decade)?
4. What R&D would enable these future opportunities?
5. What are the time and cost scales of the R&D and associated test facilities as well as the time and cost scale of the facility?

What else would be helpful for the output of Snowmass?

2. Caterina Doglioni (caterina.doglioni@hep.lu.se)

Inter-frontier connections of Dark matter study

Caterina Doglioni (Lund University), Liantao Wang (University of Chicago),
Conveners of Energy Frontier Subgroup 10 *"Dark Matter at colliders" (EF10)*

- Many experimental probes and observations are necessary for a comprehensive search for dark matter, given our ignorance of what DM is:
  - Examples: High energy Collider, direct and indirect detection, intensity frontier for rare processes, neutrino detectors, fixed-target experiment, table top experiments, cosmic ray, CMB, 21 cm, gravitational wave detectors...
  - New theory and experimental ideas continue to emerge
- Synergies crucial for a successful program
  - Connections with **all** frontiers identified!
- How can we efficiently communicate and exchange ideas throughout the Snowmass process?

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