U.S. HEP community perspective on future circular colliders

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US High Energy Physics Strategic Plan: P5

P5 = Particle Physics Project Prioritization Panel
= a HEPAP subpanel
HEPAP = High Energy Physics Advisory Panel

Note: US HEP is funded by DOE HEP, NSF EPP, NSF PA

P5 Charge = A strategic plan, executable over 10 years, in the context of a 20-year global vision, in *realistic* budget scenarios

P5 Report was submitted by HEPAP on May 22, 2014.

The plan was formulated by a panel of 25 scientists over ~6 mo

- **Benefited from 5 (*devoted)* scientists from Canada, Europe, Japan**
- **Chaired by Steve Ritz (UCSC)**

The P5 plan is science-driven.

The report includes 29 recommendations.
Only main points of likely interest to this audience are summarized here, so please read the report for the important details.

A year-long community-wide study preceded P5

Community-driven (APS DPF)

Goal: Identify compelling HEP science opportunities over an approximately 20-yr time frame

Not a prioritization; entrusted to P5

Deliverables:

Collection of "White papers"

Input to working group write-ups

Report:

- ***7x* 30-page group write-ups**
  + theory report
  w/ executive summaries input to overview
- **30-page Overview**

Served as invaluable input, the departure point for P5

Particle Physics is a Global Field for Discovery

The scientific program required to address all of the most compelling questions of the field is beyond the finances and technical expertise of any one nation or region.

- **The United States and major players in other regions can together address the full breadth of the field's most urgent scientific questions**
  - if each hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere.
  - Hosting world-class facilities and joining partnerships in facilities hosted elsewhere are both essential components of a global vision.
- Strong foundations of international cooperation exist, with the Large Hadron Collider (LHC) at CERN serving as an example of a successful large international science project. Reliable partnerships are essential for the success of international projects.
- **This global perspective is finding worldwide resonance.**
  - 2013 *European Strategy for Particle Physics* report
  - Japan, following its 2012 *Report of the Subcommittee on Future Projects of High Energy Physics*,
  - Recent ICFA statement (2014)

Recommendation 1: ***Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community.***

The Science Drivers

- P5 distilled the 11 groups of physics questions formulated at Snowmass into 5 compelling lines of inquiry that show great promise for discovery over the next 10 to 20 years.

- **The 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.**
  - **Understand cosmic acceleration: dark energy and inflation.**
  - **Explore the unknown: new particles, interactions, & physical principles.**

- *Recommendation 2:* ***Pursue a program to address the 5 science drivers.***

- The **drivers** are deliberately **not prioritized** because they are **intertwined**, probably more deeply than currently understood.
- A selected set of different experimental approaches that reinforce each other is required. **Projects are prioritized**.
- The vision for addressing each of the drivers using a selected set of experiments is given in the report, along with their approximate timescales and how they fit together.

- Explored at Energy Frontier with colliders

P5: Near-term and Mid-term High-Energy Colliders - LHC

LHC thru HL-LHC

The enormous physics potential of the LHC should be fully exploited.

Complete the LHC phase-1 upgrades and

continue the strong collaboration in the LHC with

the phase-2 (HL-LHC) upgrades of the

accelerator and

both general-purpose experiments (ATLAS and CMS)**.**

The LHC upgrades constitute our highest-priority near-term large project.

P5: Near-term and Mid-term High-Energy Colliders - ILC

Interest expressed in Japan in hosting the ILC is an exciting development.

- An e+e- collider can provide the next outstanding opportunity [after LHC/HL-LHC] to investigate the properties of the Higgs in detail.
- The ILC is the most mature in its design and readiness for construction.
- As the physics case is extremely strong, all scenarios include ILC support at some level through a decision point within the next 5 years.
- Participation by the U.S. in project construction depends on a number of important factors, some of which are beyond the scope of P5 and some of which depend on budget scenarios.

Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels of collaboration if ILC proceeds.

ILC in Scenario C (the ‘unconstrained” budget scenario)**:**

> ***Should the ILC go forward, Scenario C would enable the U.S. to play world-leading roles in the detector program as well as provide critical expertise and accelerator components.***

P5: Far-term Future-Generation Accelerators

The motivation for future-generation accelerators must be the Science Drivers

A very high-energy proton-proton collider is the most powerful future tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window.

Participate in global design studies and critical path R&D for future very high-energy proton-proton colliders. Continue to play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs.

A multi-TeV *e*+*e*– collider could be based on either the Compact Linear Collider (CLIC) or plasma-based wakefield technology.

Muon colliders can reach higher energies than *e*+*e*– accelerators, but have many technical challenges. Addressing all of the necessary challenges would require a very strong physics motivation based on results from ongoing or future accelerators.

Pursue accelerator R&D with high priority at levels consistent with budget constraints. Align the present R&D program with the P5 priorities and long-term vision, with an appropriate balance among general R&D, directed R&D, and accelerator test facilities and among short-, medium-, and long-term efforts. Focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators.

P5 Vision of Possible Future HEP Facilities

	Intensity Frontier Accelerators	Hadron Colliders	Lepton Colliders
Current Efforts	PIP	LHC	
	PIP-II	HL-LHC	ILC
Next Steps	Multi-MW proton beam	100 TeV class *pp* collider	1 TeV class energy upgrade of ILC*
Further Future Goals	Neutrino factory*		Multi-TeV e^+e^- collider*

**dependent on how physics unfolds*

Accelerator R&D – in Scenario C

Scenario C presents 3 options. One focuses on accelerator R&D:

Move boldly forward with transformational accelerator R&D.

- **A primary goal = dramatically lower cost.**
- For example,
  - **pp colliders** - **high-field accelerator magnets**
  - **e^+e^- colliders** - **improving the accelerating gradient** and **lowering the power consumption**.
  - Although these topics are R&D priorities in the constrained budget scenarios, larger investments could make these far-future accelerators technically and financially feasible on much shorter timescales.
- Large, **positive impacts beyond particle physics.**

- **HEPAP Accelerator R&D Subpanel** charged to develop detailed vision and roadmap for Scenario C.
  - As well as to align and balance existing portfolio, according to reco on earlier slide.
  - Subpanel will report to HEPAP on April 6, 2015.

- As work proceeds worldwide on long-term future-generation accelerator concepts, the **U.S. should be counted among the potential host nations**.

HEPAP Accelerator R&D Subpanel

Subpanel is charged to:

- **Consider medium-term and long-term R&D**
- **Define national goals, aligned with P5 vision**
- **Assess current program**
- **Identify impediments**
- **Assess available workforce training opportunities**
- ***Balance*:**
  - "Advise the DOE-HEP program on how to maintain a healthy and appropriately balanced national program for medium- and long-term accelerator R&D, including test facilities, in light of the budget envelopes for Scenarios A and B developed by the HEPAP-P5 panel.
  - Provide further guidance for a plan based on the science and technology case for increased investment in the HEP Accelerator R&D program called for in P5's Scenario C.
  - We would be particularly interested to know how partnerships between universities, national laboratories and international collaborators could be most effective in achieving the goals."
- **Subpanel will report to HEPAP on April 6th**

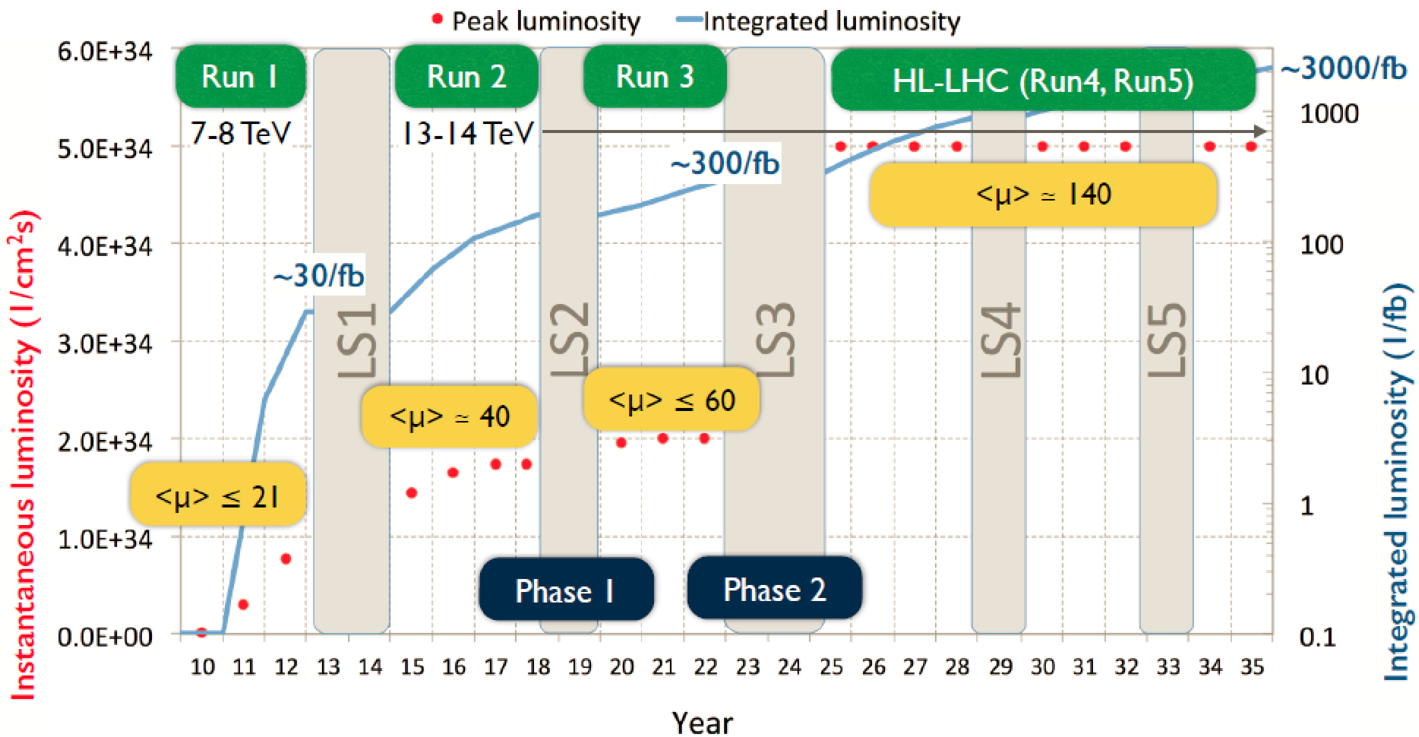
P5's collider vision: LHC Run 2

LHC Run 2 start is imminent

- **Significant increase in energy: 8 → 13(+) TeV**
- **Increase in instantaneous luminosity and integrated luminosity**
- **Significant increase in physics reach**
- **First in sequence of improvements/upgrades to LHC and exp'ts.**

P5's collider vision: LHC → HL-LHC

LHC and experiments are now actively engaged in programs of improvements and upgrades



- Increase in instantaneous luminosity and integrated luminosity
- Significant increase in physics reach
- An extended campaign of progressive enhancements of potential
- Measurements and discoveries from Run 2 and from 2018 and beyond may provide guidance to future directions

P5's collider vision: ILC

Precision tool: "***Use the Higgs boson as a new tool for discovery***"

contributes also to: "*Identify the new physics of dark matter*"

"*Explore the unknown: new particles, interactions, and physical properties*"

Energy upgrade path to ~1 TeV,

Upgrade path differs from circular colliders, whose upgrade path is to *pp.*

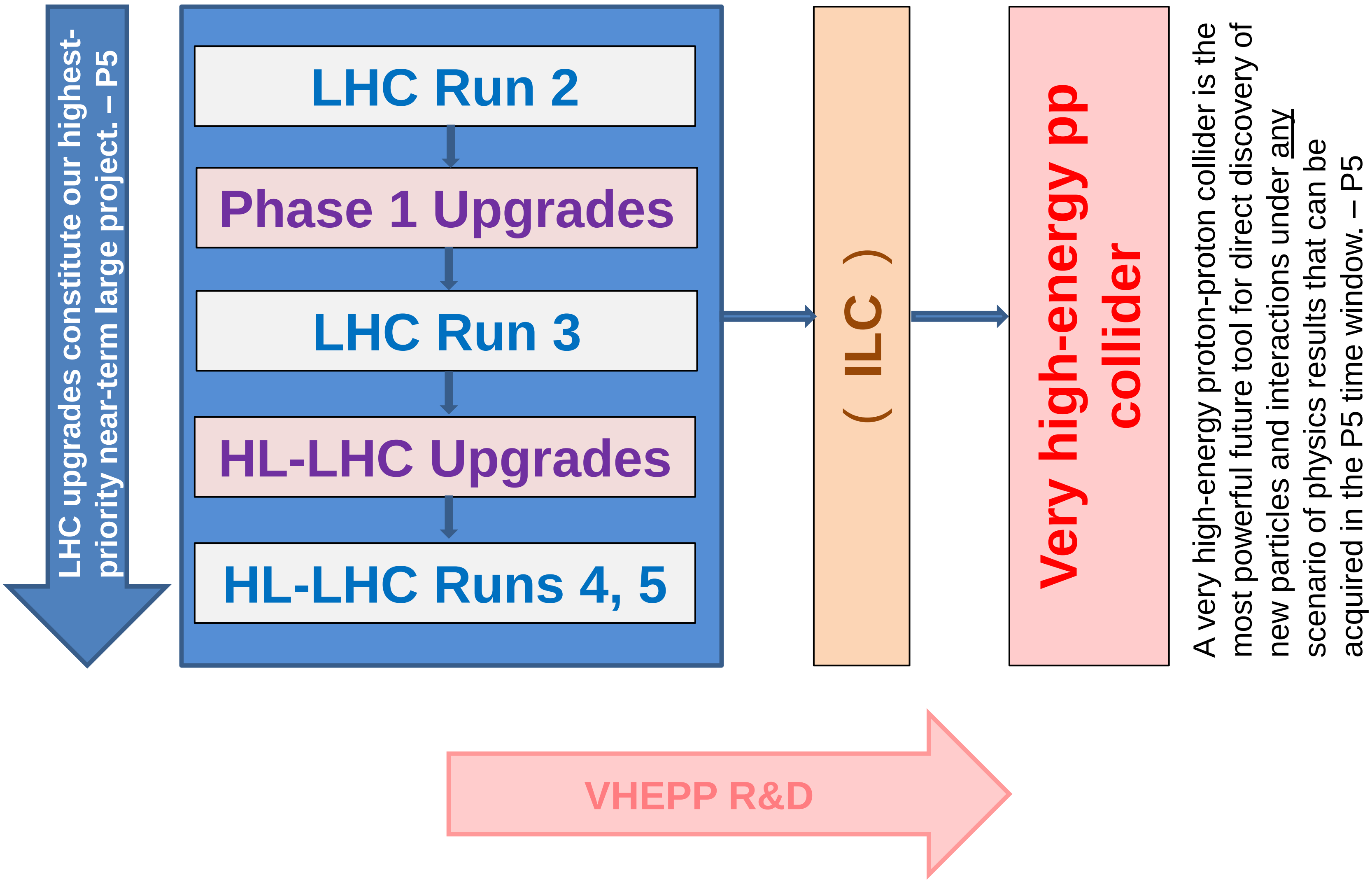
Scientifically **motivated** by:

- **Higgs self-coupling** (~13%); precision Higgs-top coupling (~2%)
- Extended **search for new particles** coupling to γ & Z
- Motivation increased if **LHC/HL-LHC discovers new particles**

Status:

- TDR – June 2013 -> ***technically ready***
- **Japan** is considering whether or not to host ILC.
- Subject of active discussion between DOE and MEXT (Japanese Ministry of Education, Culture, Sports, Science and Technology)
- LCC is targeting 2018 construction start.

P5 vision for evolution of Energy Frontier facilities



Very High-Energy Proton-Proton Collider

A very high-energy proton-proton collider is the most powerful future tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window. – P5

Why start work on the FCC-hh/SppC/VLHC/VHEPP ?
Answer: Addressing the tremendous challenges must start now.

Challenges are formidable:

1. Required technical performance must be achieved at affordable cost.
   - Particularly, high field superconducting dipole magnets
2. Adequate resources, financial & technical expertise, must be gathered.
   - Support will be needed from science community and decision makers
   - Scale of project will draw on international community, if not for resources, then for technical expertise.

VHEPP work must be balanced *wrt* more immediate priorities, *e.g.* HL-LHC.

Begin now: Tackle high-priority R&D, beginning with SC magnets
Establish critical accel. Parameters, *e.g.* E, L_{int};
Articulate scientific motivation;

Personal Remarks

A very high-energy proton-proton collider is the most powerful future tool for enabling our science and discovery.

The need to develop this tool is important and immediate.

Required technical performance must be achieved at affordable cost.

- **Those that solve this challenge will enable future discoveries.**
- (Addressing these challenges will advance technology, to wider societal benefit than HEP, and will inspire both the public & prospective young scientists.)

Adequate resources, financial & technical expertise, must be gathered.

- Articulating the motivation:

  Explore the unknown + Higgs as a tool for discovery

  - The case is richer than this, but simply stated, this is enough.

A Look Ahead: Multi-TeV e^+e^- Collider

We are awaiting the science motivation, as well as the technology.

The LHC/HL-LHC could well make discoveries that would motivate a future multi-TeV lepton collider, but we are currently without such strong motivation or knowledge of the required energy.

Technology could be based on RF acceleration or Wakefield Acceleration.

NCRF (normal conducting) or **SRF** (superconducting)

DWFA (dielectric), **PWFA** (beam-driven plasma), **LWFA** (laser-driven plasma)

Appropriate levels of R&D can be invested.

In part to prepare to realize such a machine if warranted

In part because it constitutes exciting accelerator science R&D and excellent training for accelerator scientists

Brief Summary

"The full breadth of the field's most urgent scientific questions can be addressed if each major player hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere.

> **Hosting world-class facilities and joining partnerships in facilities hosted elsewhere are both essential components of a global vision." – P5**

The future starts now, with facilities already in the plans:

- **LHC Run 2 → Run 3 → HL-LHC → (ILC) → VHEPP**

Don't overlook "existing" opportunities in looking forward to future possibilities.

The future starts now, also for the next steps

- **Realization of a facility on the scale of FCC, CEPC/SppC, VHEPP will require overcoming tremendous challenges**
  - **Increased technical performance at reduced cost.**
  - **Adequate resources, financial & technical expertise.**
- **Challenges are real, but can be overcome with ingenuity and tenacity**
  - **Begin now to:**
    - **Tackle high-priority R&D: superconducting magnets**
    - **Establish critical accelerator parameters: E, L_{int}**
    - **Articulate the scientific motivation**