

# “HEP in the LHC Era”

Where is HEP & Where is it going?

*Perspective on facilities*

*Phenomenology 2014 Symposium*

*Pittsburgh; May 5-7, 2014*

Andrew J. Lankford

*University of California, Irvine*

# HEP in the LHC Era

**New results influence & guide next steps in HEP exploration,**  
(and guide R&D for future steps).

- **Higgs boson**

**Higgs as a new tool for discovery,**  
**complementary to searches for new particles at high-energy**  
→ a rich program at LHC (→HL-LHC) then ILC (& CepC, FCC-ee)

- **$\theta_{13}$  is large**

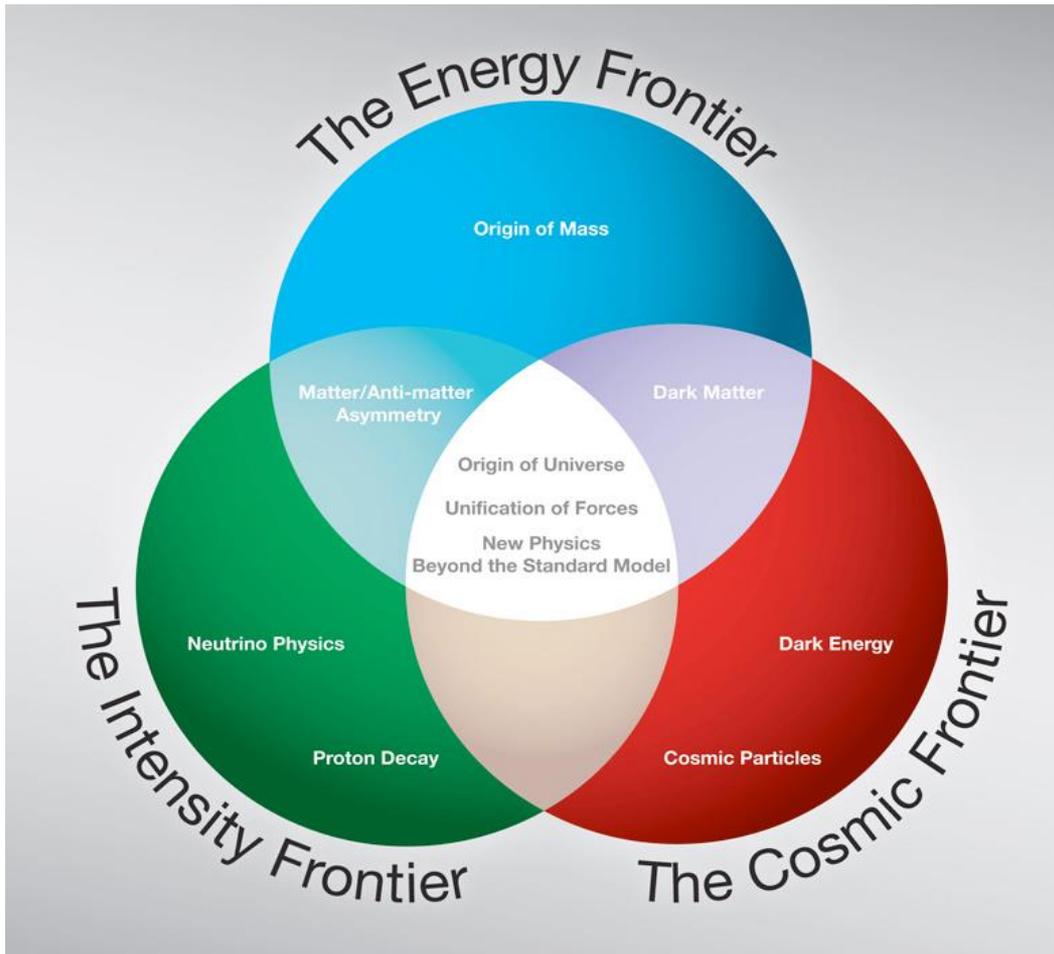
**Mass Hierarchy & CP Violation in lepton sector is likely in reach**  
**of next generation long-baseline neutrino experiments**  
→ a rich neutrino program at T2K & NOvA then HyperK & LBNE

- **BICEP2 result**

**Suggestive evidence for inflationary gravitational waves**  
→ a rich program of cosmic surveys, particularly in CMB

# Vision of 2008 P5 Strategic Plan :

*Address fundamental questions about the laws of nature & the cosmos through a strong, integrated program at the 3 frontiers*



**The three frontiers of research form an interlocking framework.**

*“The panel recommends a strong, integrated research program at the three frontiers of the field: the Energy Frontier, the Intensity Frontier and the Cosmic Frontier.”*

**Other features:**

- continuously produces important results on each frontier
- harmonizes with the worldwide program

*Particle physics is driven by  
compelling scientific questions.*

# SNOWMASS CSS 2013

## ON THE MISSISSIPPI

### JULY 29 – AUGUST 6, 2013



ORGANIZED BY THE DIVISION OF PARTICLES AND FIELDS OF THE APS  
HOSTED BY THE UNIVERSITY OF MINNESOTA

#### STUDY GROUPS

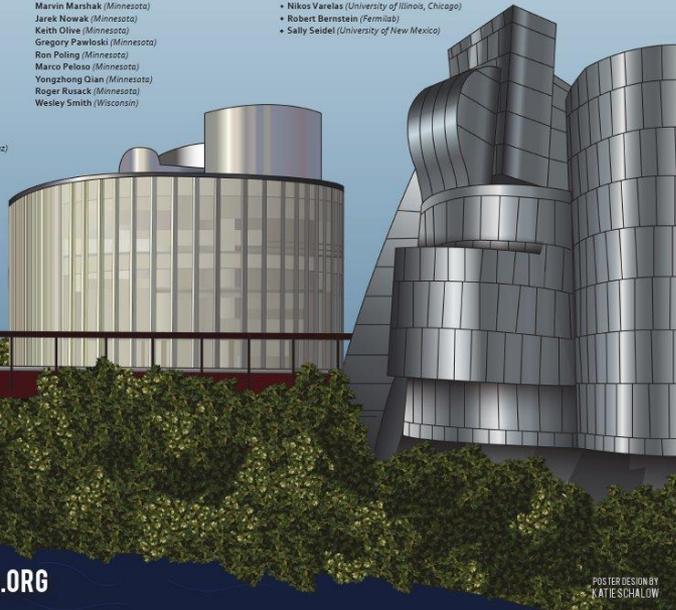
Energy Frontier  
Chip Brock (Michigan State),  
Michael Peskin (SLAC)  
Intensity Frontier  
JoAnne Hewett (SLAC),  
Harry Weerts (Argonne)  
Cosmic Frontier  
Jonathan Feng (University of California, Irvine),  
Steve Ritz (University of California, Santa Cruz)  
Frontier Capabilities  
William Barletta (MIT),  
Murdock Gilchrist (LBNL)  
Instrumentation Frontier  
Marcel Demaree (Argonne),  
Howard H. Nelson (Rice, Halyoke),  
Ron Lipton (Fermilab)  
Computing Frontier  
Lothar Bauer (Fermilab),  
Steven Gottlieb (Indiana)  
Education and Outreach  
Marge Burdeen (Fermilab),  
Dan Cronin-Hennessy (Minnesota)  
Theory Panel  
Michael Dine (University of California, Santa Cruz)

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Dan Cronin-Hennessy (Minnesota, Chair)  
Prisca Cushman (Minnesota)  
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Alec Hahn (Minnesota, Duluth)  
Ken Heller (Minnesota)  
Jody Kaplan (Minnesota)  
Yuichi Kubota (Minnesota)  
Jeremy Mans (Minnesota)  
Bridget McCoy (Minnesota)  
Marvin Marshak (Minnesota)  
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Keith Olive (Minnesota)  
Gregory Pawloski (Minnesota)  
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Yongzhong Qian (Minnesota)  
Roger Rusack (Minnesota)  
Wesley Smith (Wisconsin)

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• Nikos Varelas (University of Illinois, Chicago)  
• Robert Bernstein (Fermilab)  
• Sally Seidel (University of New Mexico)



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POSTER DESIGN BY  
KATIE SCHALOW

**Year-long, in detail study;  
Community-driven (APS DPF)**

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

**Not a prioritization,  
but scientific judgments**

#### Deliverables:

**“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**

*Particle physics is driven by  
compelling scientific questions.*

***Snowmass identified these questions,  
and the opportunities to address them.***

# Compelling Scientific Questions

## from Snowmass CSS 2013

1. How do we understand the **Higgs boson**? What principle determines its couplings to quarks and leptons? Why does it condense and acquire a vacuum value throughout the universe? Is there one Higgs particle or many? Is the Higgs particle elementary or composite?
2. What principle determines the **masses and mixings of quarks and leptons**? Why is the mixing pattern apparently different for quarks and leptons? Why is the CKM CP phase nonzero? Is there CP violation in the lepton sector?
3. Why are **neutrinos** so light compared to other matter particles? Are neutrinos their own antiparticles? Are their small masses connected to the presence of a very high mass scale? Are there new interactions invisible except through their role in neutrino physics?
4. What mechanism produced the **excess of matter over anti-matter** that we see in the universe? Why are the interactions of particles and antiparticles not exactly mirror opposites?
5. **Dark matter** is the dominant component of mass in the universe. What is the dark matter made of? Is it composed of one type of new particle or several? What principle determined the current density of dark matter in the universe? Are the dark matter particles connected to the particles of the Standard Model, or are they part of an entirely new dark sector of particles?
6. What is **dark energy**? Is it a static energy per unit volume of the vacuum, or is it dynamical and evolving with the universe? What principle determines its value?
7. What did the universe look like in its earliest moments, and how did it evolve to contain the structures we observe today? The **inflationary universe** model requires new fields active in the early universe. Where did these come from, and how can we probe them today?
8. Are there additional forces that we have not yet observed? Are there additional quantum numbers associated with **new fundamental symmetries**? Are the four known forces unified at very short distances? What principles are involved in this unification?
9. Are there **new particles at the TeV energy scale**? Such particles are motivated by the problem of the Higgs boson, and by ideas about space-time symmetry such as supersymmetry and extra dimensions. If they exist, how do they acquire mass, and what is their mass spectrum? Do they carry new sources of quark and lepton mixing and CP violation.
10. Are there **new particles that are light and extremely weakly interacting**? Such particles are motivated by many issues, including the strong CP problem, dark matter, dark energy, inflation, and attempts to unify the microscopic forces with gravity. What experiments can be used to find evidence for these particles.
11. Are there **extremely massive particles** to which we can only couple indirectly at currently accessible energies? Examples of such particles are seesaw heavy neutrinos or GUT scale particles mediating proton decay.

*Particle physics is driven by  
compelling scientific questions.*

*Snowmass identified these questions, and the  
opportunities to address them.*

***P5 was appointed on behalf of the community  
to prioritize these opportunities  
within real-world financial constraints.***

*(Particle Physics Project Prioritization Panel)*

# P5 – Scientific Drivers of HEP

**P5 has identified 5 interconnected, scientific “drivers”**

- “Driver” = a compelling line of inquiry that shows great promise for major progress over the next 10-20 years.
- Each has the potential to be transformative. Expect surprises.
- **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.**

These drivers are intertwined, possibly even more deeply than we currently understand. A selected set of different experimental approaches, which reinforce each other, is required. This effort also opens important discovery space beyond the drivers.

*Particle physics is driven by compelling scientific questions.*

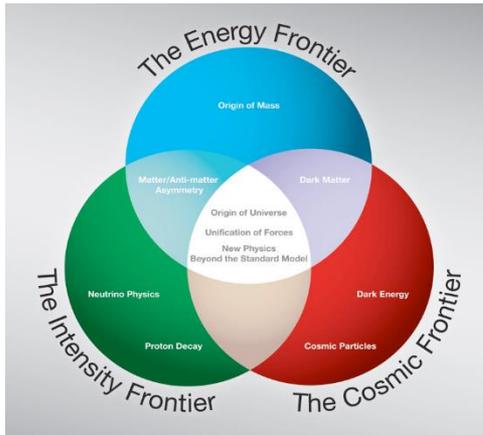
*Snowmass identified these questions, and the opportunities to address them.*

*P5 was appointed on behalf of the community to prioritize these opportunities within real-world financial constraints.*

*From the questions, P5 has identified 5 drivers of the field.*

# Scientific Drivers & Frontier Techniques

The techniques used to address the drivers are summarized by 3 frontiers.



## Energy Frontier

Characterized by very high-energy accelerators

- Hadron colliders (pp)
- Lepton colliders (e+e-)

## Intensity Frontier

Characterized by very high-power accelerators

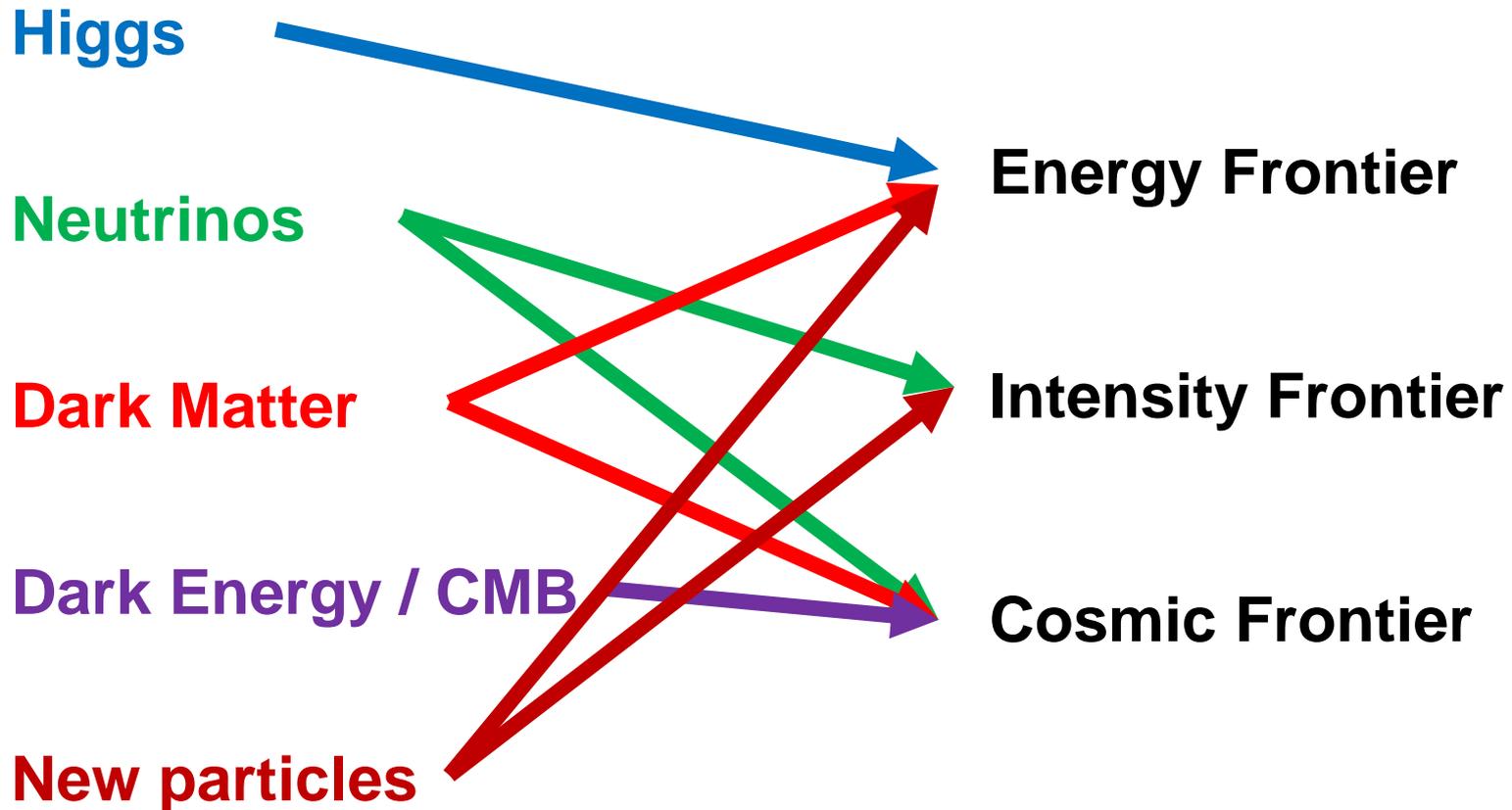
- Neutrino physics
- Precision physics

## Cosmic Frontier

Not accelerator-based

- Dark Matter
- Cosmic surveys: dark energy & inflation

# Science Drivers & Frontier Techniques



# **Sketches of the facets of the present program and Some opportunities for the future program**

Opportunities are generally those identified by  
the Snowmass study

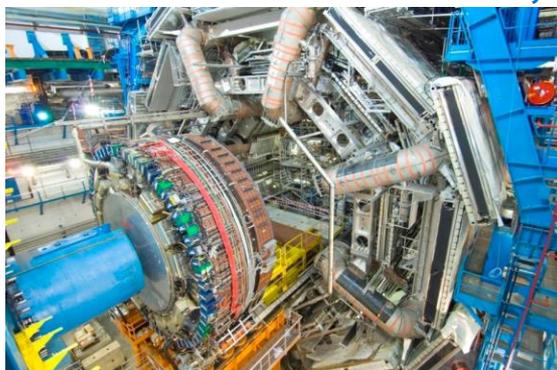
Organized by frontier, but note interplay  
between frontiers

# **ENERGY FRONTIER**

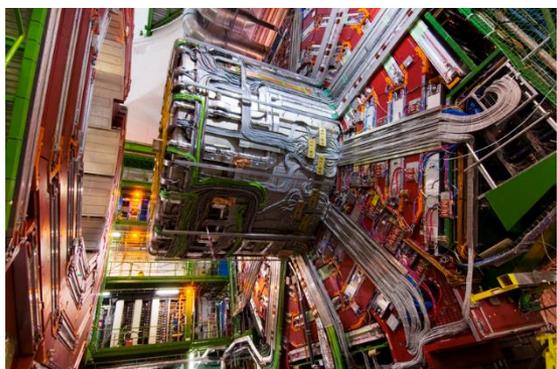
# U.S. at the Energy Frontier – Status

## 1) Exploiting the LHC

- LHC has been one of largest investments of U.S. in HEP ever.
- U.S. participates in ATLAS, CMS, LHCb, ALICE & accelerator
- 35-40% of HEP research;



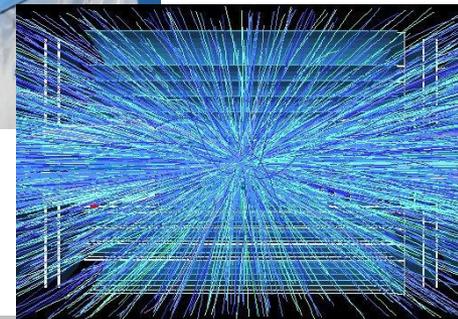
**US ATLAS:** 44 institutions  
376 PhD authors (20%); 175 students



**US CMS:** 49 institutions  
426 PhD authors (31%); 247 students

## 2) Preparing for LHC upgrades

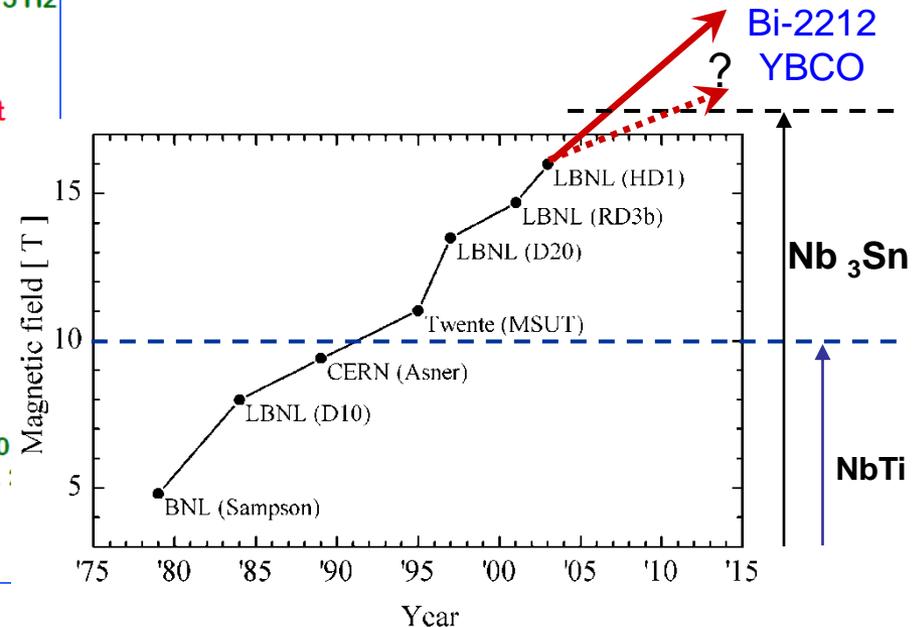
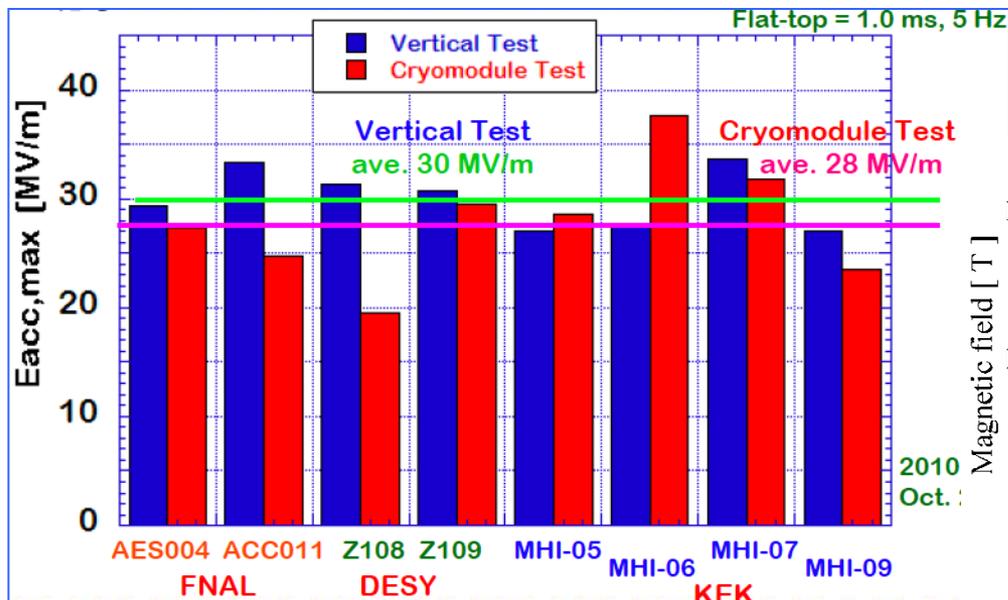
- Future physics capabilities are promising
- Phase I - detector upgrades  
U.S. transitioning from R&D to Construction
- Phase II: HL-LHC - accelerator & detector upgrades  
U.S. in active R&D on greatest technical challenges
  - *E.g.*, accelerator – Nb<sub>3</sub>Sn quadrupole magnets
  - *E.g.*, experiments – silicon trackers



# Accelerator R&D for Future EF Options

Performing a broad range of R&D for variety of future accelerator options

- **Superconducting RF (ILC)** – bottom left
- **Muon cooling (v factory;  $\mu$ collider)** - right
- **Superconducting dipoles (HE-LHC, VLHC)** – bottom right



# Energy Frontier – Snowmass Vision - I

Discovery of the Higgs boson calls for a three-pronged research program:

1. Determine the properties of the Higgs boson as accurately as possible.
  - This will guide large parts of the future particle physics program.
2. Make precise measurements of the heavy particles W, Z, t, which can carry the imprint of the Higgs field.
3. Search for new particles predicted by models of the H boson and EWSB.

**LHC → HL-LHC** will drive the EF program forward for next 15-20 yrs

- Precision study of Higgs properties at the few percent level
- Search for new particles
- Probe for new dynamics of W, Z, H at TeV energies
- Study rare decays using billions of top quarks

**ILC** continuing the EF program with a lepton collider

- Sub-percent, model-independent study of Higgs properties
- Improved precision in knowledge of W, Z, t;  
well enough to allow discovery of new physics effects
- New particle searches complementary to LHC

# Energy Frontier – Snowmass Vision - II

**Other options for high-energy colliders – a look beyond the LHC & ILC**

- **Circular e+e- colliders**
- **Muon colliders**
- **Photon colliders**
- **100-TeV class hadron collider**
  - **A large step in energy**
  - **Great potential for new insights into EWSB and DM**
- **Accelerator and Detector capabilities to enable**

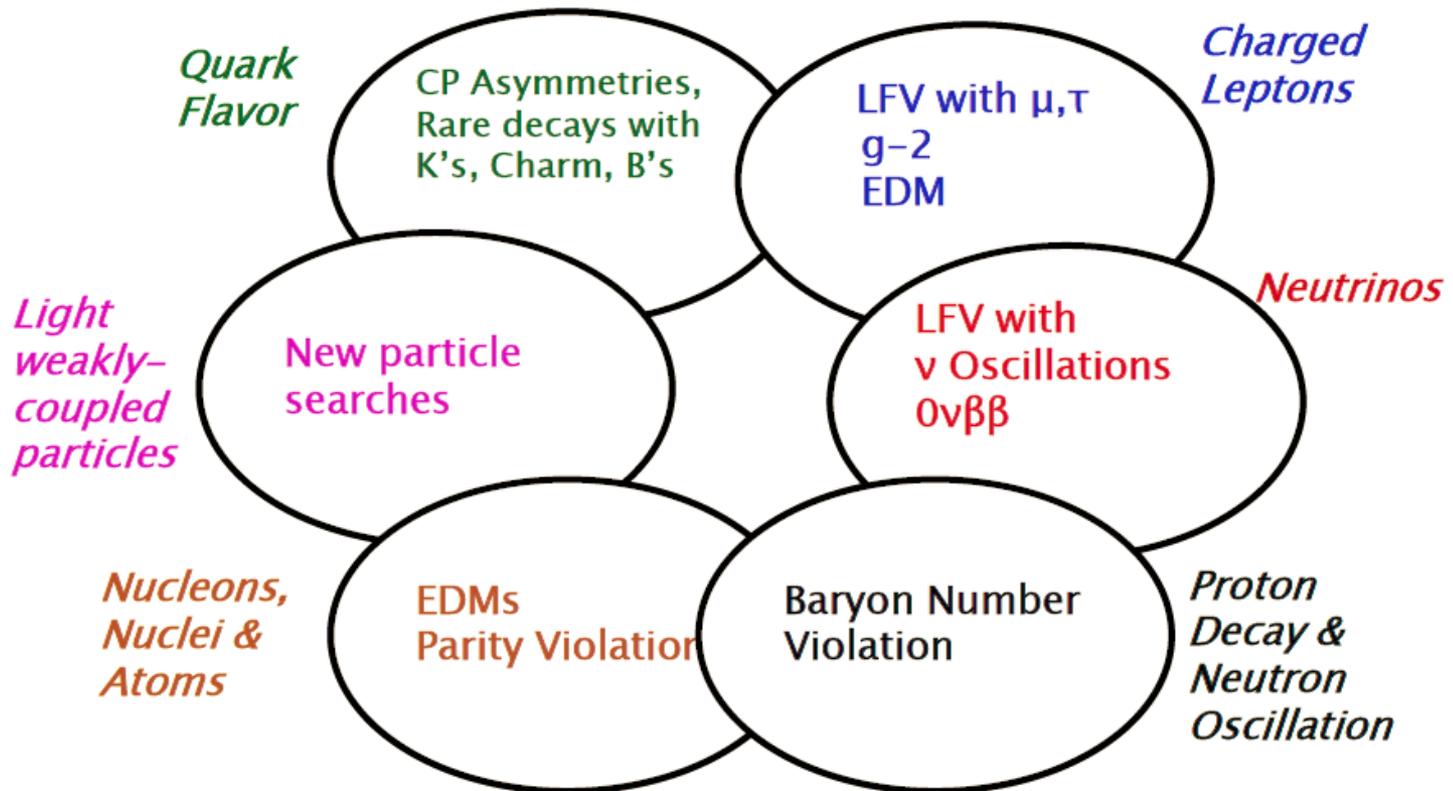
**Large circular colliders are (once again) attracting much interest worldwide.**

- **Studies are being initiated for e+e- and pp options.**
  - **VLHC - Snowmass**
  - **FCC study – Europe**
  - **CEPC + SppC - China**
- **Identify & address R&D on enabling technologies in a global effort.**

# **INTENSITY FRONTIER**

# The Intensity Frontier Program

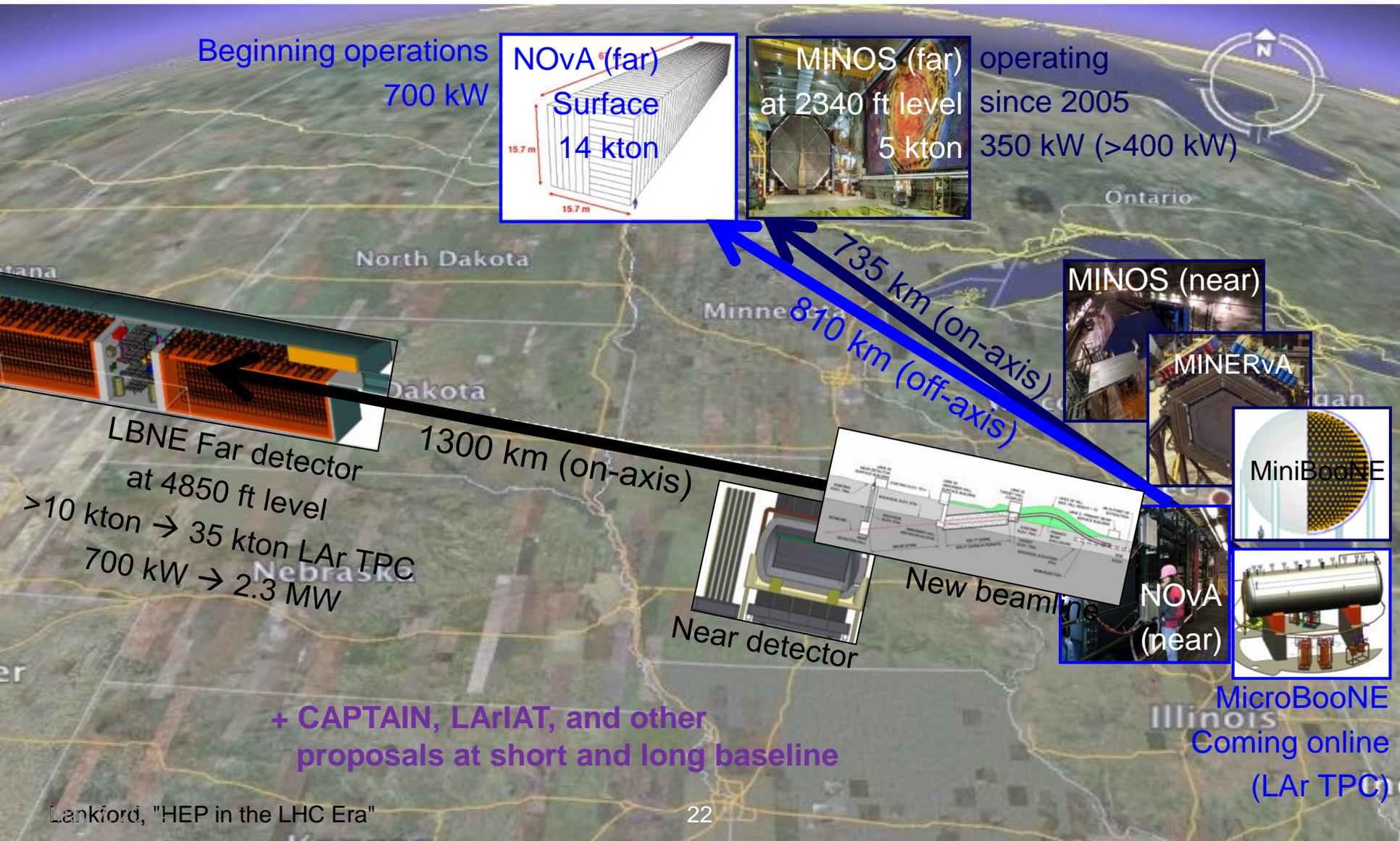
The Intensity Frontier is a broad and diverse, yet connected, set of science opportunities



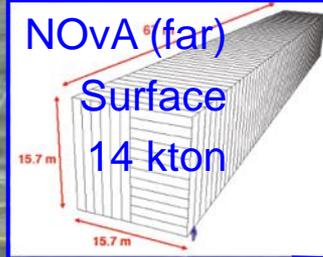
from Hewett & Weerts

*Intensity Frontier*  
**NEUTRINO PROGRAM**

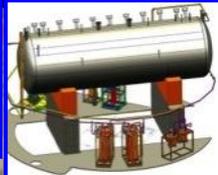
# Evolution of U.S. Neutrino Experiments



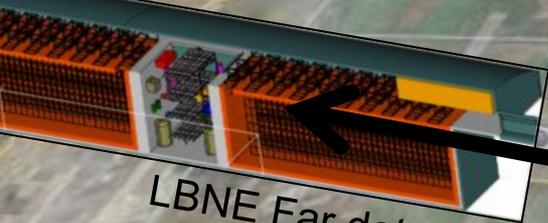
Beginning operations  
700 kW



operating since 2005  
350 kW (>400 kW)



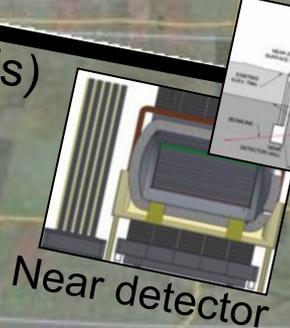
Coming online (LAr TPC)



LBNE Far detector  
at 4850 ft level  
>10 kton → 35 kton LAr TPC  
700 kW → 2.3 MW

1300 km (on-axis)

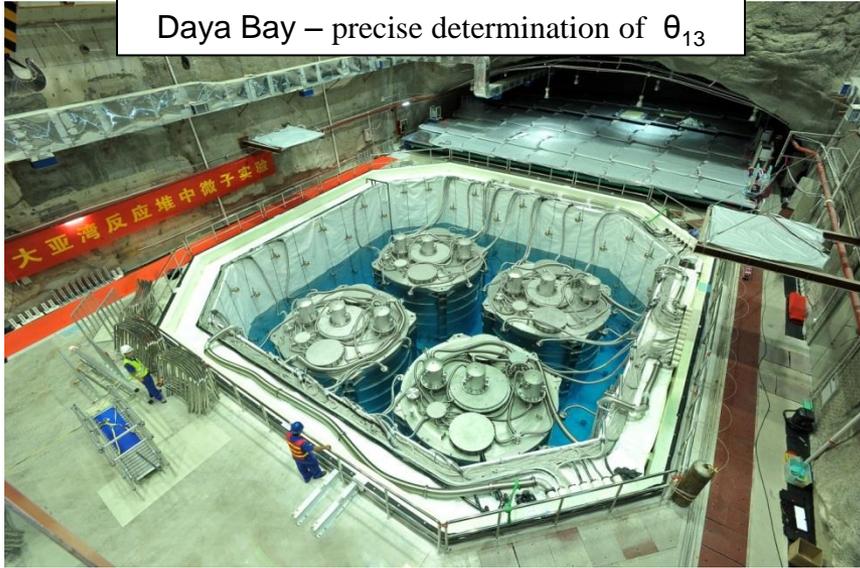
735 km (on-axis)  
810 km (off-axis)



+ CAPTAIN, LArIAT, and other proposals at short and long baseline

# Ongoing Neutrino Program beyond Fermilab

with U.S. participation



Daya Bay – precise determination of  $\theta_{13}$

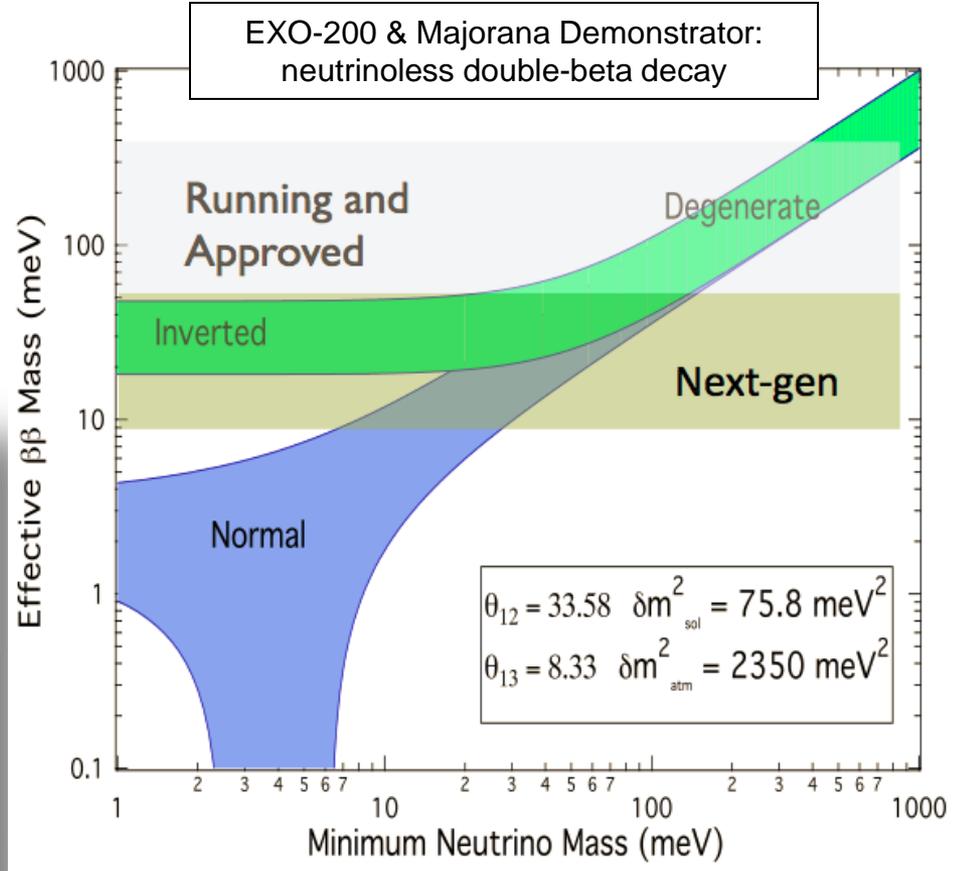


SuperK/T2K:  
long-baseline oscillations  
atmospheric neutrinos  
+ proton decay  
+ supernova search



Super-Kamiokande

Neutrino mixing/masses,  
Lepton number non-  
conservation...



$0\nu 2\beta$  stewarded by DOE NP

# Neutrino Program – Snowmass Vision

Measurement of  $\theta_{13}$  tells us that determination of two fundamental properties of neutrinos is within reach:

- Neutrino mass hierarchy (MH)
- Whether CP is violated (CPV)

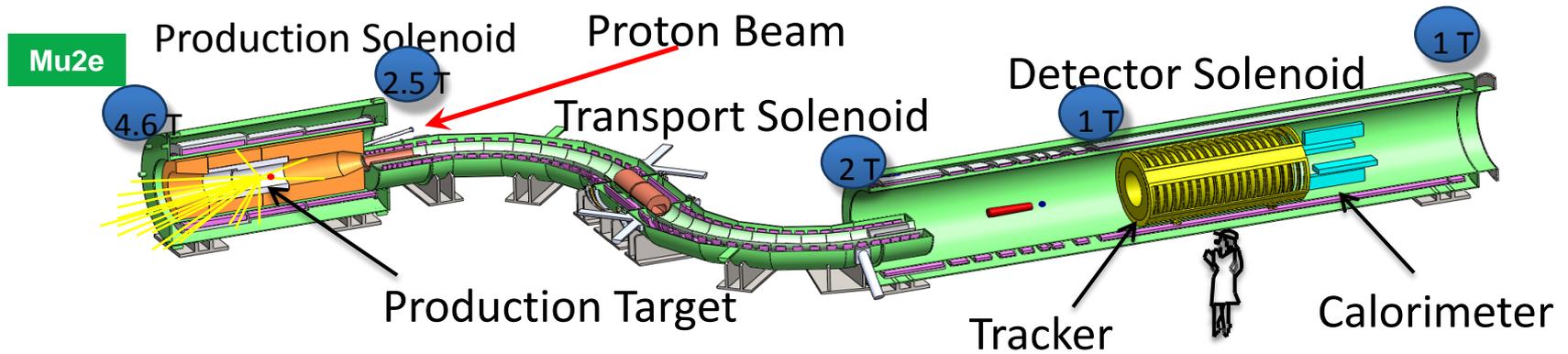
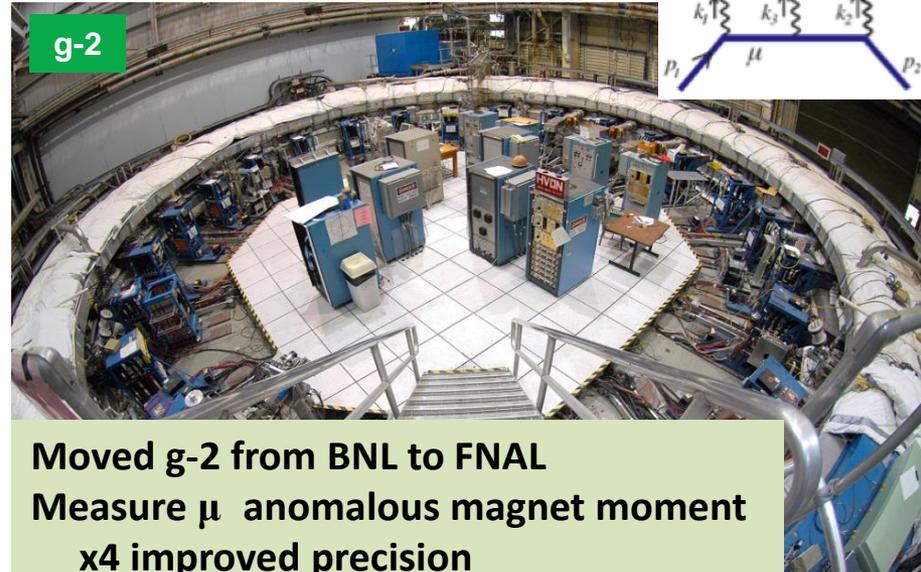
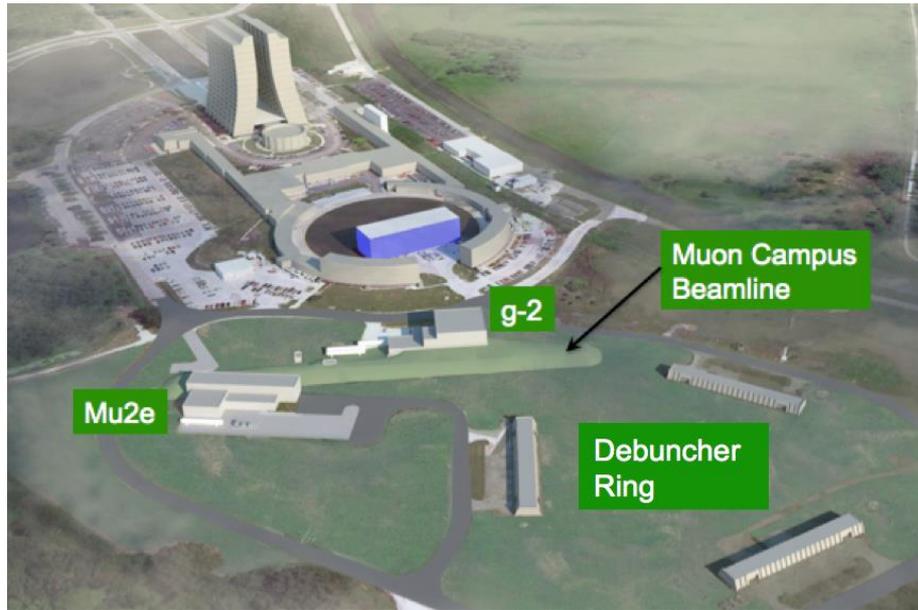
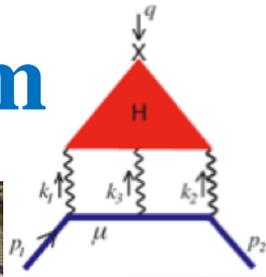
Rich program:

- **LBNE**
  - MH; positioned to determine if CPV
  - w/ multi-megawatt beam, study CPV with conclusive accuracy
  - Atmospheric neutrinos, proton decay, supernova measurement
- Experiments in Antarctic ice PINGU/IceCube to explore MH
- Reactor experiments for precision measurement of  $\theta_{13}$  and explore MH
- Testing 3 neutrino flavor paradigm w/ short-baseline experiments + LBNE
- Neutrinos have left their imprint on the history of evolution of the universe. Cosmic surveys shed light on neutrinos, e.g. absolute mass scale and number of neutrino species.
- Neutrinoless double-beta decay
  - Reaching to determine whether neutrinos are Dirac or Majorana

*Intensity Frontier*

**Flavor Physics:**  
***Quarks & Leptons***

# Emerging Fermilab Muon Program



**Mu2e to explore charged lepton mixing via conversion of  $\mu \rightarrow e$  in field of nucleus**

# Quark Flavor Physics in Japan

**SuperKEKB**

Redesign the lattice to squeeze theittance (replace short dipoles with longer ones, increase wiggler cycles)

Installation of 100 new LER dipole magnets completed.

TiN coated beam pipe with antechambers

Beam pipe production at BINP

Beam pipes after baking and TiN coating in a stock area.

SC final focus: Successfully tested without any quench up to 2157A, well over the design value for nominal operation.

ARES cavities moved from HER to LER, and wiggler magnets for HER installed in D5 Oho straight section.

Low emittance positrons to inject

Damping ring

Low emittance gun

Low emittance electrons to inject

Add / modify higher beams

Positron source

New positron capture section

New beam pipe & bellows

New IR

Belle II

$e^- 2.6 \text{ A}$

$e^+ 3.6 \text{ A}$

(NEG Pump)

Beam

SR

[SR Channel]

[Beam Channel]

**Belle II Detector Upgrade**

7.4 m

CSi(Tl) EM calorimeter: waveform sampling electronics, pure CsI for end-caps

RPC  $\mu$  &  $K_L$  counter: scintillator + Si-PM for end-caps

MPI, Bonn, Heidelberg, Valencia, Karlsruhe, Charles, DESY, Vienna, KEK, IPMU U-Tokyo, Tohoku, TIFR, Melbourne, Krakow

4 layers DS Si Vertex Detector  $\rightarrow$

2 layers PXD (DEPFET)

4 layers DSSD

Central Drift Chamber: smaller cell size, long lever arm

KEK, Taiwan, RCNP, Viet Nam, Malaysia, Chiang Mai, ...

ITEP, Virginia, KEK, Hawaii, Indiana, Wayne state, ...

Nagoya, Toho, Chiba, Niigata, Hawaii, Cincinnati, PNNL, KEK, Tokyo metro, Ljubljana, ...

PID system

Time-of-Propagation counter (barrel)

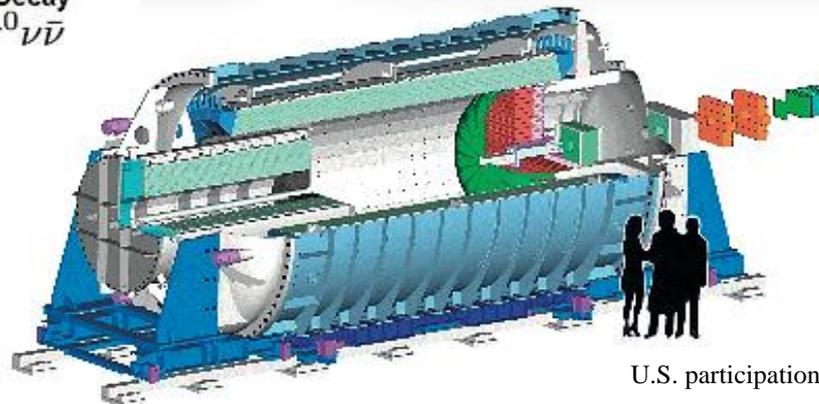
prox. focusing Aerogel RICH (forward)

U.S. participation

**Rare Kaon Decay**

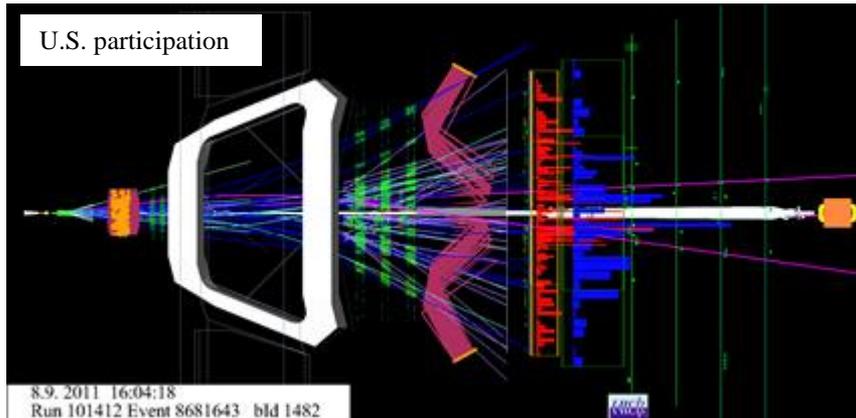
$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

U.S. participation



# Flavor Physics in Europe

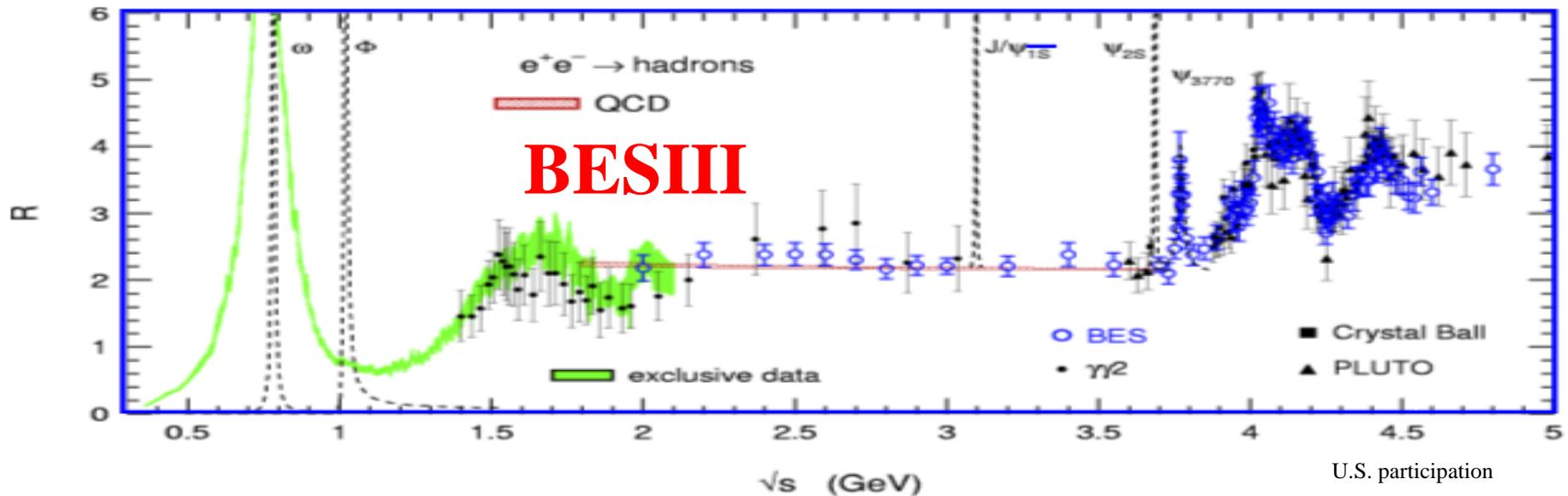
B physics at CERN - *LHCb*



Muon physics at PSI - *MEG*



# Quark Flavor Physics in China



# Precision Physics – Snowmass Vision

## Flavor physics: quarks & leptons

- probes of new physics at very high energy scales

- Fermilab accelerator complex
  - Muon anomalous magnetic moment  $g-2$
  - Search for muon-to-electron conversion  $\text{Mu}2e$
  - Rare K decays - ORKA proposal
- International opportunities at colliders
  - LHCb at LHC
  - Belle II at KEK
  - BES III at IHEP Beijing

## Electric dipole moments (EDMs)

- would violate CP

- A recent renewed focus

## Light, weakly coupled particles

- theoretically inspired, DM

- Searches possible with modest experiments in existing intense beams

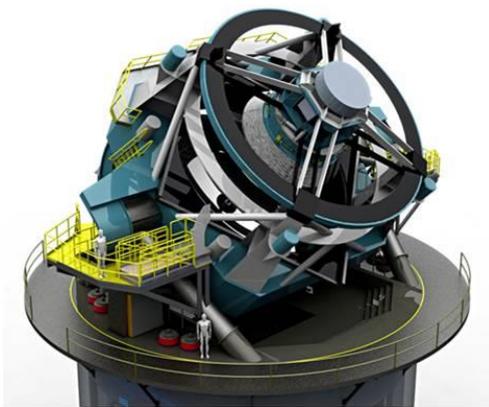
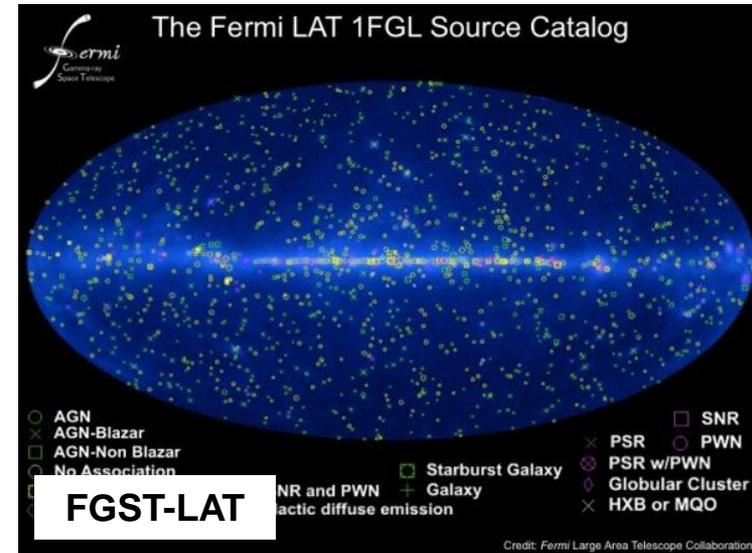
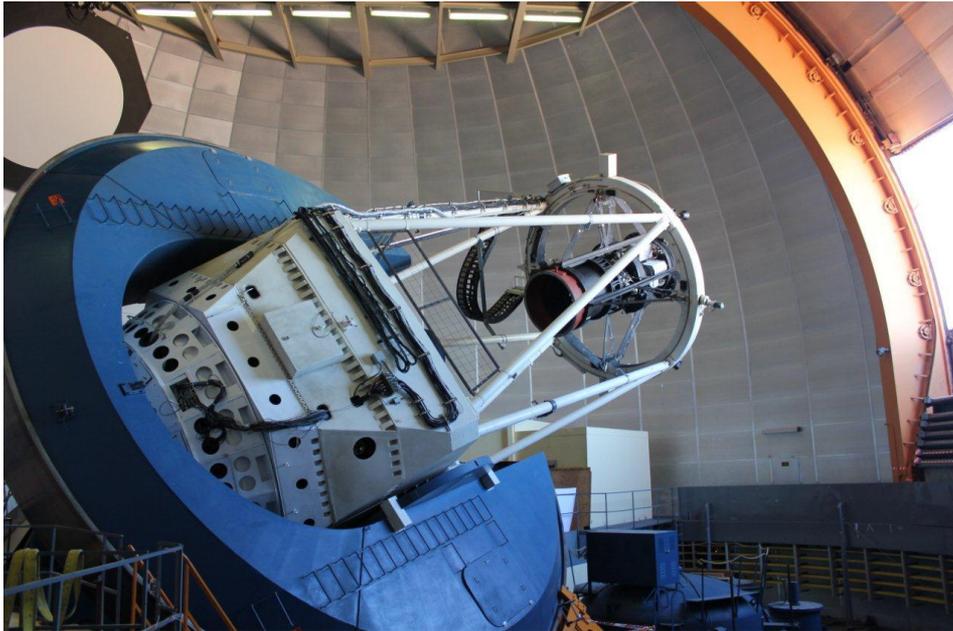
# Fermilab Proton Improvement Plan II

## Summary

- The Fermilab accelerator complex can be upgraded to establish LBNE as the leading long-baseline program in the world, with  $>1$  MW at startup (2025)
- The Proton Improvement Plan-II (PIP-II) is a complete, integrated, cost effective concept, that meets this goal, while
  - leveraging U.S. superconducting rf investment,
  - attracting international partners,
  - providing a platform for the long-term future
- PIP-II retains flexibility to eventually realize the full potential of the Fermilab complex
  - LBNE  $>2$  MW
  - Mu2e sensitivity  $\times 10$
  - MW-class, high duty factor beams for rare processes experiments
- We look forward to a positive recommendation from P5, and are in a position to move forward expeditiously.

# **COSMIC FRONTIER**

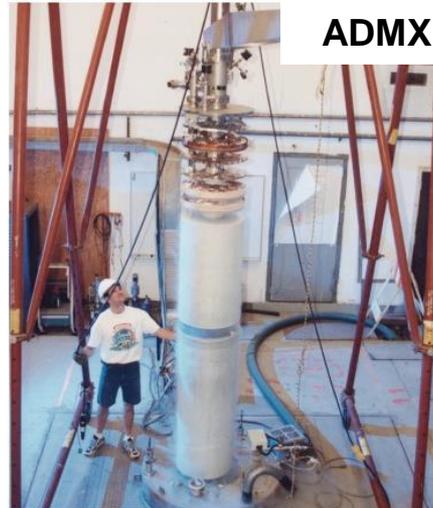
# Some Cosmic Frontier Experiments



**LSST**



**CDMS**



**ADMX**



**AMS**

# Cosmic Frontier – Snowmass Vision

## Dark matter program

- Complementary techniques for a comprehensive campaign:
  - Direct detection
  - Indirect detection (gamma rays, neutrinos, antimatter)
  - Accelerator-based searches
  - Astrophysical surveys
- An active program in the U.S. and other regions
- Search for first non-gravitational signals of dark universe; open door to exploring particle properties of DM

## Cosmic surveys

- Dark energy
  - New tests of the behavior of dark energy & general relativity over a wide range of distance and cosmic time scales
- Cosmic microwave background
  - Probe the physics of inflation (note exciting new BICEP2 result)
- Shed light on neutrino MH, sum of masses, # of light neutrinos

## Cosmic particles

- Proton interactions at energies beyond the LHC
- Neutrinos produced in interactions of cosmic rays with CMB

# Conclusion

## Particle physics has a broad and vibrant program

- A program to address 5 interconnected, scientific drivers
- 3 frontiers of research, supported by theory, accelerator R&D, computing
- Partnerships with other agencies and nations; Experiments in the U.S. and abroad

## Strategic planning for US HEP is in progress; P5 report to HEPAP May 22<sup>nd</sup>

## Particle physics has exciting opportunities.

Recent HEP results  $\Rightarrow$  HEP is at an exciting time, of momentous opportunity  
Significant, fundamental scientific questions are ready to be addressed.  
Concepts and technologies exist to address these questions.

## The challenge (the biggest challenge) is fiscal.

The scientific program required to address all the most compelling questions of the field is beyond the financial and technical resources of any one nation or region;

## A well-formulated global vision/program is needed to address this challenge.

The capability to address these questions in a comprehensive fashion is with reach of a coordinated global program.

## We seek to:

Pursue the most exciting opportunities wherever they are, and host world-leading facilities that attract the worldwide scientific community.

**BACKUP**

# Energy Frontier - Facilities

## Hadron colliders:

- Tevatron – closed 2011
- LHC operational since ~2010; Phase I LHC expt. upgrades being initiated
- **High Luminosity LHC (HL-LHC)** - in research and development - ~2023 install
- More distant options for higher energy being explored (e.g. HE-LHC, VLHC)

## Lepton colliders:

- **International Linear Collider (ILC hosted in Japan)** – TDR complete; initiative from Japan to host; allows staged approach to  $E_{\text{cm}}$
- More distant options for higher energy being explored (e.g. CLIC,  $\mu$  collider, TLEP)

# HEP Energy Frontier Experiments

Experiment	Location	CM Energy; Status	Description of Science	# Institutions; # Countries	#U.S. Institutions	#U.S. Coll.
DØ (DZero)	Fermilab Tevatron Collider [Batavia, Illinois, USA]	1.96 TeV; Operations ended: Sept. 30, 2011	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics	74 Institutions; 18 Countries	33 Univ., 1 National Lab	192
CDF (Collider Detector at Fermilab)	Fermilab Tevatron Collider [Batavia, Illinois, USA]	1.96 TeV; Operations ended: Sept. 30, 2011	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics	55 Institutions; 14 Countries	26 Univ., 1 National Lab	224
ATLAS (A Toroidal LHC ApparatuS)	CERN, Large Hadron Collider [LHC; Geneva, Switzerland / Meyrin, Switzerland]	7-8 TeV; 13-14 TeV Run 1 ended: Dec. 2012 Run 2 start: 2015	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics, and Heavy-Ion	177 Institutions; 38 Countries	40 Univ., 4 National Labs	583
CMS (Compact Muon Solenoid)	CERN, Large Hadron Collider [LHC; Geneva, Switzerland / Cessy, France]	7-8 TeV; 13-14 TeV Run 1 ended: Dec. 2012 Run 2 start: 2015	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics, and Heavy-Ion	190 Institutions; 42 Countries	49 Univ., 1 National Lab	680

*Tevatron data as of August 2013; LHC data as of December 2013.*

- **Main scientific thrusts**
  - **Tevatron at Fermilab ( $p\bar{p}$  collider): DØ Collaboration, CDF Collaboration**
  - **LHC at CERN (pp collider): CMS Collaboration, ATLAS Collaboration**
- **U.S. is single biggest collaborator in both ATLAS and CMS experiments at LHC**
  - **US-ATLAS: ~20% of the international ATLAS Collaboration**
  - **US-CMS: ~31% of the international CMS Collaboration**
- **Lepton Collider (mainly ILC): initiated small, direct support (~6 FTE) for detector R&D efforts from Energy Frontier research program**
  - **at universities through DOE grant awards**
  - **at Fermilab, and plan for FY15, at SLAC**

# Intensity Frontier - Facilities

## Neutrino physics:

- Long baseline:



- NOvA – physics in 2014; MINOS+
- **LBNE** – CD-1 approval with flexible scope, with enhancements from international collaboration

- Short baseline:



- MINERvA, MicroBooNE
- **nuSTORM**, proposed small experiments – conceptual stage

## Flavor physics in the quark sector:



- LHCb – small but important US participation
- BES III, BELLE-II
- **ORKA** - proposed

## Muon physics:



- **g-2** – CD-1 approved
- **Mu2e** – CD-1 approved

## Proton Improvement Plan:



- PIP - underway; includes 700kw to NuMI beamline
- **PIP II** – recent idea to deliver >1 MW to LBNE on Day 1
- **Further proton complex improvements**

# HEP Intensity Frontier Experiments

Experiment	Location	Status	Description	#US Inst.	#US Coll.
Belle II	KEK, Tsukuba, Japan	Physics run 2016	Heavy flavor physics, CP asymmetries, new matter states	10 Univ., 1 Lab	55
CAPTAIN	Los Alamos, NM, USA	R&D; Neutron run 2015	Cryogenic apparatus for precision tests of argon interactions with neutrinos	5 Univ., 1 Lab	20
Daya Bay	Dapeng Peninsula, China	Running	Precise determination of $\theta_{13}$	13 Univ., 2 Lab	76
Heavy Photon Search	Jefferson Lab, Newport News, VA, USA	Physics run 2015	Search for massive vector gauge bosons which may be evidence of dark matter or explain g-2 anomaly	8 Univ., 2 Lab	47
KOTO	J-PARC, Tokai, Japan	Running	Discover and measure $K_L \rightarrow \pi^0 \nu \bar{\nu}$ to search for CP violation	3 Univ.	12
LArIAT	Fermilab, Batavia, IL	R&D; Phase I 2013	LArTPC in a testbeam; develop particle ID & reconstruction	11 Univ., 3 Lab	38
LBNE	Fermilab, Batavia, IL & Homestake Mine, SD, USA	CD1 Dec 2012; First data 2023	Discover and characterize CP violation in the neutrino sector; comprehensive program to measure neutrino oscillations	48 Univ., 6 Lab	336
MicroBooNE	Fermilab, Batavia, IL, USA	Physics run 2014	Address MiniBooNE low energy excess; measure neutrino cross sections in LArTPC	15 Univ., 2 Lab	101
MINERvA	Fermilab, Batavia, IL, USA	Med. Energy Run 2013	Precise measurements of neutrino-nuclear effects and cross sections at 2-20 GeV	13 Univ., 1 Lab	48
MINOS+	Fermilab, Batavia, IL & Soudan Mine, MN, USA	NuMI start-up 2013	Search for sterile neutrinos, non-standard interactions and exotic phenomena	15 Univ., 3 Lab	53
Mu2e	Fermilab, Batavia, IL, USA	First data 2019	Charged lepton flavor violation search for $\mu N \rightarrow e N$	15 Univ., 4 Lab	106
Muon g-2	Fermilab, Batavia, IL, USA	First data 2016	Definitively measure muon anomalous magnetic moment	13 Univ., 3 Lab, 1 SBIR	75
NOvA	Fermilab, Batavia, IL & Ash River, MN, USA	Physics run 2014	Measure $\nu_\mu$ - $\nu_e$ and $\nu_\mu$ - $\nu_\mu$ oscillations; resolve the neutrino mass hierarchy; first information about value of $\delta_{cp}$ (with T2K)	18 Univ., 2 Lab	114
ORKA	Fermilab, Batavia, IL, USA	R&D; CD0 2017+	Precision measurement of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ to search for new physics	6 Univ., 2 Lab	26
Super-K	Mozumi Mine, Gifu, Japan	Running	Long-baseline neutrino oscillation with T2K, nucleon decay, supernova neutrinos, atmospheric neutrinos	7 Univ.	29
T2K	J-PARC, Tokai & Mozumi Mine, Gifu, Japan	Running; Linac upgrade 2014	Measure $\nu_\mu$ - $\nu_e$ and $\nu_\mu$ - $\nu_\mu$ oscillations; resolve the neutrino mass hierarchy; first information about value of $\delta_{cp}$ (with NOvA)	10 Univ.	70
US-NA61	CERN, Geneva, Switzerland	Target runs 2014-15	Measure hadron production cross sections crucial for neutrino beam flux estimations needed for NOvA, LBNE	4 Univ., 1 Lab	15
US Short-Baseline Reactor	Site(s) TBD	R&D; First data 2016	Short-baseline sterile neutrino oscillation search	6 Univ., 5 Lab	28

# Cosmic Frontier - Facilities

## Dark Matter:



- Generation 2 DM initiated recently; downselect in progress
- **Generation 3 DM** to follow, late in 10-yr period

## Dark Energy:



- **LSST** progressing (CD-1, NSB approved)
- DESI (mid-scale spectroscopic) being initiated
- Possible next generation DE facilities discussed

## CMB:



- Stage 2 - now
- Stage 3 - in development
- **CMB-S4** - in concept

# HEP Cosmic Frontier Experiments

Experiment	Location	Description	Current Status	# Collaborators (# US, HEP)	# Institutions (# US, HEP)	# Countries
<b>Baryon Oscillation Spectroscopic Survey (BOSS)</b>	APO in New Mexico	dark energy stage III (spectroscopic)	operating through FY14 operations started Sept. 2013	230 (150 US, 40 HEP)	(22 US, 8 HEP) 25 (13 US, 9 HEP)	7
<b>Dark Energy Survey (DES)</b>	CTIO in Chile	dark energy stage III (imaging)		300		6
<b>Large Synoptic Survey Telescope (LSST) - Dark Energy Science Collaboration (DESC)</b>	Cerro Pachon in Chile	dark energy stage IV (imaging)	science studies	232 (200 US, 134 HEP)	53 (41 US, 16 HEP)	3
<b>Large Synoptic Survey Telescope (LSST) - LSSTcam Project</b>	Cerro Pachon in Chile	dark energy stage IV (imaging)	CD1 for LSSTcam approved; FY14 Fabrication start ; CD3a May 2014	142 (111 US, 111 HEP)	17 (11 US, 11 HEP)	2
<b>Dark Energy Spectroscopic Instrument (DESI)</b>	KPNO in AZ ??	dark energy stage IV (spectroscopic)	CD0 approved Sept 2012; planning CD1 in FY14	180 (95 US, 72 HEP)	42 (23 US, 18 HEP)	13
<b>Axion Dark Matter eXperiment (ADMX-IIa)</b>	Univ Washington	dark matter - axion search	operating	24 (20 US, 17 HEP)	7 (6 US, 3 HEP)	2
<b>Chicagoland Observatory for Underground Particle Physics (COUPP-60) --&gt; PICO</b>	SNOLab in Canada	dark matter - WIMP search	operating	60 (26 US, 8 HEP)	14 (6 US, 1 HEP)	5
<b>DarkSide-50</b>	LNGS in Italy	dark matter - WIMP search	operating	122 (66 US, 12 HEP)	26 (12 US, 3 HEP)	7
<b>Large Underground Xenon (LUX)</b>	SURF in South Dakota	dark matter - WIMP search	operating	102 (86 US, 56 HEP)	17 (13 US, 9 HEP)	3
<b>Super Cryogenic Dark Matter Search (SuperCDMS-Soudan)</b>	Soudan in Minnesota	dark matter - WIMP search	operating	83 (70 US, 38 HEP)	19 (16 US, 6 HEP)	3
<b>Dark Matter Generation 2 (DM-G2) experiment(s)</b>	TBD	dark matter Gen 2: 1+ direct detection experiments selected in June 2014 to move forward to fabrication	CD0 approved Sept 2012; planning CD1 in FY14			
<b>Very Energetic Radiation Imaging Telescope Array System (VERITAS)</b>	FLWO in AZ	gamma-ray survey	operating	92 (74 US, 32 HEP)	20 (15 US, 5 HEP)	4
<b>Pierre Auger Observatory</b>	Argentina	cosmic-ray	operating	463 (51 US, 12 HEP)	100 (20 US, 5 HEP)	18
<b>Fermi Gamma-ray Space Telescope (FGST)</b>	space-based	gamma-ray survey	June 2008 launch; operating in space	319 (157 US, 73 HEP)	49 (14 US, 3 HEP)	9
<b>Large Area Telescope (LAT)</b>	space-based (on ISS)	gamma-ray survey	May 2011 launch; operating	600	60 (6 US, 2 HEP)	16
<b>Alpha Magnetic Spectrometer (AMS-02)</b>		cosmic-ray	Fabrication; Operations starts late FY2014		31 (16 US, 2 HEP)	
<b>High Altitude Water Cherenkov (HAWC)</b>	Mexico	gamma-ray survey		111 (54 US, 8 HEP)		2

# HEP Project Status

Subprogram	TPC (\$M)	CD Status	CD Date
<b>INTENSITY FRONTIER</b>			
Long Baseline Neutrino Experiment (LBNE)	TBD	CD-1	December 10, 2012
Muon g-2	45	CD-1	December 19, 2014
Mu2e	249	CD-1	July 11, 2012
Next Generation B-Factory Detector Systems (BELLE-II)	16	CD-2/3	April 23, 2014
NuMI Off-Axis Electron Neutrino Appearance Exp't (NO $\nu$ A)	278	CD-3b	October 29, 2009
Micro Booster Neutrino Experiment (MicroBooNE)	19.9	CD-3b	March 29, 2012
Main INjector Experiment for $\nu$ -A (MINER $\nu$ A)	16.8	CD-4	June 28, 2010 [Finished]
Daya Bay Reactor Neutrino Experiment	35.5	CD-4b	August 20, 2012 [Finished]
<b>ENERGY FRONTIER</b>			
LHC ATLAS Detector (Phase-1) Upgrade	33.3	CD-1	October 17, 2013
LHC CMS Detector (Phase-1) Upgrade	33.3	CD-1	October 17, 2013
<b>COSMIC FRONTIER</b>			
Dark Matter (DM-G2)	TBD	CD-0	September 18, 2012
Dark Energy Spectroscopic Instrument (DESI)	TBD	CD-0	September 18, 2012
Large Synoptic Survey Telescope (LSST)	173	CD-1	April 12, 2012
Dark Energy Survey (DES)	35.1	CD-4	June 4, 2012 [Finished]
<b>ADVANCED TECHNOLOGY R&amp;D</b>			
Accelerator Project for the Upgrade of the LHC (APUL)	11.5	CD-4	March 27, 2014 [Finished]
Berkeley Lab Laser Accelerator (BELLA)	27.2	CD-4	January 17, 2013 [Finished]
Facility for Advanced Accelerator Experimental Tests (FAcET)	14.5	CD-4	January 31, 2012 [Finished]

# **PLANNING**

*The future of US HEP*

# Planning for Future of U.S. HEP Program

- **US program presently guided by HEPAP's 2008 P5 Roadmap**
  - A long-range plan for projects, under various budget scenarios
    - projects based in U.S. + U.S. involvement in projects based abroad
  - Plan now 5 years old
  - Important discoveries and progress since 2008 (e.g. Higgs boson,  $\theta_{13}$ )
  - Budget has not been as good as scenarios considered. DUSEL terminated.
- **Looking to the future:**
- **Community planning (“Snowmass”) process**
  - Led by APS Division of Particles & Fields
  - Extended “workshop”, ~year long, allowing detailed studies
  - Culminates in July 29 – August 6 meeting in Minnesota
  - Considers a wide portfolio of activities, beyond major projects
  - ~20 year time horizon
- **Particle Physics Project Prioritization Panel (P5)**
  - Expected after Snowmass process is complete
  - Work with input from Snowmass + budgetary input from DOE/NSF
  - Form strategic plan in various budget scenarios
  - Complete report in 1<sup>st</sup> half 2014(?)
  - HEPAP/P5 is one of few official paths for agencies to gather community input.

# Initiating P5: Context

- **DOE OHEP & NSF MPS have charged the HEPAP Chair to “constitute a new P5 panel to develop an updated **strategic plan** for U.S. high energy physics that can be executed over a **10-year timescale**, in the **context of a 20-year global vision** for the field.”**
- **Particle Physics Project Prioritization Panel (P5)**
  - HEPAP subpanel, appointed by HEPAP Chair
  - 24 members, chosen for their combination of expertise and broad view of field
  - Chaired by Steve Ritz (UC Santa Cruz)
  - Reports to HEPAP, which reviews & approves report and submits to agencies
- **Much has changed since the 2008 P5 report (from the charge) :**
  - “... a need to understand the priorities, ... under more stringent budgets ...”
  - “the recent discovery of what appears to be the long-sought Standard Model Higgs boson and the observation of mixing between all three known neutrino types at unexpectedly large rates have opened up the possibility of new experiments and facilities that can address key scientific questions about the fundamental nature of the universe in new and incisive ways.”
- **Preliminary comments – March; Report - May**

# P5 Budget Scenarios

## Charge to P5 contains 3 budget scenarios for consideration

- “... consider these scenarios not as literal guidance but as an opportunity to identify priorities and make high-level recommendations.”

A. FY2013 budget baseline: flat for 3 years, the +2% per year

B. FY2014 President’s budget request baseline: flat for 3 years, the +3% per year

C. “Unconstrained” budget scenario

Beyond A and B, prioritize projects “... needed to mount a leadership program addressing the scientific opportunities identified by the research community.”  
Identify opportunities.

Note that P5 must address budget scenarios A & B. The current fiscal climate may change in the future though. The P5 plan should allow the field to benefit from realizing more of its ambitions sooner if the climate changes.

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# P5 Preliminary Comments

HEPAP  
13-14 March 2014

S. Ritz

March 2014

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## Topics

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- Review of the key elements of the charge; summary of P5 processes and activities since September
- Context:
  - The evolution of our field since the previous P5 report
  - Big scientific questions and drivers
  - The global nature of our field
- Key elements of strategic planning:
  - Opportunities to address the big scientific questions and how they fit together
  - Budgetary constraints compared with proposed programs
  - National planning in the global context
  - Balancing investments
- Discussion of prioritization criteria
- Steps to completion, and communication planning

March 2014

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## Key Aspects of the Charge

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- Updated strategic plan for the U.S. that can be executed over a 10 year timescale, in the context of a 20 year global vision for the field.
- Appropriate balance of small, mid-scale, and large experiments.
- Technical readiness and feasibility. Estimate time and resources needed.
- Maintain healthy and flexible domestic infrastructure...maintain leadership position...a healthy balance that preserves essential roles and contributions for national laboratories and universities and enables opportunities for global coordination of large initiatives.
- Three budget scenarios. Not literal guidance, but an opportunity to identify priorities and make high-level recommendations.
- Articulate opportunities that can and cannot be pursued, and approximate overall level of support needed in core research and advanced technology R&D.
- A detailed perspective on whether and how the pursuit of major international partnerships might fit into the program in each of the scenarios.
- Effective communications about the excitement, impact, and vitality of particle physics for non-scientific audiences.
- Preliminary comments by March 1, final report by May 1.

March 2014

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## Members

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**Hiroaki Aihara** (Tokyo)

**Marty Breidenbach** (SLAC)

**Bob Cousins** (UCLA)

**André de Gouvea**  
(Northwestern)

**Marcel Demarteau** (ANL)

**Scott Dodelson** (FNAL/  
Chicago)

**Jonathan Feng** (UCI)

**Bonnie Fleming** (Yale)

**Fabiola Gianotti** (CERN)

**Francis Halzen** (Wisconsin)

**JoAnne Hewett** (SLAC)

**Andy Lankford** (UCI)

**Wim Leemans** (LBNL)

**Joe Lykken** (FNAL)

**Dan McKinsey** (Yale)

**Lia Merminaa** (TRIUMF)

**Toshinori Mori** (Tokyo)

**Tatsuya Nakada** (Lausanne)

**Steve Peggs** (BNL)

**Saul Perlmutter** (Berkeley)

**Kevin Pitts** (Illinois)

**Steve Ritz** (UCSC, chair)

**Kate Scholberg** (Duke)

**Rick van Kooten** (Indiana)

**Mark Wise** (Caltech)

**A very dedicated, hardworking panel!**

## Important Changes Since the Previous P5

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- Scientific:
  - Higgs discovered! The Higgs mass is relatively low, pointing the way for next steps and informing choices for long-term planning.
  - The neutrino mixing parameter  $\sin^2(2\theta_{13})$  measured! The value is relatively large, enabling a program of measurements of fundamental properties.
  - Three Nobel Prizes: CKM, Higgs boson, and dark energy.
  - Demonstrates importance of diversity of topic and scale.
- Programmatic:
  - DUSEL did not proceed, SURF continued. JDEM did not proceed.
  - Tevatron collider operations ended.
  - PEP-II/B-factory operations ended.
  - Budgets lower than anticipated.
  - International cooperation continues to be extremely productive, enabling many of the big discoveries driving the field. A model for international science projects.
- These developments play central roles in most of our planning.
- The Snowmass process was very helpful for collecting, assessing, and disseminating the great scientific challenges and opportunities for the field. An expanding sense of unity emerged.

March 2014

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## Particle Physics is Global

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- World-leading countries pursue particle physics:
  - A very successful field of discovery and exploration
  - The questions are profound and exciting, and the techniques are beautiful and useful
  - Attracts great minds, talent, and dedication to a common purpose
- Cooperation and competition are both needed for continued success
  - Large projects require cooperation for technical know-how and the required resources.
  - Competition spurs innovation, speed, and efficiency.
  - The U.S. has leadership roles in both modes.
- Global optimization and cooperation are now critical for progress in several key areas
  - Strong foundations exist (LHC is a model, *e.g.*). Building further international cooperation is an important theme.

March 2014

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## Criteria (I): Overall Program Optimization

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- Science-driven big picture: where we want to go and how to get there.
- Prioritized portfolio for discovery and exploration.
- International context and optimization:
  - Pursue the most important opportunities wherever they are, and host world-leading facilities that attract the worldwide scientific community.
  - Reliable partnerships are essential.
  - Duplication only when significant value added or when competition helps propel us in important directions. When competing, be clearly leading in key ways.
- Health of the field, sustained productivity:
  - Maintain a stream of results while investing in facilities and future capabilities => a balance of project scales.
  - Maintain and develop critical technical and scientific expertise and infrastructure to enable future discoveries.
  - a guideline: total expenditures on projects around 20-25% of total budget; research fraction >~40% for both project data analysis and blue-sky research to explore unplanned new directions.

March 2014

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## Criteria (II): Projects

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- Science first: how does it address key questions in particle physics?
- Discovery space. How might it change the direction of the field, and what is the value of null results?
- When is it absolutely needed, and how does it fit into the larger picture? What does the experiment add that is unique, is it definitive, and/or where might it lead? Are there alternatives?
- Cost vs value.
  - Is the scope well defined and does it match the physics case? For multi-disciplinary/agency projects, does the support match the distribution of science?
  - One main measurement or a preponderance of interesting possible results? Solid result(s) expected or possibly marginal?
  - At what cost/schedule/capability changes does the priority change?
- Take into account previous prioritization and existing commitments. What are the impacts of changes in direction?
- Is the project feasible as proposed? Technical, cost, schedule risks.
- Is U.S. particle physics leadership, or participation, critical, and how?
- What are the other benefits of the project?

March 2014

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## Steps to Completion, Communication Planning

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- Current plan:
  - Internal draft report to HEPAP members ~3 weeks prior to 22 May meeting
    - Aiming for a short report
      - More effective
      - Plenty of great text from Snowmass already!
    - One-week turnaround for comments by peer reviewers
  - Final draft report to HEPAP members in advance of 22 May meeting discussion. Public release upon acceptance by HEPAP.
- Communication
  - At the time of the May HEPAP meeting:
    - International partner consultations
    - Draft versions of 1-page overview and talking points
    - Press release and web features ready to go
  - Followed quickly by
    - **Community: Virtual Town Hall, emails, news items, briefings by phone and talks/discussions at universities and labs, and conferences.**
    - Briefing decision makers as requested
    - Additional options under discussion, including Op-Eds, informational events,...  
Suggestions welcome!
  - Continued talks/discussions at community meetings, universities, and labs

March 2014

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# P5 Process

<http://www.usparticlephysics.org/p5>

- **P5 teleconferences**
- **Face-to-face P5 meetings during “input phase”** - all with open sessions and town hall meetings
  - **Nov 2-4: FNAL** Snowmass, international context , neutrino program
  - **Dec 2-5: SLAC** Cosmic Frontier, theory. computing
  - **Dec 15-18: BNL** Energy Frontier, precision physics, ‘proton driver’, accelerator R&D, detector R&D
- **Face-to-face meetings during “deliberation phase”** ~ 3-4 week intervals
- **Please note:**
  - P5 will build on the investment in the Snowmass process and outcomes.
  - P5 will continue interactions with the community: public meetings, town halls, further input, communications. Note that website with RSS feed set up.
  - P5 will strive for transparency & present the rationale for its recommendations.
  - HEPAP will perform an independent review of the draft P5 report.