# HEPAP Accelerator R&D Subpanel Report

Don Hartill's materials for HEPAP and APS

April 2015

# Background

- Subpanel was formed in response to a 2013 OHEP COV recommendation
- P5 also recommended formation of the Subpanel

- Summary of the Charge to the Subpanel
- Members of the Subpanel
- P5 Guidance
- Information gathering process
- Meetings
- Community input
- Workforce needs
- GARD thrust areas
- Challenges
- Fundamental Accelerator Research

# Summary of the Charge to the Panel

**National Goals:** Appropriate goals in broad terms for medium term ( $\leq$ 10 years – bring new concepts to practice) and long term ( $\leq$ 20 years – exploratory research developing new concepts) U. S. Accelerator R&D for a world leading future program in accelerator based particle physics ***aligned with the recommendations of P5***

**Current Effort:** Examine the scope of the current effort and evaluate how well medium- and long-term R&D address the ***HEP mission as expressed by P5***

**Impediments:** Describe any impediments that may exist in achieving these goals

# Summary of the Charge to the Panel

**Training:** Accelerator R&D efforts play a major role in training future accelerator scientists and technologists. Are current programs adequate including local partnerships between laboratories and local universities?

**Balance:** How do we maintain a healthy and appropriately balanced national program? Provide further guidance for a plan based on the science and technology case for increased investment in HEP Accelerator R&D called for in P5's Scenario C

Current projects including PIP-II, HL-LHC, and the ILC were not part of the Subpanel considerations, and not "Accelerator Stewardship"

Preliminary report by the end of November with a final report by March 2015

# Members of the Subpanel

| | | | |
|---|---|---|---|
| Bill Barletta | Fermilab/ MIT | Young-Kee Kim | U of Chicago |
| Ilan Ben-Zvi* | BNL & Stony B. | Tadashi Koseki | KEK/J-PARC |
| Marty Breidenbach• | SLAC | Geoff Krafft | JLAB (NP Obs) |
| Oliver Bruning | CERN | Andy Lankford*• | UCIrvine *(ex.ofc)* |
| Bruce Carlsten* | Los Alamos | Lia Merminga• | Triumf |
| Roger Dixon | Fermilab | Jamie Rosenzweig | UCLA |
| Steve Gourlay | LBNL | Mike Syphers | MSU |
| Don Hartill (Chair) | Cornell | Bob Tschirhart* | Fermilab |
| Georg Hoffstaetter* | Cornell | Rik Yoshida | Argonne |
| Zhirong Huang | SLAC(BES Obs.) | | |

* Members of HEPAP • Members of P5

# Guidance from P5

- **Science Drivers**
  - Use the Higgs boson as a new tool for discovery
  - Pursue the physics associated with neutrino mass
  - Identify the new physics of dark matter
  - Explore the unknown: new particles, interactions, and physical principles
  - (Cosmic Acceleration)
- **Projected startup dates for existing projects**

| | |
|---|---|
| LHC: Phase 1 upgrade | ~ 2020 |
| HL-LHC | ~ 2025 |
| LBNF | ~ mid 2020s |
| ILC | ~ late 2020s |

- **Possible future projects ("Next Steps" and Further Future accelerators)**
  - Multi-MW proton source, 1 TeV e+e- collider, and ~very high-energy pp collider
  - $\geq$ 3 TeV $e^+e^-$ collider, Neutrino factory (physics case is yet to be made)
- Assuming ~ 10 years for the prime era for discovery of new physics for each of the "existing" projects sets the time scale for the construction start of future projects
- Assuming ~ 10 year R&D phase to develop the needed technologies to produce a credible conceptual design sets the start date of a significant R&D program

# Information Gathering by the Subpanel

Meetings were held at BNL, Fermilab, Argonne, SLAC and LBNL on a road trip during the last week in August

Subpanel Website:
http://www.usparticlephysics.org/p5/ards

The website has the agendas and the talks for the lab visits.

Town Hall meetings were held at most of the labs.
In addition, a virtual Town Hall meeting was held on Oct. 10

# Meetings of the Subpanel

First Meeting (Organizational) at SLAC July 7 & 8

Road Trip to BNL, Fermilab & Argonne, and SLAC & LBNL week of August 25 to 30.

Second Two Day Meeting Newport Beach, CA Nov. 6 & 7

Third Two Day Meeting Chicago, IL Dec. 3 & 4

Fourth Two Day Meeting UCLA, LA Jan. 9 & 10

Fifth Two Day Meeting SLAC Feb. 27 – Mar. 1

Numerous teleconferences (both full Subpanel and subgroups of the Subpanel)

# More on the Road Trip

The energy frontier was the focus at BNL.  There was also a report on programs in other regions.

The intensity frontier was the topic at Fermilab.

Novel particle acceleration schemes were the themes at SLAC and LBNL.

A two hour executive session was held at end of the LBNL visit and was followed by having a two page written report submitted by each subpanel member of their impressions from the road trip.

# HEP General Accelerator R&D (GARD) Thrust Areas Before the Review

Superconducting RF Cavities

Accelerator Beam Physics

Particle Sources

Beam Instrumentation and Controls

Normal Conducting RF and High Gradient Accelerating Structures

New Accelerator Concepts

Superconducting Magnets and Materials

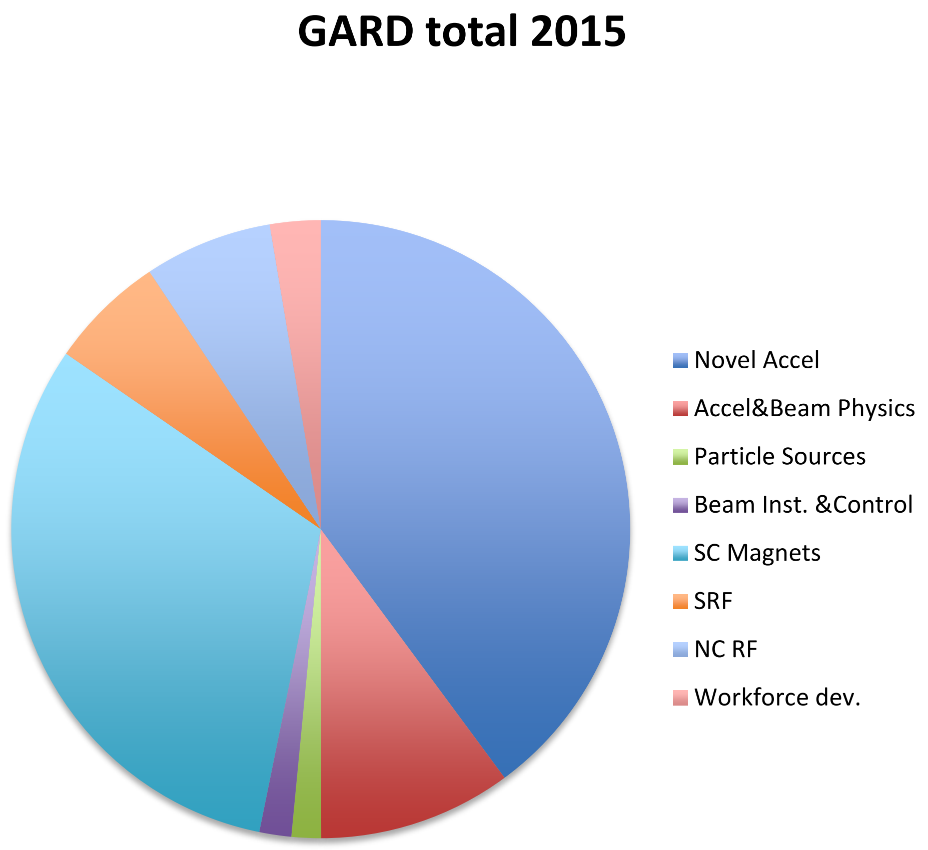
# Current GARD Program (FY 2015)

For FY 15 (President's request) the current General Accelerator Research and Development budget is 68 M$.

This includes the facility operation costs at Argonne (AWA), Fermilab (SRF and SC Magnets), SLAC (FACET) and LBNL (BELLA) which total 28.6 M$. Both FACET and BELLA were constructed using ARRA funds which did not include operational support.

This leaves a net of ~ 39.4 M$ for the GARD base programs and is divided among the previously listed seven GARD thrusts areas. The following pie chart illustrates the current division:

# Current GARD Program



# The NSF Program in Accelerator Science

In addition to the DOE GARD program, NSF has started their new program in Accelerator Science with a total funding level of 9.8 M$ for this year.

Fourteen awards have been made covering a broad range of topics in Accelerator Science.

And, it is a very welcome addition to the NSF portfolio.

# US GARD Opportunities

For the Intensity Frontier, the performance measure is MW•Ktons•beamtime/yr so producing higher beam power has significant leverage. Beam stability at synchrotron injection energies combined with higher power targets could have large benefits.

Future high energy colliders will be expensive and complex. *Optimization studies will be key* to lowering the construction cost and maximizing the operating efficiency. Optimized superconducting magnet design both in field intensity and manufacturability will require R&D for a very high-energy proton-proton collider. For $e^+e^-$ colliders, more efficient RF sources as well as much higher accelerating gradients could lower operating costs.

Advanced acceleration technologies potentially have the promise of dramatically increasing the accelerating gradient and thereby significantly reducing the cost of a very high energy $e^+e^-$ collider.

# Challenges

- Limited funding for the GARD program
- Time scales for the possible construction starts for the next generation of accelerator facilities are long
- Next generation of multi-MW proton sources, very high-energy pp colliders, 1 TeV $e^+e^-$ colliders, and $\geq$ 3 TeV $e^+e^-$ colliders will be complex machines
- The current sketch designs for these accelerators have a broad spectrum of maturity
- The very high stored energy of both the beams and the magnet systems of a very high-energy proton-proton collider provide interesting design challenges
- Intense synchrotron radiation from the beams in a very high-energy proton-proton collider presents very significant challenges for both the vacuum system design and the needed cryogenic cooling capacity
- The cost of using known technologies for these machines is very high
- The applicability of the advanced acceleration technologies to HEP colliders is at an early stage of understanding
- Cost of R&D facilities (both construction and operating costs)
- A key driver for the GARD program is to understand and develop strategies to significantly reduce the costs of construction and operation for future facilities

# Further Challenges

The Accelerator R&D Subpanel is not a project review panel. Our task is to recommend a balanced program in accelerator R&D to OHEP to provide the US with a world leading program in accelerator based particle physics. And, parenthetically developing a science and technology case for increased investment in accelerator R&D.

The current funding level (FY2015) for the entire GARD program is 68 M$ of which 28 M$ is for operations.

A HEPAP subcommittee report presented last spring concluded that there was a shortage of accelerator scientists and technologists. Our observations and conversations with members of the accelerator community confirmed this.

# Process towards the Report

After the Road Trip the Subpanel merged the seven GARD thrust areas into the following five accelerator R&D areas for study:

**Accelerator physics and instrumentation:**
Beam dynamics, simulation, computation, beam loss monitoring, etc

**Particle Sources and Targets:**
High power beams, horns, targets, and collimators
Beam dumps

**Superconducting RF**

**Superconducting Magnets and Materials**

**Advanced Acceleration (see next slide):**

# Process towards the Report (cont.)

**Advanced acceleration:**

Normal conducting RF structures and sources

Dielectric wakefield accelerators

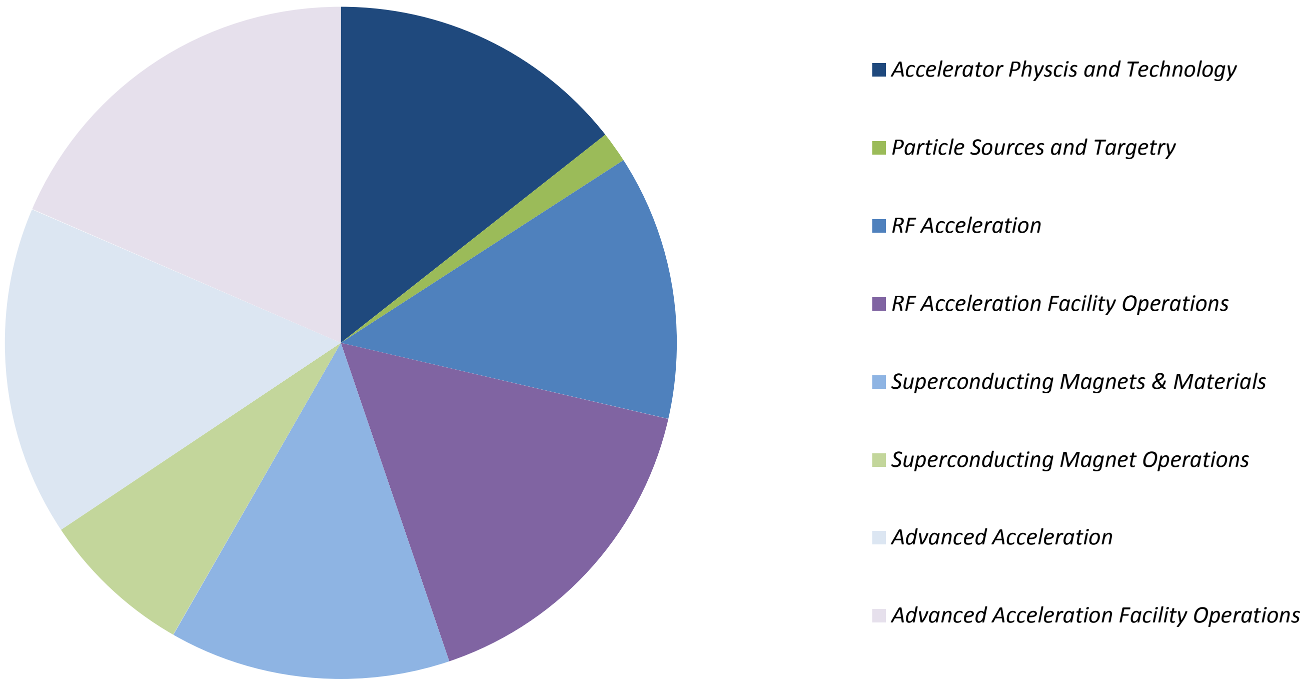
Beam driven plasma wakefield acceleration

Laser driven plasma wakefield acceleration

Direct laser acceleration

Fundamental aspects of muon acceleration

# Current GARD Program (rearranged areas)



# “Accelerating Discovery”

The report summarizes the Subpanel’s findings from our analysis of the GARD program with the guidance from P5 firmly in mind.

The budget for the GARD program was assumed to be constant at the current FY 2015 level (Scenario A) for the future GARD program.

The GARD program is world leading in accelerator R&D, however, this position is at risk due to a large fraction of the total budget going to facility operations.

To limit this risk and to move forward more rapidly on the necessary R&D for the Next Steps and Further Future accelerators a Scenario B budget is proposed (a 10 – 20% increase).

To move forward more rapidly on the needed R&D for a very high-energy proton-proton collider and for a > 3 TeV $e^+e^-$ collider a Scenario C budget as suggested by P5 is proposed.

# Report Outline

Executive Summary
Introduction
Recommendations in Scenario A, Scenario B, and Scenario C
Area Details:
- Accelerator Physics and Technology
- Particle Sources and Targetry
- RF Acceleration
- Superconducting Magnets and Materials
- Advanced Acceleration
- Facilities

Conclusion and Appendices

# Comments on the Introduction

As a guide for the R&D needed for the Next Steps and Further Future accelerators, the particle physics community has to come together and *agree on the physics parameters* for the research programs on these accelerators. The required energy and luminosity for both the very high-energy proton-proton collider and for the multi-TeV $e^+e^-$ collider are key cost drivers for these accelerators.

The size and operating energy of the accelerators also directly determine their operating cost and the reliability in addition to the construction cost. Dealing with the synchrotron radiation load on the vacuum system and superconducting magnets drives important aspects of the design of these systems for a very high-energy proton-proton collider.

# Recommendations

The focus of our analysis was to align GARD with P5’s vision of the Next Steps and Further Future Accelerators.

The recommendations are organized in this fashion in Scenario A.

The Scenario B recommendation is for an overall funding increase to fund definite projects in each of the accelerator areas.

Scenario C is to fund two programs:

a) increased R&D for superconducting magnets and materials along with other needed R&D aimed at a very high-energy proton-proton collider and
b) b) R&D for a multi-TeV $e^+e^-$ collider.

# Recommendations - continued

**For the multi-MW proton beam:**

High power components, IOTA (space charge), simulations, and SRF (Recommendations 1-4, 14, 15)

**For a very high-energy proton-proton collider:**

Design effort, simulation, high field magnets, $Nb_3Sn$, HTS, and industrialization for cost reduction (Recommendations 5, 5a-5f, 14, 15)

**For a 1 TeV ILC:**

Higher Gradient SRF (Recommendation 6)

**For a >3 TeV $e^+e^-$ collider:**

Facility to continue particle-driven wakefield acceleration, continue laser-driven wakefield acceleration, develop a roadmap, efficient RF sources, component test facilities, and a next step plan for normal conducting RF technology (Recommendations 7-13, 14, 15)

# Recommendations in Scenario A

**Organized by Next Steps accelerators followed by Further Future accelerators.**

**Multi-MW proton beam**

**Recommendation 1. Fund generic high-power component R&D at a level necessary to carry out needed thermal shock studies and ionizing radiation damage studies on candidate materials that are not covered by project-directed research.**

**Recommendation 2. Construct the IOTA ring, and conduct experimental studies of high-current beam dynamics in integrable non-linear focusing systems.**

**Recommendation 3. Support a collaborative framework among laboratories and universities that assures sufficient support in beam simulations and in beam instrumentation to address beam and particle stability including strong space charge forces.**

**Recommendation 4. Direct appropriate investment in superconducting RF R&D in order to inform the selection of the acceleration technology for the multi-MW proton beam at Fermilab.**

# Recommendations in Scenario A - continued

**Very high-energy proton-proton collider**

**Recommendation 5. Participate in international design studies for a very high-energy proton-proton collider in order to realize this Next Step in hadron collider facilities for exploration of the Energy Frontier. Vigorously pursue major cost reductions by investing in magnet development and in the most promising superconducting materials, targeting potential breakthroughs in cost-performance.**

**Recommendation 5a. Support accelerator design and simulation activities that guide and are informed by the superconducting magnet R&D program for a very high-energy proton-proton collider.**

**Recommendation 5b. Form a focused U.S. high-field magnet R&D collaboration that is coordinated with global design studies for a very high-energy proton-proton collider. The over-arching goal is a large improvement in cost-performance.**

**Recommendation 5c. Aggressively pursue the development of $Nb_3Sn$ magnets suitable for use in a very high-energy proton-proton collider.**

# Recommendations in Scenario A - continued

**Very high-energy proton-proton collider - continued**

**Recommendation 5d. Establish and execute a high-temperature superconducting (HTS) material and magnet development plan with appropriate milestones to demonstrate the feasibility of cost-effective accelerator magnets using HTS.**

**Recommendation 5e. Engage industry and manufacturing engineering disciplines to explore techniques to both decrease the touch labor and increase the overall reliability of next-generation superconducting accelerator magnets.**

**Recommendation 5f. Significantly increase funding for superconducting accelerator magnet R&D in order to support aggressive development of new conductor and magnet technologies.**

# Recommendations in Scenario A - continued

**1-TeV ILC Upgrade**

**Recommendation 6. Increase funding for development of superconducting RF (SRF) technology with the goal to significantly reduce the cost of a ~1 TeV energy upgrade of the ILC. Strive to achieve 80 MV/m accelerating gradients with new SRF materials on the 10-year timescale.**

# Recommendations in Scenario A - continued

**Further Future Accelerators**

**Multi-TeV $e^+e^-$ Collider**

**Recommendation 7. Vigorously pursue particle-driven plasma wakefield acceleration of positrons at FACET in the time remaining for the operation of the facility. Between the closing of FACET and the operation of a follow-on facility, preserve the momentum of particle-driven wakefield acceleration research using other facilities.**

**Recommendation 8. Continue to support laser-driven plasma wakefield acceleration experiments on BELLA at the current level.**

**Recommendation 9. Reduce funding for direct laser acceleration research activities.**

**Recommendation 10. Convene the university and laboratory proponents of advanced acceleration concepts to develop R&D roadmaps with a series of milestones and common down-selection criteria towards the goal of constructing a multi-TeV $e^+e^-$ collider.**

# Recommendations in Scenario A - continued

**Further Future Accelerators**

**Multi-TeV $e^+e^-$ Collider - continued**

**Recommendation 11. Continue research on high efficiency power sources and high gradient normal conducting RF structures.**

**Recommendation 12. Make NLCTA available for RF structure testing using its RF power and beam sources.**

**Recommendation 13. Focus normal conducting RF R&D on developing a multistage prototype of high-gradient, high-efficiency normal conducting RF technology to demonstrate the effectiveness of the technology for a multi-TeV $e^+e^-$ collider based upon the development of high-efficiency power sources and high-gradient structures.**

# Recommendations in Scenario A - continued

**Further Future Accelerators (Particle Driven Wakefield Accelerator)**

FACET-II would allow significant progress on much lower emittance and energy spread electron beams in the context of very high acceleration gradients. It would eventually have a new small damping ring for positrons that would utilize the existing positron source and a "sailboat" chicane, which would allow adjustable separation of the drive electron and witness positron beams. FACET-II would enable beam matching and transport at the entrance/exit of a single module, but does not permit independent stages with drive beams. Initial staging experiments can be performed at the ATF and AWA facilities.

The cost of this project is substantial and cannot be accommodated within the current GARD budget.

# Recommendations in Scenario A - continued

**Further Future Accelerators (Neutrino Factory)**

Physics results from long-baseline neutrino oscillation studies using the multi-MW proton beam of the Next Steps could call in the further future for more neutrino oscillation studies using a beam from a neutrino factory based upon a muon storage ring, rather than a high-intensity proton “super-beam”.

The MICE experimental results expected by 2017 will provide answers to the effectiveness of ionization cooling of the muon beam needed for such a storage ring.

P5 recommended termination of MAP and also recommended incorporating into the GARD program MAP activities that are of general importance to accelerator R&D. Under this guidance, fundamental aspects of muon beam dynamics R&D could be funded on a competitive basis against other activities of general interest.

# Recommendations in Scenario A - continued

**Support for Next Steps and Further Future Accelerators**

**Recommendation 14. Continue accelerator and beam physics activities and beam instrumentation and control R&D aimed at developing the accelerators defined in the Next Steps and the Further Future Goals. Develop coordination strategies, both nationally and internationally, to carry out these studies in an efficient manner.**

**Recommendation 15. To ensure a healthy, broad program in accelerator research, allocate a fraction of the budget of the Accelerator Physics and Technology thrust to pursue fundamental accelerator research outside of the specific goals of the Next Steps and Further Future Goals. Research activities at universities should play a particularly important role.**

# Scenario B

Whereas the current GARD budget (Scenario A) is insufficient to satisfy the expectations of P5, a modest rise in base funding for GARD research (Scenario B: an increase of ~10-20% of GARD research, ~1-2% of HEP) would open numerous critical R&D opportunities that do not fit in the current base, as well as invigorate fundamental accelerator science research.

**Recommendation B1. Increase base GARD funding modestly in order to open numerous critical R&D opportunities that do not fit in the current base, as well as to invigorate fundamental accelerator science research, and to step up development of the national accelerator workforce.**

Opportunities include ambitious computational accelerator science, R&D on NCRF, higher gradient SRF using new materials, expanding use of the BELLA facility, more robust superconducting magnet R&D, and radiation damage in candidate target materials for neutrino beams.

# Scenario C

The P5 report called for a roadmap for the U.S. to "move boldly toward development of transformational accelerator R&D [...] with an aggressive, sustained, and imaginative R&D program [...] changing the capability-cost curve of accelerators" in Scenario C. Motivated by the P5 science drivers, the goal is to "make these further-future accelerators technically and financially feasible on much shorter timescales."

**Recommendation C1. Hasten the realization of the accelerator of P5's medium-term vision for discovery: a very high-energy proton-proton collider and the realization of the accelerators of P5's long-term vision for discovery: a multi-TeV $e^+e^-$ collider.**

# Scenario C

For the very high-energy proton-proton collider:

**Recommendation C1a. Ramp up research and development of superconducting magnets, targeted primarily for a very high-energy proton-proton collider, to a level that permits a multi-faceted program to explore possible avenues of breakthrough in parallel. Investigate additional magnet configurations, fabricate multi-meter prototypes, and explore low cost manufacturing techniques and industrial scale-up of conductors. Increase support for high-temperature superconducting (HTS) materials and magnet development to demonstrate the viability of accelerator-quality HTS magnets for a very high-energy collider.**

# Scenario C

Increased investment enabled by Scenario C will permit the exploration of several possible avenues in parallel including investigation of additional magnet configurations, fabrication of multi-meter prototypes, and exploration of low-cost manufacturing techniques.

It will also fund the industrial scale-up of conductors ($Nb_3Sn$) and provide increased support for HTS material and magnet development.

Demonstration of an accelerator quality HTS magnet is an additional goal.

# Scenario C

Following this first project on magnets and materials and guided by its results, second-generation R&D projects will be launched targeting the next set of breakthroughs needed for the realization of a very high-energy proton-proton collider.

As the enabling technology and cost-driver, superconducting magnets will require further R&D both for more complex magnets and conductor material.

The extremely high stored energy in the beams combined with the synchrotron radiation load on the magnets will drive further R&D.

Simulation activities will also be needed to optimize the collider design because of these technical challenges.

# Scenario C

For the multi-TeV $e^+e^-$ collider:

**Recommendation C1b. Develop, construct, and operate a next-generation facility for particle-driven plasma wakefield acceleration research and development, targeting a multi-TeV *$e^+e^-$* collider, in order to sustain this promising and synergistic line of research after the closure of the FACET facility.**

# Scenario C

To reach the goal of having a credible design for a multi-TeV $e^+e^-$ collider, a number of R&D steps will be needed to determine the most promising acceleration technique and to further develop that technique for a practical collider.

Seven Steps are listed in the report beginning with continued studies of the candidate techniques on existing facilities.

Community engagement in defining roadmaps with key milestones along with the agreement on down select criteria will be a key part of this process.

Next generation R&D facilities will be needed followed by perhaps next-to-next generation facilities before a down selection to a single technique.

After enough R&D has been performed with the selected technique a demonstration facility will need to be constructed in order to demonstrate the technique on a scale that gives confidence that further scaling can be done to the multi-TeV scale $e^+e^-$ collider.

# Scenario C

Scenario C funding would enable the U.S. accelerator R&D program to "move boldly toward development of transformational accelerator R&D […] with an aggressive, sustained, and imaginative R&D program", as called for by the P5 strategic plan.

By funding R&D projects that would hasten the development of a very high-energy proton-proton collider and of a multi-TeV $e^+e^-$ collider, Scenario C funding would consolidate R&D areas in which the U.S. already has significant strengths and leadership positions. With this additional funding, the U.S. could maintain its traditional leadership in accelerator R&D.

The R&D projects chosen would significantly enhance the state-of-the-art; consequently, they can be expected to generate exciting results that will draw new practitioners into the accelerator R&D enterprise, and that can be applied across the Office of Science.

Scenario C funding would energize a vibrant accelerator-based U.S. particle physics program.

# Conclusions

http://science.energy.gov/~/media/hep/hepap/pdf/20150406/Accelerator_RandD_Subpanel_Report--DRAFT_FOR_APPROVAL-1-4.pdf

A healthy program in accelerator R&D is key to ensuring that the US accelerator based high energy particle physics program is world leading.

Training of the next generation of accelerator scientists and technologists is a very important element of the GARD R&D program. See the HEPAP Subcommittee on Workforce Development report published this past spring.

Need to provide continued support for fundamental accelerator R&D that is not directed towards the possible projects presently under discussion. This has provided us with our current suite of accelerator capabilities.

Our hope is that our report will provide useful guidance to DOE OHEP in charting the future of accelerator R&D in the US.