Recommendations on the Extended Tevatron Run
Report of the Particle Physics Project Prioritization Panel

October 26, 2010

1. Introduction and Recommendations

The Tevatron at Fermilab is scheduled to run through the end of 2011. At its August meeting the Fermilab Program Advisory Committee (PAC) recommended extending the Tevatron run by three years beyond 2011, to run in 2012, 2013 and 2014. The agencies, DOE and NSF, requested the High Energy Physics Advisory Panel (HEPAP) to reconvene the Particle Physics Project Prioritization Panel (P5) to give advice on this issue. Appendix A gives the charge to HEPAP.

The panel met on October 15 and 16 in Rockville, Maryland to consider the proposed extension of the Tevatron run. Appendix B shows the membership of the panel. All members of the panel participated in this meeting, although some did so via a telephone connection. The panel heard presentations on the Tevatron and the LHC science programs and on the impacts that an extension of the Tevatron run would have on the Fermilab program as well as on the broader HEP program in the US. Appendix C gives the agenda for the meeting.

Two years ago, after a lengthy in-depth study, P5 developed a ten-year plan for the US particle physics program, which HEPAP accepted on May 29, 2008. A summary of that plan is given in section 3. The panel today reaffirms the priorities in the 2008 report.

The Tevatron Collider and its experiments, CDF and D0, have performed extremely well. The analysis techniques of the two experiments have increased considerably in sophistication, allowing sensitivity to new science to increase more rapidly than the increases due to improved statistics alone. These Tevatron experiments are now at the point where they enter the region of significant sensitivity to the Standard Model Higgs boson. This achievement is remarkable.

The Large Hadron Collider (LHC) at CERN, the facility that replaces the Tevatron as the flagship accelerator at the Energy Frontier of particle physics, has had a slower turn-on than the panel anticipated when formulating the P5 plan two years ago. However, the LHC and its experiments are now performing extremely well, and performance is expected to continue to improve.

These changed circumstances create an exciting new opportunity for our field. With an extended run, the Tevatron would have significant sensitivity over the entire Higgs mass range favored by precision electroweak measurements. With a three-year extension, it could make a significant contribution to understanding the central issue of our field, the existence and nature of the Higgs boson, complementing the information physicists can expect from the LHC while it ramps up to its full energy and luminosity. Working together, the Tevatron and the LHC would provide answers to questions of fundamental importance to physics significantly sooner, particularly if reality is more complex than the Standard Model. Section 2 of this report discusses the science returns of such an extended Tevatron run.

An extension of the Tevatron run would require considerable resources. Fermilab management estimates that, in addition to belt tightening at the laboratory, an extended run would require additional funding of the order of 35M$ per year for four years. The panel looked in considerable depth into where these resources could be found within the present HEP budget. As mentioned above, the Panel reexamined the ten-year plan it put forward two years ago, and found it to be valid today as a vibrant but lean program to ensure a leading scientific role in our field for the US. The budget realities today, and the forecasts for the future, are leaner than the projections that the panel used in the 2008 study. The program is thus already under considerable fiscal pressure. Since the elements of this plan are interrelated in a sequential way, taking the resources required for an extended Tevatron run out of this lean base program, either at Fermilab or outside of Fermilab, would jeopardize the success of this long range plan to an unacceptable degree. Section 3 presents a discussion of the impact on the base program.

Having examined the physics opportunities that an extended Tevatron run would provide as well as the financial strain it would place on the rest of the HEP program, the panel makes the following recommendation:

Recommendation 1: The panel recommends that the agencies proceed with a three-year extension of the Tevatron program if the resources required to support such an extension become available in addition to the present funding for HEP. Given the strong physics case, we encourage the funding agencies to try to find the needed additional resources.

The panel found that besides funding issues, an extended Tevatron run would adversely affect the neutrino program at Fermilab, in particular the NOvA experiment. The present plan calls for a refitting of the Fermilab Recycler from antiprotons to protons in 2012 to allow the proton intensity to go from 400 kilowatts to 700 kilowatts. With an extended Tevatron run, which requires antiprotons in the Recycler, this refitting could not happen until 2015, reducing the accumulated protons on target for the experiment in its first three years by about a factor of two. The previous reduction of its target mass from a proposed 30 kilotons to 14 kilotons has already considerably impacted the NOvA experiment. The panel discussed two ways to mitigate the negative effect of an extended Tevatron run on NOvA : (i) explore the possibility of increasing the proton intensity beyond 400 kilowatts without refitting the Recycler and (ii) increase the detector target mass beyond 14 kilotons. (The detector hall is large enough to accommodate 18 kilotons.)

Given the importance of neutrino physics which is the heart of the future Intensity Frontier program at Fermilab, the panel makes the following recommendation:

Recommendation 2: The panel recommends that Fermilab make a strong effort to minimize the impact of an extended Tevatron run on the NOvA experiment.

2. The science case for an extended Tevatron run.

The most critical open issue in particle physics is the mechanism for the breaking of electroweak symmetry, leading to the generation of mass of all known elementary particles. Discovering and understanding that process is the most pressing issue in the field today. In the Standard Model, the Higgs mechanism breaks this symmetry, predicting the existence of a fundamental scalar boson, the Higgs boson. Extensions to the Standard Model include more complex Higgs sectors.

The precision electroweak measurements point to the existence of a light Higgs. The LEP2 experiments rule out Higgs masses below 115 GeV, and the Tevatron experiments exclude the region from 158 to 174 GeV. Thus the presently favored region for the mass of a Standard Model Higgs lies between 115 and 158 GeV. As mentioned above the electroweak measurements indicate a preferred region between 115 and 135 GeV, making this a prime region for future searches.

Measurements at the Tevatron and the LHC in the next years will test different aspects of Standard Model Higgs interactions and will probe for new physics in complementary ways. The complementary nature of the two facilities arises because the most accessible production and decay modes in the critical low-mass Higgs region differ between the Tevatron and the LHC. In this low mass region (115 to 135 GeV) the preferred production and decay modes for searches at the Tevatron are $q\bar{q} \rightarrow WH, H \rightarrow b\bar{b}$. Since the $b\bar{b}$ background from Standard Model $t\bar{t}$ and W-plus-jet production at hadron colliders is extremely large and grows more rapidly with energy than the Higgs signal, the most accessible process at the LHC is $gg \rightarrow H, H \rightarrow \gamma\gamma$.

The Tevatron experiments, CDF and DO, typically record 85 percent of the luminosity delivered by the Tevatron as data with sufficiently high quality to be useful for data analysis. At the present time the Tevatron experiments have published results based on 6 fb^{-1} of recorded luminosity. Given the highly sophisticated data analysis methods developed by these collaborations, with this data sample the Tevatron experiments have entered the realm of significant sensitivity to Higgs searches, allowing them to exclude the region of 158 GeV< M_H<174GeV.

With the assumption that the Tevatron maintains its present performance, extrapolation leads to 10 fb^{-1} of recorded luminosity by the end of 2011, and a three-year extension would yield a recorded luminosity of 16 fb^{-1}. With these luminosities and projected improvements in analysis techniques the Tevatron experiments would probe a gradually increasing range of Higgs masses. With 16 fb^{-1} of luminosity the Tevatron will reach a better then 3 standard deviation sensitivity over the whole interesting Higgs mass region of 115 to 180 GeV. This is the main motivation for the three-year run extension.

With the three-year extension, the Tevatron would be sensitive to the $H \rightarrow b\bar{b}$ decay mode in the favored Higgs mass range of 115 to 135 GeV with a 4 standard deviation significance at 115 GeV and 3 standard deviations at 135 GeV. Due to the increased standard model background, the observation of the $b\bar{b}$ decay mode is much more difficult at the LHC. The present estimates indicate that it will require an accumulated luminosity of 30 fb^{-1} at the full 14 TeV energy to see this decay mode. This is not expected to occur until 2014. On the same timescale, the LHC experiments will also be sensitive to the $H \rightarrow \tau\tau$ decay mode which could be important for the low-mass Higgs search.

The sensitivity to the $b\bar{b}$ decay mode is very significant for a number of reasons. The observation of this decay mode allows a measurement of the coupling of the Higgs to b quarks if a Higgs is seen in the $\gamma\gamma$ decay channel at the LHC. An observation of the $b\bar{b}$ decay would provide information on the product of the Higgs production cross section times its decay branching ratio. Comparing this with the Standard Model prediction would give an indication whether the Higgs is a Standard Model Higgs or something more complicated. Providing an earlier answer to this very important question at the Tevatron than might be possible at the LHC could provide important complementary information for ongoing Higgs studies at the LHC.

At the same time, the LHC has begun to collect data and is now performing impressively. The integrated luminosity recently passed 20 pb^{-1}, and it is expected that by the end of 2011 it will have accumulated between 1 and 2 fb^{-1} at 7 TeV. With this luminosity the LHC will be probing the high-mass Higgs region via the WW decay mode. In the low mass region, as discussed above, the Tevatron will use the $b\bar{b}$ mode, while the LHC searches will mostly rely on the rare decay of Higgs into photons, a loop-induced effect that is quite sensitive to new physics at the weak scale. Thus the Tevatron and LHC experiments explore the low mass Higgs region in complementary channels. The scientific value of having experiments at different colliders probing the same mass region in different channels over the next few years is very high.

Eventually, after reaching 30 fb^{-1} at 14 TeV, the LHC will be able to clearly detect the $H \rightarrow b\bar{b}$ mode. This can be combined with the evidence for the Higgs at the Tevatron to yield an estimate of the energy dependence of the Higgs production cross section. This would be another valuable check on the nature of the Higgs.

Interesting extensions of the Standard Model have been suggested. In many of these extensions the decay of the Higgs into two photons may be suppressed, delaying the discovery of the Higgs at the LHC unless the new physics provides additional sources of Higgs production or decays. In such a scenario the Tevatron might see a 3 to 3.5 standard deviation evidence for $H \to b\bar{b}$ before the LHC confirms with a solid 5 σ discovery. This would allow the Tevatron program, after 25 years of effort, a share in the Higgs discovery.

In the long run, the LHC is clearly the machine to do Higgs physics. A solid 5 σ discovery is possible only at the LHC. For the near term, until 2013 or 2014, when the LHC reaches 14 TeV, the energy needed to extend the 5 sigma discovery down to the 115 GeV mass region, the two colliders are complementary, and the Tevatron could make significant contributions to elucidate the nature of the Higgs boson. The two colliders together will likely provide a clearer picture of new physics more quickly than either alone. The Tevatron is a proton-antiproton collider, while the LHC is a proton–proton collider. There are other differences as well, including a significantly lower $b\bar{b}$ background at Tevatron energies than at energies of the LHC. Considering the uncharted nature of the Higgs sector, surprises should not be surprising (!), and the different properties of the two colliders may combine in unexpected ways to shed more light on the nature of the Higgs sector.

The expectation that the Standard Model Higgs is relatively light comes from the electroweak measurements from LEP, SLC, and the Tevatron. An extended Tevatron run would provide more precise measurements of the W and top quark masses. An estimate of these improvements is that, if the central values do not change, the 95 percent confidence level upper limit on the Higgs mass would come down to around 125 GeV. This would bring the electroweak measurements and the direct Higgs mass measurements into an early direct confrontation. Pushing the precision of these measurements to their limits builds on many years of detector calibration and experience at the Tevatron. The LHC will of course also make these measurements, but it might take a few years to reach the required level of precision.

Although the strongest physics argument for a continuation of the Tevatron run is associated with Higgs physics, the Tevatron experiments are multipurpose experiments and it is important to stress their broad physics capability.

The Tevatron experimental collaborations have studied the expected future degradation of their detectors and conclude they are capable of maintaining their performance through 2014. They have also established significant enthusiasm within their collaborations, ensuring adequate human resources to carry out the proposed run extension and the subsequent data analysis of the significant physics topics.

The graduate students, post docs and junior faculty are the people who will move our field forward and keep the science vital. Some of these young people are members of the Tevatron community. The continued running of the Tevatron would provide an opportunity for these very dedicated young scientists to extract the maximum science from the additional data sample. Understanding the electroweak sector is the most exciting area of particle physics, and these young scientists at Fermilab will remain active players in the game with this extension.

3. The P5 Roadmap for Particle Physics and the impact of a Tevatron extension

In 2008, HEPAP, through its P5 subpanel, created a strategic plan for the US elementary particle physics program. It was carefully crafted to attack the most important scientific questions and maintain US leadership in the three broad areas of the field: the Energy Frontier using high energy colliders, the Intensity Frontier using high intensity but lower energy beams, and the Cosmic Frontier using particles produced in the cosmos. The Energy-Frontier studies would initially be carried out at the Fermilab Tevatron, but soon the Energy Frontier would pass to the Large Hadron Collider at CERN, with US scientists playing a major role. The LHC, currently performing extremely well, has the highest priority in the HEP program because of its great scientific promise. The plan also provided for R&D for future lepton colliders that would likely be needed to understand in detail the new phenomena discovered at the LHC.

The P5 roadmap called for a world-leading Intensity Frontier program centered at Fermilab. It would include a program to measure the fundamental properties of neutrinos, continuing with the NOvA experiment and culminating in a new high-power proton source producing a very high intensity neutrino beam aimed at a massive detector in the proposed DUSEL underground laboratory in South Dakota. The new proton source would also enable searches for processes forbidden or highly suppressed in the Standard Model. The near term program at Fermilab would also include a muon-to-electron-conversion experiment that would exploit the existing accelerator complex. This aggregate program at Fermilab would be complemented by reactor experiments in France and China and by participation in an overseas next-generation B Factory.

The Cosmic Frontier program would largely focus on the search for the 95 percent of the energy in the universe whose identity remains unknown, namely dark energy and dark matter. Powerful telescopes to measure the history of the expansion of the universe and the growth of structure in the universe would pursue dark energy both on the ground and in space. Deep underground experiments sensitive to the low-energy scattering of dark matter particles by atomic nuclei in the detectors would carry out the direct search for cosmic dark matter. The roadmap also envisioned support for a few experiments studying high-energy particles produced in space. The HEPAP PASAG (Particle Astrophysics Scientific Assessment Group) subpanel and the NRC Astro2010 committee and panels further defined priorities for the Cosmic Frontier.

P5 reaffirms this roadmap for the US high-energy physics program. The roadmap offers the best path to answering the most crucial questions in elementary particle physics and for maintaining US leadership. That program is well under way in all three of the frontiers, and P5 does not recommend altering it significantly. At the same time, as noted above, continuation of Tevatron collider operations for another three years provides an added opportunity to obtain information complementary to that from the LHC on the search for a low-mass Higgs boson, the most pressing and one of the most challenging problems in our field. P5 recommends a funding bump to run the Tevatron and the CDF and D0 experiments. Even so, there will be a negative impact on two of the Intensity Frontier projects at Fermilab. The muon-to-electron conversion experiment would likely be delayed by approximately six months, a relatively minor delay that P5 found acceptable. More serious is a possible 1.5-year delay in results from the NOvA experiment, because the neutrino beam intensity could not reach the planned 700 kW while the Tevatron is running. P5 recommends that Fermilab work to minimize the impact of the Tevatron extension on the NOvA experiment. It is important not to delay work on the centerpiece of the Intensity Frontier program, the future long baseline neutrino experiment and the intense proton source that would provide the neutrinos (Project X), and to preserve the planned Fermilab workforce transition to the Intensity Frontier.

Appendix A

U.S. Department of Energy
and the
National Science Foundation

SEP 20 2010

Professor Mel Shochet
Chair, HEPAP
Enrico Fermi Institute
University of Chicago
Chicago, Illinois 60637

Dear Professor Shochet:

The scientific opportunities for the U.S. particle physics program in the coming decade have been most recently identified and articulated in the Particle Physics Project Prioritization Panel (P5) report submitted in May 2008. The guidance provided in the report has been utilized by the agencies in their strategic planning and for making programmatic decisions. The guidance has generally proved to be robust to changing circumstances; however, there are occasions when a request for additional guidance or a reassessment of scientific opportunities and priorities is warranted. The request last year for additional guidance on opportunities and priorities for particle astrophysics is a recent example. At this time, we are charging The High Energy Physics Advisory Panel (HEPAP) to provide an assessment of the scientific opportunity presented by a possible extension of the Tevatron program beyond its planned termination at the end of FY 2011 and of the impacts of such an extension on other elements of the future HEP program.

The Fermilab Program Advisory Committee (PAC) has recommended that the Tevatron be run for an additional 3 years beyond the currently planned termination of operations in FY 2011. After receiving this recommendation, the Fermilab Director, in consultation with the Department of Energy (DOE) Office of High Energy Physics, determined that the laboratory will not proceed with the recommendation without additional resources and some stretch-out of the future projects. We have identified what additional funding above the planned funding for Fermilab would be needed and have estimated the impacts on the planned future HEP program. The agencies would like HEPAP's assessment of the articulated science case and impacts. In particular, we are asking HEPAP to reconvene its Particle Physics Projects Prioritization Panel (P5) to provide the following assessments:

- Without regards to available resources, is it important to run the Tevatron to obtain additional data in FY 2012-2014 under the assumption that the LHC is fully successful in reaching its stated luminosity trajectory and physics performance? What information will the additional Tevatron data contribute beyond the expected LHC results? Will it contribute in a unique fashion to our understanding of physics beyond the standard model?

- If the answer to the first question is positive, is the value of the additional Tevatron data worth the anticipated impacts on the presently planned program?

We request your assessment by October 29, 2010. We understand this is a difficult task; however, your considerations on these issues will provide essential input for our planning.

Sincerely,

Dr. Dennis Kovar
Associate Director
for High Energy Physics
Office of Science
Department of Energy

Dr. Edward Seidel
Assistant Director
Mathematical and Physical Sciences
National Science Foundation

Appendix B

Particle Physics Project Prioritization Panel (P5)

Charles Baltay, Yale University, Chair
Hiroaki Aihara, University of Tokyo
James Alexander, Cornell University
Daniela Bortoletto, Purdue University
James Brau, University of Oregon
Peter Fisher, Massachusetts Institute of Technology
Josh Frieman, Fermi National Accelerator Laboratory, University of Chicago
Fabiola Gianotti, CERN
Donald Hartill, Cornell University
Andrew Lankford, University of California, Irvine
Joseph Lykken, Fermi National Accelerator Laboratory
William Marciano, Brookhaven National Laboratory
Jay Marx, California Institute of Technology
Steve Ritz, University of California, Santa Cruz
Tor Raubenheimer, Stanford Linear Accelerator Center
Marjorie Shapiro, Lawrence Berkeley National Lab., University of California, Berkeley
Henry Sobel, University of California, Irvine
Robert Tschirhart, Fermi National Accelerator Laboratory
Carlos Wagner, Argonne National Laboratory, University of Chicago
Stanley Wojcicki, Stanford University
Melvyn Shochet, University of Chicago, *Ex-Officio*

Appendix C

Agenda for the October P5 Meeting

October 15,16, 2010

Friday October 15

9:00- 9:15	Charge to the Panel	Mel Shochet
9:15- 9:30	Panel Organization	
9:30-10:15	Science case for an extended Tevatron Run	S. Soldner-Rembold
10:15-10:45	LHC Plans and Possibilities	Fabiola Gianotti
10:45-11:00	Coffee Break	
11:00-11:30	Impact on the Fermilab Program	Pier Oddone
11:30-12:00	Discussion of the Science	Panel
12:00- 1:00	Working Lunch, continued discussion	
1:00-1:20	The view from DOE	Dennis Kovar
1:20-1:40	The view from the NSF	Joe Dehmer
1:40- 5:00	Discussion (Executive Session)	
5:00 - 6:00	Discussion with Fermilab Director	Pier Oddone

Saturday October 16

9:00-12:00	Discussion within the Panel, Report Drafting
12:00- 1:00	Closeout with DOE and NSF