Status Report on Evaluation of the DOE-HEP Program's Long Term Performance Goals

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HEP Long-term Goal	*Definition of: “Success”*	*“ Minimally Effective”*
Measure the properties and interactions of the heaviest known particle (the top quark) in order to understand its particular role in the Standard Model.	Measure the top quark mass to ±3 GeV/c^2 and its couplings to other quarks with a precision of ~10% or better.	Measure the top quark mass to ±4 GeV/c^2 and its couplings to other quarks with a precision of 15% or better.
Measure the matter-antimatter asymmetry in many particle decay modes with high precision.	Measure the matter-antimatter asymmetry in the primary ($B \rightarrow J/\psi K$) modes to an overall relative precision of 4% and the time-integrated asymmetry in at least 15 additional modes to an absolute precision of <10%.	Measure the matter-antimatter asymmetry in the primary modes to an overall relative precision of 7% and the time-integrated asymmetry in at least 10 additional modes to an absolute precision of <15%.
Discover or rule out the Standard Model Higgs particle, thought to be responsible for generating the masses of elementary particles.	If discovered, measure the mass of the Standard Model Higgs with a precision of a few percent or better. Measure other properties of the Higgs (e.g., couplings) using several final states.	Discover (>5 standard deviations) or rule out (>95% CL) a new particle consistent with the Standard Model Higgs from a mass of 114 GeV, up to a mass of 800 GeV.

HEP Long-term Goal	*Definition of: "Success"*	*" Minimally Effective"*
Determine the pattern of the neutrino masses and the details of their mixing parameters.	Confirm or refute present evidence for additional neutrino species. Confirm or rule out the current picture of atmospheric neutrino oscillations. If confirmed, measure the atmospheric mass difference Δm^2 to 15% (full width at 90% CL); and measure a non-zero value for the small neutrino mixing parameter $\sin^2(2\theta_{13})$, or else constrain it to be less than 0.06 (90% CL, ignoring CP and matter effects)	Measure atmospheric neutrino mass difference Δm^2 to 25% using accelerator neutrino beams. Improve current limits on neutrino oscillations.
Confirm the existence of new supersymmetric (SUSY) particles, or rule out the minimal SUSY "Standard Model" of new physics.	Extend supersymmetric quark and/or gluon searches to 2 TeV in a large class of SUSY models. For masses below 1 TeV, measure their decays into several channels and determine masses of SUSY particles produced in those decays.	Extend supersymmetric quark and/or gluon searches to 1.5 TeV for some SUSY models (i.e. mSugra and similar models).
Directly discover, or rule out, new particles which could explain the cosmological "dark matter".	Discover (>5 standard deviations) the particle responsible for dark matter, or rule out (95% CL) many current candidates for particle dark matter (e.g., neutralinos in many SUSY models)	Rule out (90% CL) new particle(s) consistent with cosmological dark matter with a nuclear interaction cross-section larger than 10^{-44} cm^2.

HEP Performance Milestones by 2008

- Top Quark
  - CDF and D0 will have accumulated xx fb-1 (thru 2006) with excellent detector performance and will have announced results based on this data
  - Specifically, improved measurements of the top quark mass will have been announced.
- CP Violation
  - BaBar will have accumulated xx fb-1 (thru 2006) with excellent detector performance and will have announced results based on this data.
  - Specifically, improved measurements of the angle sin(2β) using J/Ψ K final states will have been announced and first precision measurements of other modes will have been announced.
- Higgs
  - The LHC project will be on schedule for producing significant physics results by the time of the next milestone review.
  - CDF and D0 will have begun exploring the low mass (>110 GeV) region for evidence of the Standard Model Higgs.
- Neutrinos
  - NuMI operations will be underway at or near design intensities.
  - The MINOS collaboration will have announced an improved measurement of the atmospheric neutrino mass difference.
  - The MiniBooNE collaboration will have announced final results using a neutrino beam to confirm or rule out the Los Alamos anti-neutrino oscillation results.
- Supersymmetry
  - The LHC project will be on schedule for producing significant physics results by the time of the next milestone review.
  - CDF and D0 will have extended searches for low mass supersymmetry particles.
- Dark Matter
  - The CDMS-II collaboration will have announced improved limits on dark matter particles using their full detector array.

Measure Properties of Top Quark

- Long term goals
  - Measure top quark mass to σ_{RMS} of 3 GeV/c^2.
  - Measure couplings to other quarks with 10% precision.
- Status and prospects
  - Top quark mass measured to 2.1 GeV/c^2 – The long term goal is met.
  - V_{td} = 0.0074 ± 0.0008 measured from Δm_d, dominated by theory error
    The long term goal is nearly met.
  - V_{ts} = 0.041 ± 0.003 measured with inclusive $B \rightarrow X_s\gamma$ mixing.
    The long term goal has been met.
  - V_{tb} can be directly measured with single top production; it will require 4-8 fb^{-1} at the Tevatron based on CDF estimates. ATLAS and CMS estimate a precision of 5% may be achieved
    The long term goal is likely to be met.

Measure CP Violation in Many Modes

- Long term goals
  - Measure CP asymmetry in $B \rightarrow J/\Psi K$ to 4%
  - Measure time-integrated asymmetry in 15 modes to <10%
- Status and prospects
  - All 2008 milestones have been reached
  - Combined BaBar/Belle result for $\sin(2\beta)$ has a precision of 3.8%. This long term goal has been achieved.
  - BaBar has recorded 391 fb^{-1} of data and measured asymmetries in 9 separate $b \rightarrow s$ hadronic penquin modes. With 1000 fb^{-1} collected by the end of 2008 these and other modes ($B \rightarrow \pi\pi$, $\rho\rho$, $\rho\pi$ which measure $\sin 2\alpha$, the electroweak penguin transitions with final states $K^*\gamma$, $s\gamma$, and $s\ell\ell$, and the direct CP violation modes $K\pi$, $\pi\pi$, $\eta'K$, $\eta'\pi$, ηK, $\eta\pi$, $\eta\rho$, ϕK, ωK, $\omega\pi$, $K\rho$, $\rho\pi$, $\rho\rho$, KKK, and $\pi\pi\pi$ with all possible charge combinations) will be measured. It is expected that 10% precision will be reached in at least 15 of these modes.
  - CDF and D0 have measured the CP asymmetry in inclusive di-muon events, in $B_s \rightarrow K\pi$, $\psi\phi$, and $\Lambda_b \rightarrow p\pi$, pK and the precision is expected to reach 10% in some of these modes by the end of run 2.
  - The second long term goal should be achieved.

Discover or Rule Out Higgs Particle

- Long term goals
  - If discovered, measure mass of Standard Model Higgs to few percent
  - Measure other properties using several final states
- 2008 milestones
  - LHC on schedule for producing significant results by the next milestone review
  - CDF and D0 will have begun exploring the low mass region for evidence of SM Higgs
- Status and prospects
  - LHC is currently on schedule for first collisions at 0.9 TeV in 2007 and collisions at 14 TeV in 2008. If no problems arise, 2008 goal will be met.
  - Current estimates from D0 and CDF are that ~3 fb^{-1} is needed to discover a 115 GeV/c^2 SM Higgs. This sensitivity requires the use of new analysis tools that have been developed by the collaborations. The performance of these tools is currently under study.
  - Projections for ATLAS and CMS performance are that the SM Higgs will be found if it exists in the full mass range up to 1 TeV, and measure branching fractions to several final states.

Discover Supersymmetric Particles or Rule Out Minimal Weak-Scale Supersymmetry

- Long term goals
  - Extend supersymmetric quark and/or gluon searches to 2 TeV/c^2
  - For masses below 1 TeV/c^2 measure several decay channels and masses of particles produced
- 2008 milestones
  - The LHC project is on schedule for producing significant physics results by the time of the next milestone review.
  - CDF and D0 will have extended searches for supersymmetric particles.
- Status and prospects
  - LHC is currently on schedule for first collisions at 0.9 TeV in 2007 and collisions at 14 TeV in 2008. If no problems arise, 2008 milestone will be met.
  - Tevatron experiments have extended supersymmetry searches by ~50 Gev/c^2 and expect to extend sensitivity by another 50 Gev/c^2 by the end of the run. The 2008 milestone has been met.
  - Numerous LHC studies show that the long term goals for supersymmetry searches should be met.

Determine Pattern Of Neutrino Masses and Mixing - 1

- Long term goals: atmospheric ΔM^2
  - Confirm or rule out the current picture of atmospheric ν oscillations
  - Measure atmospheric ΔM^2 to 15% full width 90% CL
- 2008 milestones
  - NUMI underway at or near design intensity
  - Improved result reported by MINOS on atmospheric ΔM^2
- Status and prospects
  - NUMI delivered 0.17 MW average (0.29 MW peak) – 2008 milestone has been achieved.
  - MINOS reported atmospheric $\Delta M^2 = 2.74 +0.44 -0.26 \times 10^{-3}\ eV^2$ – 2008 milestone has been achieved.
  - Atmospheric ν oscillations confirmed in K2K and MINOS – long term goal has been achieved
  - Projecting the first MINOS result to 7.5×10^{20} delivered protons (1.27×10^{20} in first year) gives 90% CL full width ~15% statistical. Many systematic errors should decrease with increased statistics – prospects for achieving long term goal is good.

Determine Pattern Of Neutrino Masses and Mixing - 2

- Long term goals other than atmospheric ΔM^2
  - Confirm or refute evidence for additional neutrino species
  - Measure a non-zero value for $\sin^2(2\theta_{13})$ or constrain it to <0.06 (90% CL)
- 2008 milestones
  - Final results from MiniBooNE confirming or refuting LSND result
- Status and prospects
  - MiniBoone has shown projected sensitivity of 3σ coverage of the putative LSND signal region with full ν data sample, with results expected late 2006 or early 2007. MiniBooNE is currently running with anti-neutrinos and the approved running will give a significantly smaller anti-neutrino data sample. Meeting the 2008 goal is not assured. Reaching a sensitivity for 95% exclusion or 5σ detection at the LSND signal value would require at least a significant new commitment of running.
  - The Double Chooz reactor neutrino experiment in France is expected to start operation in 2007 with one detector and 1-2 years later with two detectors. It expects to reach a sensitivity to $\sin^2(2\theta_{13})$ of 0.02-0.03 in 3 years of data taking. The long term goal is expected to be reached.
  - The Daya Bay reactor neutrino experiment could extend the $\sin^2(2\theta_{13})$ range by a factor of 3 or so over the Double Chooz sensitivity.
  - The NOVA off axis neutrino experiment could also extend the $\sin^2(2\theta_{13})$ range on a somewhat longer time scale.

Discover Dark Matter Particles or Rule Out Existence of Such Particles

- Long term goals
  - Discover (>5σ) DM particle or rule out (95% CL) many current candidates
- 2008 milestones
  - Improved results announced by CDMS-II using full detector
- Status and prospects
  - Accelerator searches for dark matter candidates (e.g. neutralinos) are addressed in section on supersymmetry. Discovering or ruling out candidate particles is likely to be achieved in early LHC running. Confirming a particle detected at the LHC as the dominant source of dark matter particle will require significant analysis and, in some scenarios, more detailed information (e.g. from the ILC).
  - CDMS-II (5 kg Germanium) expects to reach a sensitivity of 1-5 x 10^{-44} (depending on mass) within 2 years using their full detector. 2008 milestone is likely to be met.
  - SUPERCDMS 25 kg could reach ~10^{-45} sensitivity in approximately 2012. This covers the mass range of many current candidates for DM particles and would meet the long term goal for WIMP DM candidates.
  - Either a larger version of SUPERCDMS or one of a number of promising techniques using liquid noble gasses could reach higher sensitivity. If R&D on some of the noble gas techniques is successful, sensitivity approaching 10^{-46} could be reached on this timescale
  - The ADMX axion experiment expects to reach interesting coupling sensitivity in 2 years over full mass region in which axions could account for all DM. Technical improvements (lower temperature) could push the coupling sensitivity over this range by another factor of 2.