"Outlook"

National/International Planning

or

Realizing our Dreams for the Future

Exploring the Physic Frontier
with ~~Circular~~ Colliders

Aspen Center for Physics; February 1, 2015

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Introduction

This has been an exceptionally good meeting

- My congratulations and thanks to the organizers
- Excellent atmosphere
- Informative and interesting talks

Delightful and encouraging to see the excitement and optimism for the future

Outline:

- Planning for the Future – the most recent iterations
- The Future starts Now – on the threshold of opportunity
- Planning for the Future – the next iterations
- Conclusion – the future starts now

The future starts *Now*: 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.**

PLANNING FOR THE FUTURE

the most recent iterations

Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context

Report of the Particle Physics Project Prioritization Panel – May 2014

What did P5 have to say about the future, and future colliders in particular?

P5 strategic plan identified 5 interconnected, science "drivers"

- **Use the Higgs boson as a new tool for discovery.**
- **Explore the physics associated with neutrino mass.**
- **Identify the new physics of Dark Matter.**
- **Test the nature of Dark Energy, and probe the physics of the highest energy scales that governed the very early Universe.**
- **Search for new particles and interactions; new physical principles.**

- Explored at Energy Frontier with colliders

P5: Near-term and Mid-term High-energy Colliders

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.

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.
- 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.
- As the physics case is extremely strong, all scenarios include ILC support at some level through a decision point within the next 5 years.

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.

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. The wakefield technology would be done as an energy upgrade to the ILC, or located elsewhere.

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.

European Strategy Update

May 2013 report:

http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf

High-priority large-scale activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) LHC -> HL-LHC

d) post-LHC accelerator project at CERN

e) ILC

f) Neutrino oscillations

ESU: High-priority large-scale scientific activities

… the following four activities have been identified as carrying the highest priority:

c) LHC → HL-LHC

The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.

Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

d) post-LHC accelerator project at CERN
e) ILC
f) Neutrino oscillations

ESU: High-priority large-scale scientific activities

… the following four activities have been identified as carrying the highest priority:

c) LHC -> HL-LHC

d) post-LHC accelerator project at CERN

To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available.

CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.

e) ILC

f) Neutrino oscillations

ESU: High-priority large-scale scientific activities

… the following four activities have been identified as carrying the highest priority:

c) LHC -> HL-LHC

d) post-LHC accelerator project at CERN

e) ILC

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate.

Europe looks forward to a proposal from Japan to discuss a possible participation.

f) Neutrino oscillations

ESU: High-priority large-scale scientific activities

… the following four activities have been identified as carrying the highest priority:

c) LHC -> HL-LHC
d) post-LHC accelerator project at CERN
e) ILC

f) Neutrino oscillations

Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector.

CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan.

Japanese Strategic Planning

February 2012

The Final Report of the Subcommittee on Future Projects of High Energy Physics

Official translation: http://www.jahep.org/office/doc/201202_hecsubc_report.pdf

Japan: Recommendations

The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- **Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider.** In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.

- **Should the neutrino mixing angle θ_{13} be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations.** This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.

It is expected that the Committee on Future Projects, which includes the High Energy Physics Committee members as its core, should be able to swiftly and flexibly update the strategies for these key, large-scale projects according to newly obtained knowledge from LHC and other sources.

+ SuperKEKB + medium/small scale projects

JAHEP statement Oct 2012

In March 2012, the Japan Association of High Energy Physicists (JAHEP) accepted the recommendations of the Subcommittee on Future Projects of High Energy Physics[(1)] and adopted them as JAHEP's basic strategy for future projects. In July 2012, a new particle consistent with a Higgs Boson was discovered at LHC, while in December 2012 the Technical Design Report of the International Linear Collider (ILC) will be completed by a worldwide collaboration.

On the basis of these developments and following the subcommittee's recommendation on ILC, JAHEP proposes that ILC be constructed in Japan as a global project with the agreement of and participation by the international community in the following scenario:

(1) Physics studies shall start with a precision study of the "Higgs Boson", and then evolve into studies of the top quark, "dark matter" particles, and Higgs self-couplings, by upgrading the accelerator. A more specific scenario is as follows:

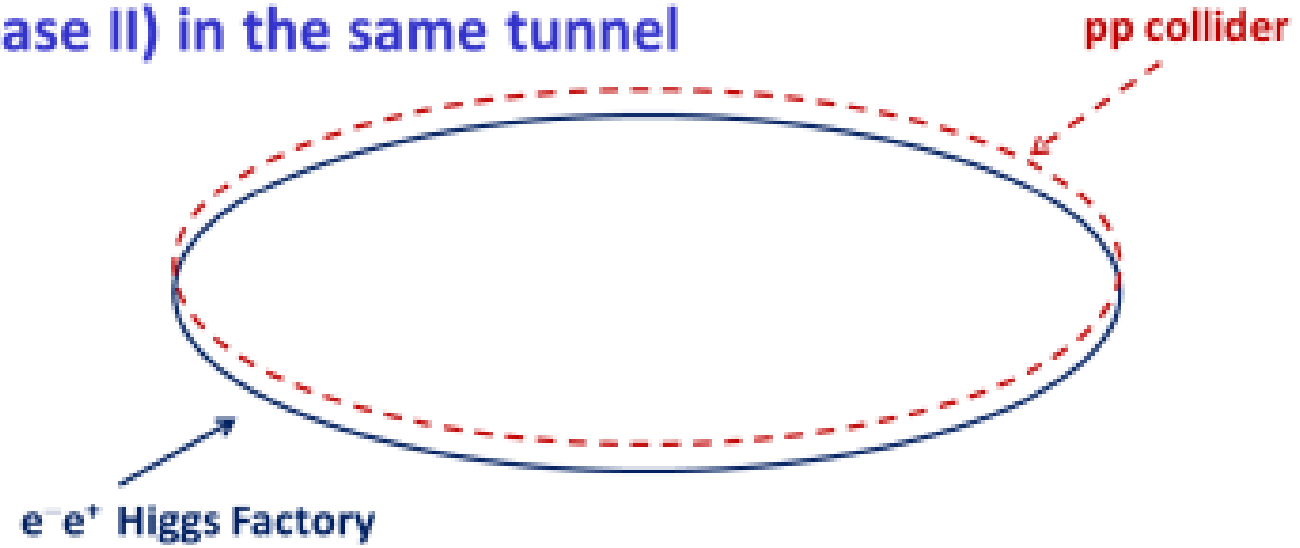
(A) A Higgs factory with a center-of-mass energy of approximately 250 GeV shall be constructed as a first phase.

(B) The machine shall be upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project.

(C) Technical extendability to a 1 TeV region shall be secured.

Chinese Strategic Planning

- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel



Proposed at IHEP, Sept. 2012

Preliminary Conceptual Design Report (**preCDR)**

Document ready for 13th 5 Year Plan (2015)

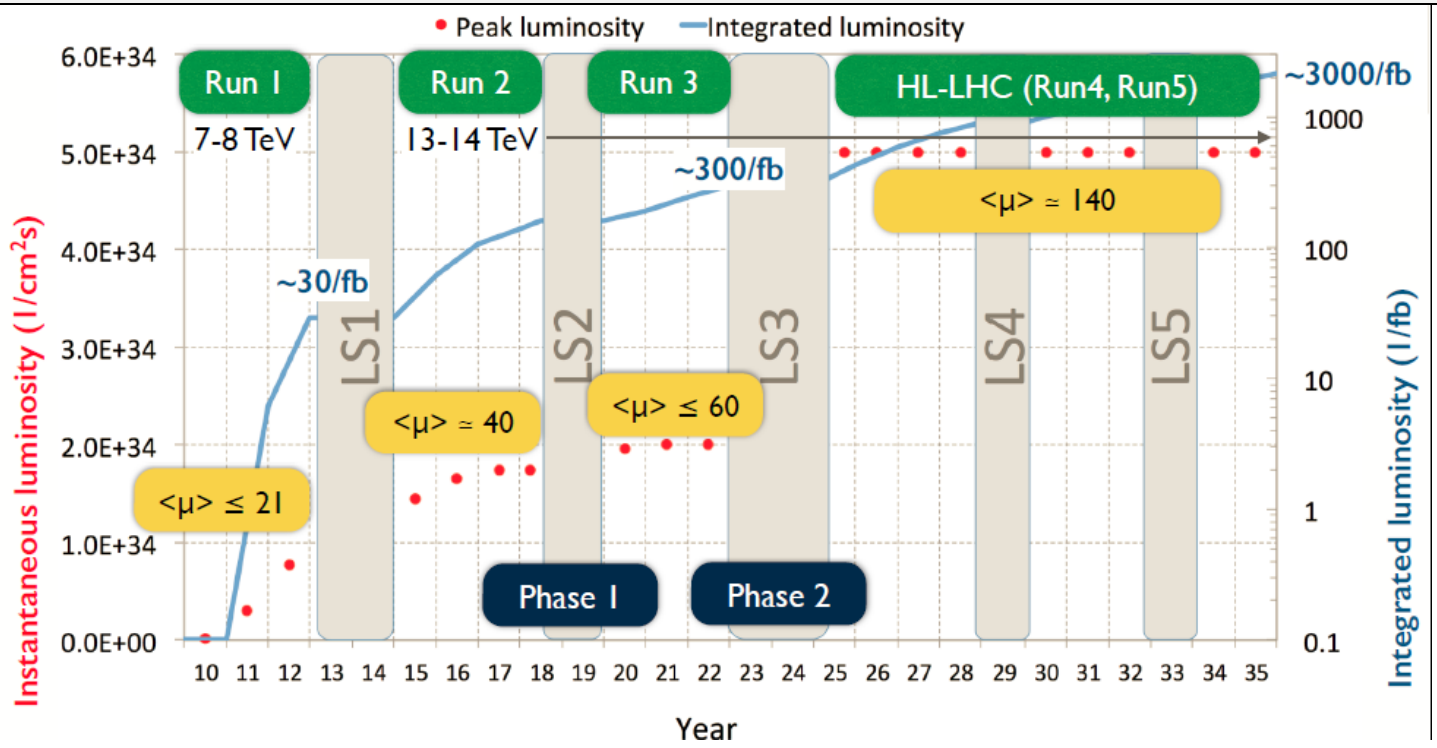
Planning proceeds differently in China

THE FUTURE STARTS NOW

on the threshold of opportunity

The future starts *Now*: 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

The future starts *Now*: 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,
scientifically motivated if LHC/HL-LHC makes a relevant discovery
Upgrade path differs from circular colliders, whose upgrade path is to *pp.*

Status:

- TDR – June 2013 -> *technically ready*
- Japan is pondering whether or not to host ILC
  See H. Murayama's presentation on Tuesday am
- Other nations are anxiously awaiting initiation by Japan of intergovernmental discussions
  Recall ESU and P5 statements
- LCC targeting 2018 construction start

The future starts *Now*:

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.

Why is the FCC-hh/SppC/VLHC "now" ?
Answer: Addressing the tremendous challenges must start now.

Challenges are formidable:

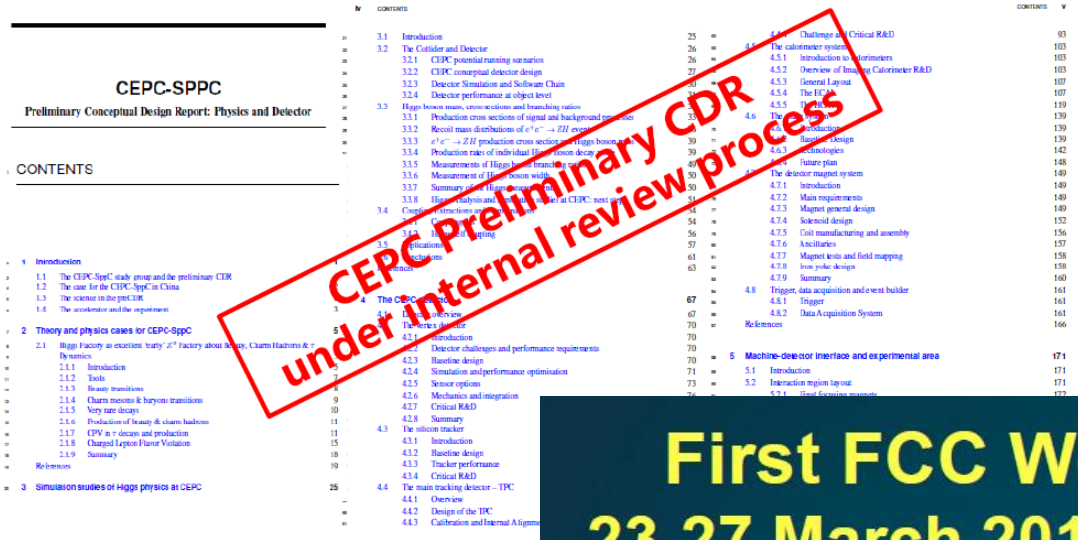
1. **Required technical performance must be achieved at affordable cost.**
   - **Particularly, high field superconducting dipole magnets**
2. **Adequate resources, financial & technical expertise, must be gathered.**
   - **Support will be needed from science community and decision makers**
   - **Scale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

Begin now: Tackle high-priority R&D; Establish critical accel. parameters; Articulate scientific motivation;

The future starts *Now*: Circular *e+e-* Colliders

Preliminary Conceptual Design Report **(preCDR)** physics + exp.

Official webpage: http://cepc.ihep.ac.cn/, preCDR author registration is OPEN



CEPC-SPPC

Preliminary Conceptual Design Report: Physics and Detector

CONTENTS

CEPC Preliminary CDR under internal review process

January

First FCC Week, Washington DC 23-27 March 2015 – DRAFT SCHEDULE

Monday (23.3)		Tuesday (24.3)			Wednesday (25.3)			Thursday (26.3)				Friday (27.3)
Registration	Welcome	FCC-hh Lattice Design & Optics	FCC-ee Detectors	Novel SRF cavity concepts & cryomodules	Machine Configuration & Magnet Specs	FCC-hh Experiments	FCC-ee Lattice Design & Optics	Civil Engineering handling & transport	Magnet Design Options	Cryogenic Beam Vacuum System	Physics & Phenomenology	Summary FCC-hh collider
	Plenary: study overview											Summary FCC-ee collider
												Summary infrastructure
Coffee Break		Coffee Break			Coffee Break			Coffee Break				Coffee Break
Plenary: Physics motivation and overview		FCC-hh Beam physics and technology	FCC-ee Physics studies & Simulations	Novel SRF cavity concepts & cryomodules	Conductor R&D	FCC-hh Experiments	FCC-ee EIR Design & MDI	Reliability, Energy, Controls, IT	Magnet Design Options	Beam Transfer Systems & Instrumentation	Physics & Phenomenology	Summary technologies
Plenary: Machine overview (hh, ee)												Summary FCC-hh experiments
												Summary FCC-ee experiments
Lunch		Lunch			Lunch			Lunch				Conclusions and outlook
												Lunch
Plenary: Infrastructure and Civil Engineering Overview		FCC-hh EIR Design & MDI	FCC-ee MDI	Coating technologies for SRF cavities	Conductor R&D	FCC-hh Experiments	FCC-ee Beam-beam & Energy Calib.	Cryogenics, Safety	Magnet Design Options	Materials & Engineering Breakthroughs	Physics & Phenomenology	International Collaboration Board
Plenary: Magnet and RF overview												
Coffee Break		Coffee Break			Coffee Break			Coffee Break				Coffee Break
Plenary: Special Technologies Overview		FCC-hh Injector Options & Design	FCC-he Parameters, EIR & Detector Design	Higher Efficiency RF Power Generation	TBD	FCC-he Physics Highlights	FCC-ee Injector & Booster Design	TBD	Magnet Cost Model	Magnet & Machine Protection	Physics & Phenomenology	EuroCirCol Coordination Committee
Teatime		Teatime			Teatime			Teatime				Break
Plenary: Study organisation, governance, quality, documentation		Gender Equality working group	EuroCirCol schedule working group	Industry Fast Track	Communications working group	FCC-hh and FCC-ee parameter working group	Technologies R&D working group	Plenary: US Contributions				FCC International Steering Committee
Welcome reception					Workshop Banquet							
					Workshop Banquet							

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:

Exploration + Higgs as a tool for discovery

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

PLANNING FOR THE FUTURE

the next iteration

Future Planning

EUROPE: The next European Strategy Update ~2018

- ESU 2013: "*To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available*."

LHC Run 2 results are potentially important indicator for future directions.

What other news may be available on the time scale of ~2018?

- Fate of ILC in Japan
- Outcome of CEPC proposal to 2015 five-year plan
- Progress on international neutrino program in US
- Dark Matter results ?, Cosmic survey results (incl. on neutrinos) ?

US: The next P5 ~2018-2019

- (What sort of community planning should precede next P5 subpanel?)

JAPAN: The next Japanese HEP project plan is not yet scheduled

Most recent planning cycle offers the global HEP community a strong program whose complementary international pillars are LHC/HL-LHC, ILC, LBNF.

- What sort of synchronization/coordination of plans would be beneficial?

Bottom line: Likely to see another round of planning in 2018-19 timeframe.

A Broader Picture of Possible Future HEP Facilities

	HADRON COLLIDERS	LEPTON COLLIDERS	INTENSITY FRONTIER
CURRENT PROGRAM			
	HL-LHC	**ILC**	**PIP-II**
NEXT STEPS			
	Very high-E p-p collider	**~1 TeV ILC upgrade***	**Multi-MW proton beam**
POSSIBLE FURTHER FUTURE	* dependent upon how physics unfolds		
		Multi-TeV lepton collider*	**Neutrino factory***

An Alternative Picture of Possible Future HEP Facilities

	HADRON COLLIDER	LEPTON COLLIDER	INTENSITY FRONTIER
CURRENT PROGRAM			
	HL-LHC	ILC	PIP-II
NEXT STEPS			
	Very hi-E p-p collider	~1 TeV ILC upgrade	Multi-MW proton beam
POSSIBLE FURTHER FUTURE			
		Multi-TeV lepton collider	Neutrino factory

	HADRON COLLIDER	LEPTON COLLIDER	INTENSITY FRONTIER
CURRENT PROGRAM			
	HL-LHC	~~ILC~~ CEPC/FCC	PIP-II
NEXT STEPS			
	Very hi-E p-p collider	~~~1 TeV ILC upgrade~~	Multi-MW proton beam
POSSIBLE FURTHER FUTURE			
		Multi-TeV lepton collider	Neutrino factory

ILC -> CEPC or FCC-ee

Notes:

- No upgrade path to 1 TeV
- CEPC no physics reach above Higgs
- Very high-energy p-p collider queued in time after CEPC/FCC-ee

A Look Ahead: Multi-TeV Lepton Collider

A multi-TeV lepton collider could be an e+e- collider or a muon 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 lepton collider, but we are currently without such strong motivation (or knowledge of the required energy).

Nevertheless, appropriate levels of R&D could be invested

- In part to prepare to realize such a machine if warranted
- In part because it is exciting accelerator science R&D and excellent training for accelerator scientists

Brief Conclusions

The Future Starts Now, with facilities already in the plans

- **LHC Run 2 → Run 3 → HL-LHC**
- **ILC**

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, VLHC 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;**
    - **Establish critical accellerator parameters;**
    - **Articulate the scientific motivation;**

Thank you again to the organizers, on behalf of all the participants.