

Invigorated and unified, US particle-physics community considers future directions

Moving forward requires closer global collaboration from design to realization.

The Higgs boson changes everything. We're obligated to understand it using all tools," Michigan State University experimentalist Chip Brock said in his wrap-up talk at "Snowmass on the Mississippi." Nearly 700 high-energy physicists, mostly from the US, gathered at the University of Minnesota for nine days in late July and early August to take stock of their field.

Snowmass wasn't all about the Higgs, though. For example, the third mixing angle for neutrinos, θ_{13} , was recently measured to be larger than expected, which set the stage for further investigation. Another big question is why the universe has more matter than antimatter. And University of Chicago physicist Jonathan Rosner notes that "the elephant in the room is dark matter. There's five times more of it than us, and we don't know what it is. We have a lot of unanswered questions. It's not time to close the books and go home." Rosner coordinated Snowmass in his role as chair of the American Physical Society's division of particles and fields, the organizing body.

Reports from Snowmass will feed into the Particle Physics Project Prioritization Panel (P5), which is tasked with setting priorities given various budget scenarios. A subpanel of the High Energy Physics Advisory Panel, P5 is chaired by Steven Ritz of the University of California, Santa Cruz; its recommendations are supposed to be delivered to NSF and the Department of Energy by next summer.

"Seeing all the recent important results together was wonderful and energizing," says Ritz. "The surprise was the prevalent sense that the community needs to speak with one voice. People had a renewed appreciation that it's really one field."

Deep connections

In the US, the field of particle physics is organized into energy, intensity, and cosmic frontiers. Those categories were put forth by P5 in 2008 and recognized by both DOE and NSF. The focus of

high-energy physics was shifting from the Tevatron at Fermilab to the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland, and there was concern about the US continuing to be a leader in the field. The Long-Baseline Neutrino Experiment (LBNE), which will study neutrinos sent from Fermilab to a "far" detector 1300 km away in South Dakota, will put the US out front in the intensity frontier.

But the frontiers apply best to experimental approaches. It's "crystal clear," says LBNE spokesperson Milind Diwan of Brookhaven National Laboratory, that the next step is much more precise measurements—on the Higgs boson, neutrinos, and dark matter. "They are islands of discovery, but there are deep connections."

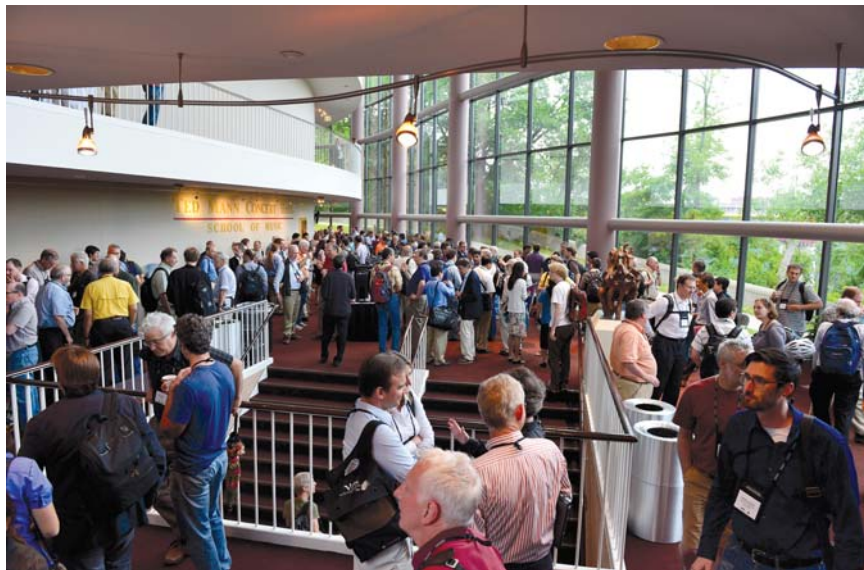
Great opportunities

Snowmass meetings have taken place at irregular intervals since 1982, with previous ones held for three weeks in the Colorado resort town of the same name. This time, pushed by cost caps—\$500 000 total for government employees for any single conference—set by the White House Office of Management

and Budget, organizers transformed the meeting into a process: nine months of preparation—including several dozen meetings—building up to an intense nine-day powwow. "The evolution was a creative response to financial pressure," says Daniel Cronin-Hennessy, a University of Minnesota physicist who helped organize this year's Snowmass. The extended schedule meant there was "time to ask questions and actually answer them." Holding Snowmass at a university campus in the summer meant cheap dormitory lodging and access to cafeterias; and national lab employees carpooled from Fermilab and Argonne.

At the last Snowmass meeting, in 2001, talk centered on finding the Higgs boson and on building the International Linear Collider (ILC). At the time, says Rosner, "some felt it was at the expense of other projects." This time, he says, "I sensed more diversity." Indeed, the very discovery of the Higgs opened the way to a broader focus. "We don't know what will happen next. An exploratory element is there, and people have different opinions about which way to go," says Kyle Cranmer, a New York University experimental physicist who took part in a public outreach event during Snowmass (see the story on page 20).

"We were in this situation in the 1950s with beta decay, and in the 1960s



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Hundreds of particle physicists attended Snowmass this summer to participate in long-term planning for their field.

we didn't have QCD [quantum chromodynamics] and we didn't have electroweak theory," says Rosner. "There were a huge number of experiments, and nobody could make sense of them. It was a period where we were wandering for a while. Not knowing where to go next is not necessarily a handicap. It's a great opportunity."

Promising areas

The purpose of Snowmass was to discuss the "really interesting options for the field, for the US in a global context," says Ritz. And although the community didn't prioritize projects at Snowmass, it did identify promising areas. Those included taking a significant role in the ILC if Japan bids to host it—the most promising path (see *PHYSICS TODAY*, March 2013, page 23); precision measurements of Higgs boson properties would be done there. The community also wants the US to continue its involvement in the LHC as it is upgraded to higher energy and luminosity to study Higgs bosons and search for new particles. Realizing the LBNE as a global project gained appreciation. And people are excited both about looking for dark matter at two orders of magnitude higher sensitivity—down to the limit

set by the neutrino background—and about shedding light on dark energy.

Those are the main areas. Some smaller projects also generated excitement. One at Fermilab, for example, would study rare kaon decays. Cosmic microwave background experiments would measure polarization; distinguish between inflation models; and, along with dark-energy surveys, infer the sum of the masses of the different neutrino types. Projects in the cosmic frontier, including a multitude of dark-matter searches and CMB experiments, "would need to grow, but they are still small enough not to need global collaborations," says SLAC theorist JoAnne Hewett, who was a Snowmass organizer for the intensity frontier.

Late last year the LBNE got DOE approval, but for only enough money to build a compromised form with a 10-kiloton far detector above ground, instead of a 34-kiloton detector below ground (see *PHYSICS TODAY*, February 2013, page 19). Says Rosner, "The community generally recognized it will produce much more physics if we are able to get a large far detector underground from the start."

"I would like Fermilab to have a flagship, and I think the community has

endorsed this idea. That was not clear before Snowmass," says Nigel Lockyer, who took the lab's helm on 3 September (see the Q&A with him at http://www.physicstoday.org/daily_edition/singularities). In its full-fledged form, which would require that other nations participate to the tune of \$400 million–\$500 million, the experiment might reveal whether *CP* violation occurs in the lepton sector. "Once we know this, the world is different. Symmetry between the lepton and quark sectors makes you believe there could be a grand unified theory," he says.

Looking further ahead, people at Snowmass talked about CLIC, the compact linear collider being developed at CERN; a 100-TeV hadron collider; TLEP, a high-luminosity circular electron-positron collider; a muon collider; and a neutrino factory.

A new global model

Global planning has taken a big step forward in the past year, Lockyer says. "The old model of global collaboration is the LHC: 'We are building, come and join us.' The new model is the ILC: 'Let's get together and design this.'" People are looking at the three major regions and seeing Europe with CERN as a

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center for the energy frontier, Japan as the host of the ILC, and the US as leading with the LBNE in the intensity frontier, says Howard Haber, a theorist at the University of California, Santa Cruz. Japan also has a strong program in the intensity frontier, including T2HK (Tokai to Hyper Kamiokande), a proposed neutrino experiment with a larger detector but shorter baseline than the LBNE. Says Haber, "The big wildcard is international collaboration. If physicists around the world are amenable to developing a common strategy based on international collaboration, then it should be possible to achieve the major objectives of all three frontiers."

Europe and Japan are largely on board for global collaborations; the roles of China and other possible major players are not yet clear. Not only has Japan shown an interest in hosting a global scientific facility and in internationalizing its science community, but it's clear that financially and in terms of know-how, the ILC would have to be a global effort. "The Japanese government may start contacting other countries later this year," says Hitoshi Murayama, who promotes the ILC from his position as director of the Kavli Institute for the Physics and Mathematics of the Universe in Tokyo. And CERN, which represents Europe on matters of particle physics, earlier this year announced that its medium- and long-term priorities are the upgrades to the LHC and a future accelerator project; the European strategy also explicitly embraces involvement in the ILC and long-baseline neutrino projects outside Europe.

For a long time, the US was the leader in particle physics, says Ian Shipsey of Purdue University. "Today, we are a big player along with other big players; we share leadership. We can't set the course alone. To stay at the cutting edge, we have to be able to participate in science wherever it is."

He lists three arguments for pursuing particle physics: "Particle physics helps draw people to all of science—and our standard of living is based on science and engineering. Particle physics drives accelerator science. And all great societies ask these great questions. It's not a luxury." The challenge, he says, is "to make sure that the government understands that it's good for the US economy and the community for the US to play a role in both onshore and offshore projects."

Toni Feder

Physics Slam on Ice

Kyle Cranmer glided into the ice arena on a sled powered by a fire extinguisher. Sarah Demers had a 900-strong audience singing about particle physics to the tune of "My Favorite Things" from *The Sound of Music*. At the Physics Slam on Ice, six physicists had 10 minutes each to expound on their research or something related to it. A takeoff on poetry slams, the outreach event took place on 2 August at the University of Minnesota during "Snowmass on the Mississippi," at which hundreds of particle physicists gathered to assess their field and its future directions (see the story on page 18).

"The goal was to engage the public about what we do," says Cranmer, a physicist at New York University. "From the outside world, the Large Hadron Collider looks like a big, impersonal machine. In my slam, I didn't try to explain my research but told my story of searching for the Higgs for 14 years—from graduating from college, going to CERN to work on the LHC, about when the LHC exploded, and when my daughter was born. It's not like you turn on a machine and wait. There are ups and downs. I told about the unclear parts of science—people miss out on that."

As part of an arts and sciences working group at Yale University, where she is on the faculty, Demers recently viewed a painting—possibly by Diego Velázquez—of the Virgin Mary as a child. "I was floored," she says. "I asked myself, What am I doing with my life? Fundamental particles are identical. They're cold." In her slam, she says, "I tried to bring people to this point of crisis. How can I compare what I do with how moving this painting is?" Demers asked the audience to imagine the arena was a particle detector. People in certain seats stood up, and the pattern they formed was like the tracks of a particle collision. "We got lucky and got a Higgs candidate!" she says. For her, "The nature of particles saves them in the end. The fact that they don't change means we have access to the beginning of the universe."

The other slammers were Stuart Henderson of Fermilab, Mark Messier of Indiana University, Vladimir Savinov of the University of Pittsburgh, and Tim Tait of the University of California, Irvine. Savinov was the winner, as measured by an "applause-o-meter" (see photo). "He was a firestorm," says Demers. "It was unbelievable. It was fantastic. It was hilarious. He started ranting about penguins. I was practically rolling on the floor laughing."

"I spent the first three-and-a-half minutes being more and more ridiculous, schizophrenic, hyping people up," says Savinov. "Then I jumped to hard science. I went from a global conspiracy to the Big Bang, Nobel laureates, matter and antimatter, CP violation." Savinov says he "wanted to tell the audience something new, and make it entertaining." And, he says, "I had never put so much effort into any presentation. Not even my faculty job interviews."

Demers's lyrics and a link to a video of the slam are available in the online version of this story on PHYSICS TODAY's website.

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