Particle Physics Program in North America

Asian Linear Collider Workshop 2018
Fukuoka, Japan;   May 28, 2018

Hugh Montgomery

Jefferson Lab

USA

Acknowledgements

The US segment of this talk was largely taken from a talk by Andy Lankford, the outgoing Chair of the High Energy Physics Advisory Panel to the US DOE Office of High Energy Physics, to the US-Japan collaboration meeting in April 2018.

The Canadian segment of the talk is based on information provided my Mike Roney, Institute of Particle Physics Director, and Jon Bagger, TRIUMF Director

U.S. Long-term View

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

U.S. HEP program is guided by the 10-year strategic plan of 2014 P5 report:

Building for Discovery

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

"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."

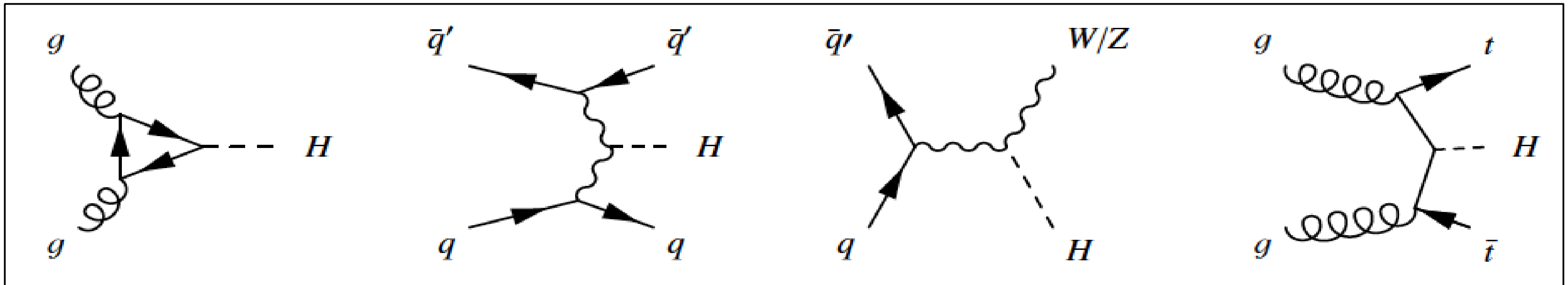
P5’s Science Drivers

Five topics that should drive U.S. HEP program for next 10 years:

- **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, and physical principles.**

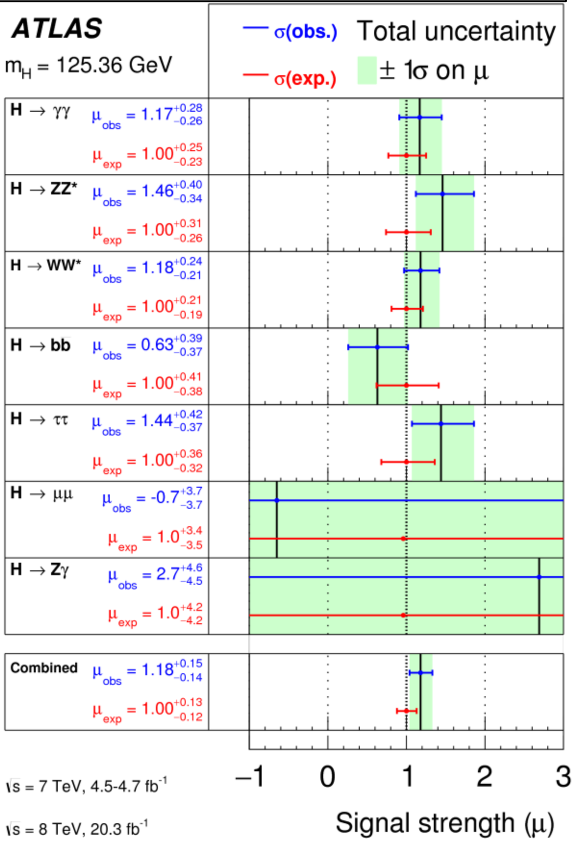
P5 identified the highest priority projects for a balanced program that addresses these science drivers in constrained budget scenarios.

Use the Higgs boson as a new tool for discovery.



(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$

- **LHC and its upgrades are the only means to produce and characterize the Higgs for the next decade or longer.**
  - **Precision measurements of Higgs properties leading to any deviations at the few %-level.**
  - **Access to rare processes, H decay to μμ.**
- **ILC (or other Higgs factory) would eventually allow measurements of higher precision.**
- **A very high energy proton-proton collider would later allow other improved measurements, such as Higgs self-coupling.**



The U.S., the LHC and the LHC upgrades

LHC has been one of the largest investments of U.S. in HEP, ever.

- **LHC accelerator** (DOE)
- **ATLAS** (DOE+NSF), **CMS** (DOE+NSF), **LHCb** (NSF), **ALICE** (DOE NP)

U.S. is single largest collaborating nation on both ATLAS & CMS.

- **US-ATLAS: ~19% of ATLAS;   US-CMS: ~27% of CMS**

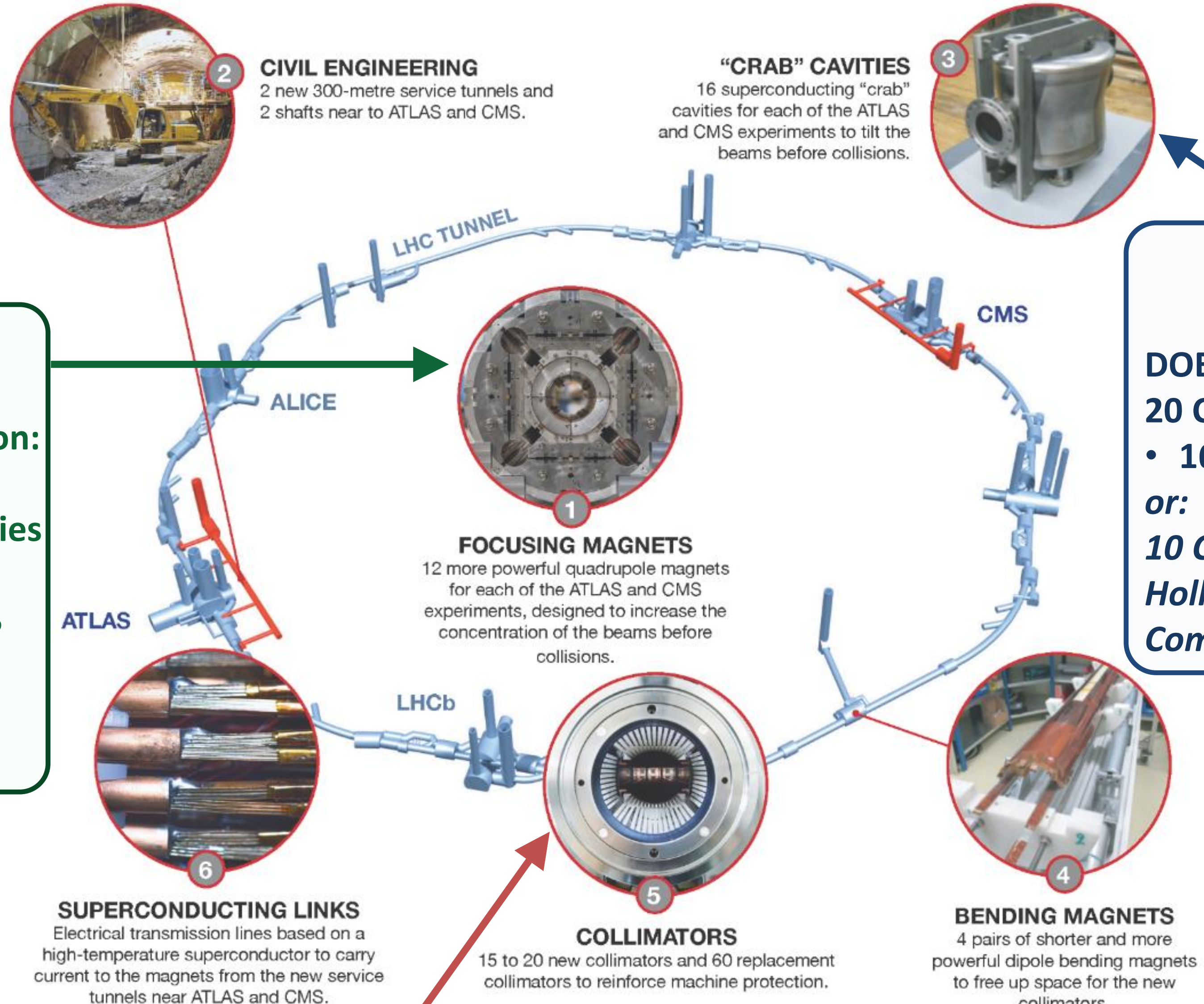
U.S. investment continues for Phase-I & HL-LHC upgrades.

- **DOE & NSF: Phase-I ATLAS & CMS detector upgrades**
  - Now nearing completion. Some components already installed.
- **DOE: HL-LHC Accelerator Upgrade Project**
  - CD-1/3a – Oct 2017;   CD-2 ~ early 2019
- **DOE & NSF: HL-LHC [Phase-II] ATLAS & CMS upgrades**
  - CD-1 ~June-July 2018; NSF PDR's held.

May 2017: Signed DOE-CERN addenda to U.S.-CERN Int'l. Cooperative Agreement and Protocols signed in 2015.

- **DOE contributions to HL-LHC accelerator & detector upgrades**
- **CERN's contribution to U.S.-hosted neutrino program**

HL-LHC Accelerator Upgrades:
Enabling U.S. Science Participation



DOE contribution:
10 cold mass (Nb_3Sn) assemblies
- **4 each for ATLAS & CMS interaction regions**
- **2 spares**

DOE contribution:
20 Crab Cavities
- **16 + 4 spares**

or:
10 Crab cavities & Hollow e-Lens Components

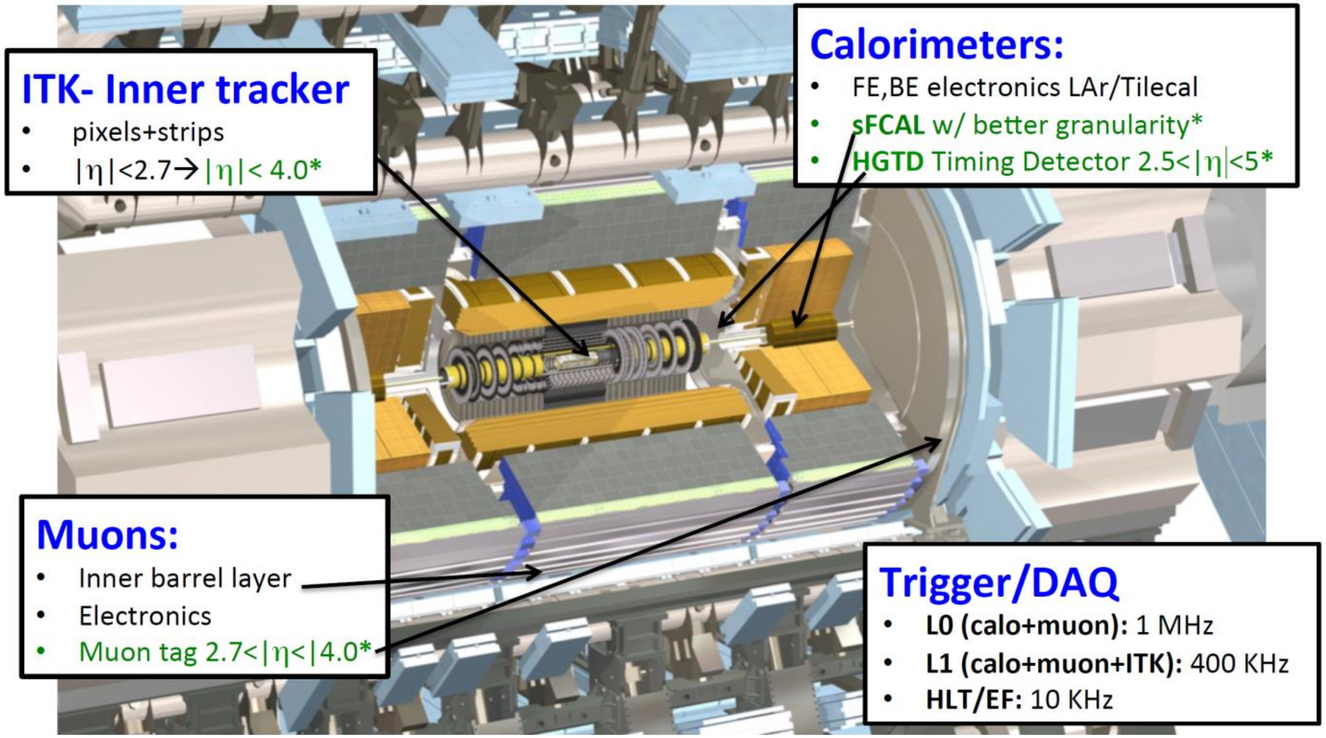
DOE contribution:
Hollow e-Lens Components (under discussion)

ATLAS HL-LHC Upgrade

- **Similarly, U.S. ATLAS is defining the scope of its contributions to HL-LHC by leveraging interests and experience of U.S. groups, coordinating with international ATLAS**

- **DOE Scope:**
  - **Barrel Inner Tracker (pixel & strip detector)**
  - **LAr Calorimeter front-end analog chip development**
  - **DAQ hardware (data flow elements)**

- **NSF Scope:**
  - **'Triggering' at high luminosities**
  - **Readout electronics for LAr, Tile, Muons**



** Large forward rapidities, as described in the 2015 ATLAS HL-LHC scoping document (for the reference 275 MCHF CORE total cost scenario)*

CMS HL-LHC Upgrade

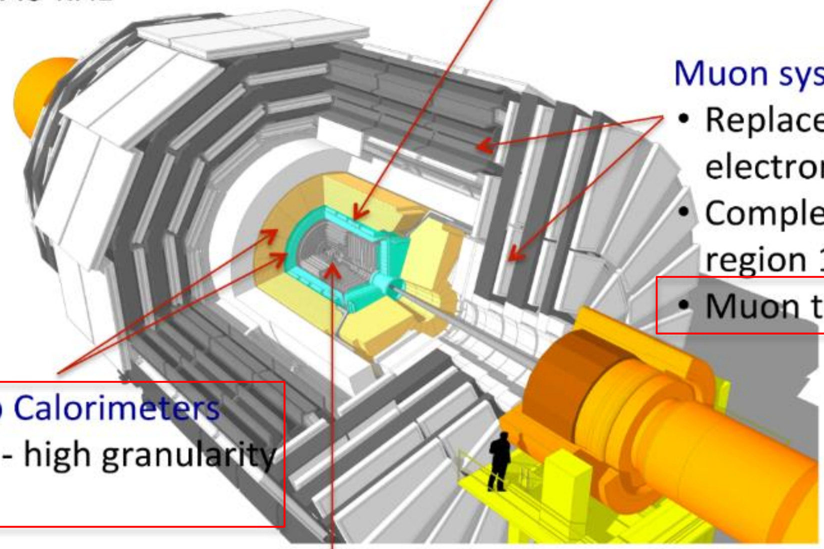
- DOE and U.S. National Science Foundation coordinating U.S. contributions with CERN and international partners on CMS
- Scope of the U.S. deliverables leverages expertise by U.S. scientists

DOE NSF

Trigger/HLT/DAQ
- Track information at L1-Trigger
- L1-Trigger: 12.5 μs latency - output 750 kHz
- HLT output ≃7.5 kHz

Barrel EM calorimeter
- Replace FE/BE electronics
- Lower operating temperature (8∘)

NSF



Muon systems
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

NSF DOE

DOE

*Replace Endcap Calorimeters
- Rad. tolerant - high granularity
- 3D capability

Replace Tracker *
- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for L1-Trigger
- Extend coverage to η = 3.8

DOE NSF

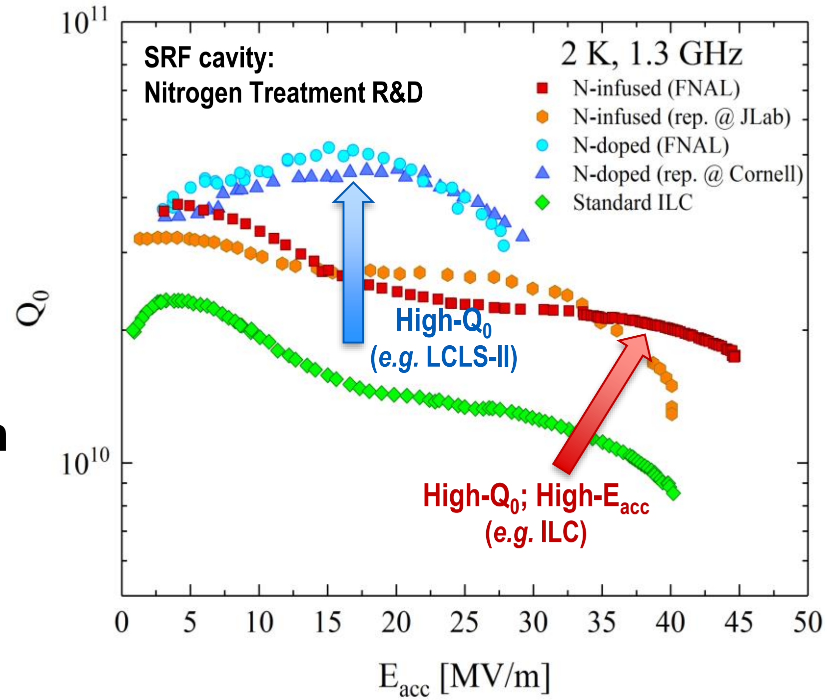
= U.S. contributions to CMS HL-LHC Upgrade Scope

ILC: Status in the U.S.

While awaiting a decision by the Government of Japan to host the ILC, the U.S. continues R&D efforts, focusing on areas of cost reduction for the accelerator (*e.g.* SRF cavities, gradient, *Q*-factor).

R&D:

- **U.S. has invested heavily in ILC and detector R&D in past years, particularly Superconducting RF.**
- **Present R&D program focuses on cost reduction for SRF** (gradient, Q_0)**.**
- **Builds upon past investment and upon Fermilab & Jefferson Lab experience in providing SRF for the LCLS-II light source at SLAC**
- **Other ILC R&D efforts, *e.g.* positron source, detectors, are very modest in current budget situation.**



See A. Grassellino presentation.

Silicon Detector

Tracking System

SLAC, U.Oregon, UC Davis, ANL, UNM, Yale, (Bristol)

Electro-magnetic calorimeter

SLAC, U. Oregon

Hadronic calorimeter

UTA, SLAC, ANL

Muon system

FNAL

Forward region

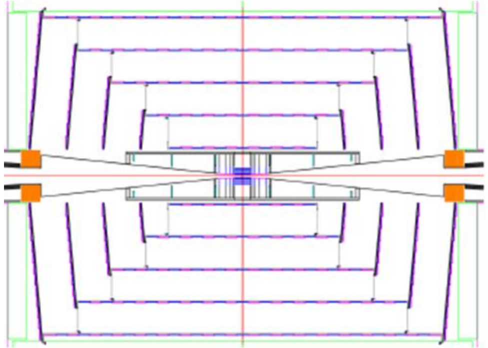
UCSC, SLAC

MDI/Installation

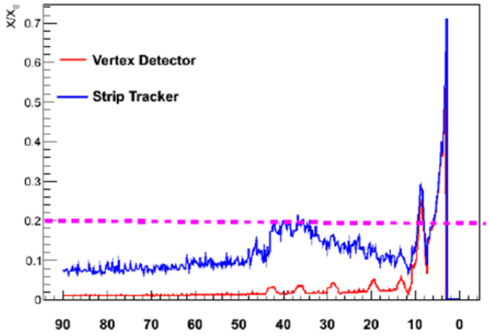
SLAC, (DESY)

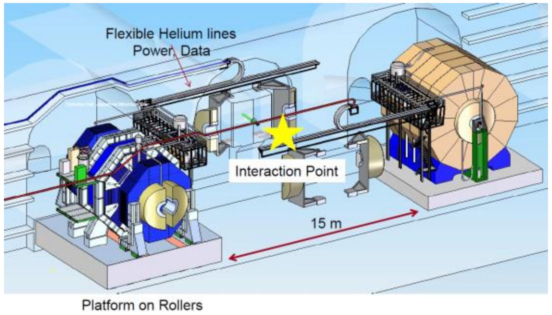
Computing/Software/Physics

SLAC(DESY), PNNL, (Glasgow), UO, UTA, ANL



- Weekly detector optimization meetings (many students)
- Design options
- New (DD4HEP) simulation
- Physics studies
- Cost estimation/reduction
- Mechanical/electronics engineering to support conceptual design



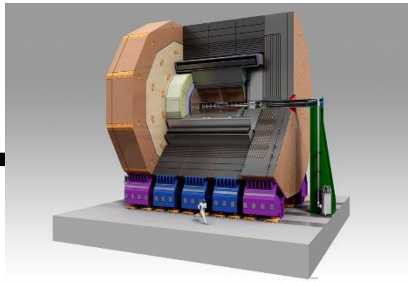


Spokes

Andy White, UTA

Marcel Stanitzki, DESY

International Large Detector



- Letter of Intent published in 2010. Includes 12 US and 5 Canadian institutions.
- Since 2015, ILD has transitioned to a more formal management structure. Currently 71 institutions are members of the Institute Assembly including 7 from the US and Canada.
  - Carleton, Indiana, Kansas, McGill, NIU, Princeton, Victoria
- ILD's current effort is focused on preparing the groundwork for a real proposal and understanding better the detector optimization and performance.
- Pending the green-light, securing funding for ILC targeted work in North America has been difficult. Some limited funding possibilities with base-grant funding and now with US-Japan. Canada similar.
- Activities:
  - McGill, NIU – participation in CALICE R&D collaboration
  - Carleton, Victoria, Cornell – contributions to LC-TPC R&D collaboration
  - Kansas - physics and detector studies, ILD management (Wilson)
- Contacts in North America: Alain Bellerive (Canada) and Graham Wilson (US).

CLIC Detector

ANL, U. Michigan, and Pontificia Universidad Catolica, Santiago, Chile

Pursue the physics associated with neutrino mass.

Operating in U.S.:

Short-baseline:
- MINERvA
- MicroBooNE
- COHERENT

Long-baseline:
- NOvA

U.S. working abroad:

Reactor:
- Daya Bay

Long-baseline:
- T2K/SuperK

→

Future in U.S.:

Reactor:
- Prospect

Short-baseline:
- SBN
  - MicroBooNE
  - SBND
  - ICARUS
- COHERENT

Long-baseline:
- LBNF/DUNE

P5: ***"In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab."***

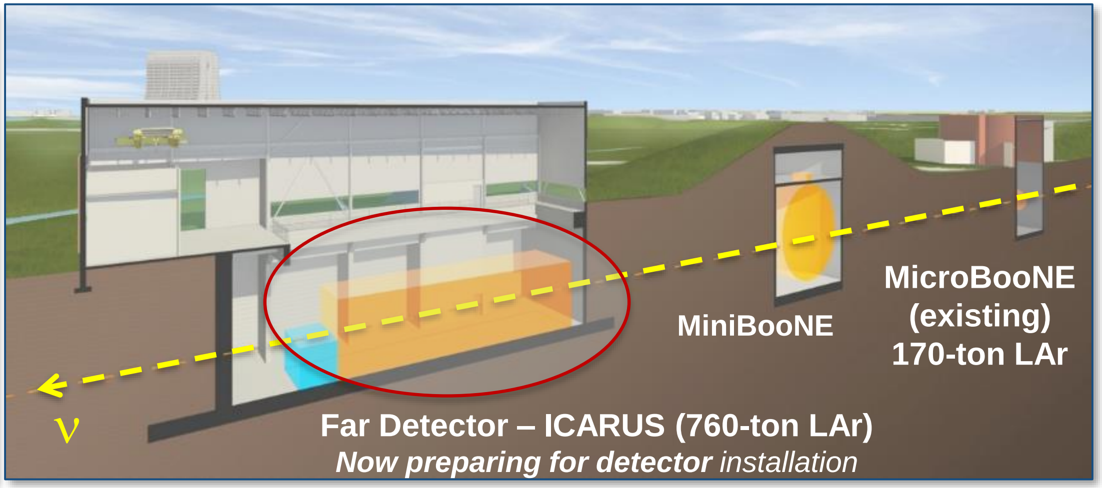
Short-Baseline Neutrino Program

Two goals:

- **Resolve experimental anomalies in measured ν-spectrum, including search for sterile neutrinos.**
- **Demonstrate the liquid argon TPC detector technology for DUNE.**

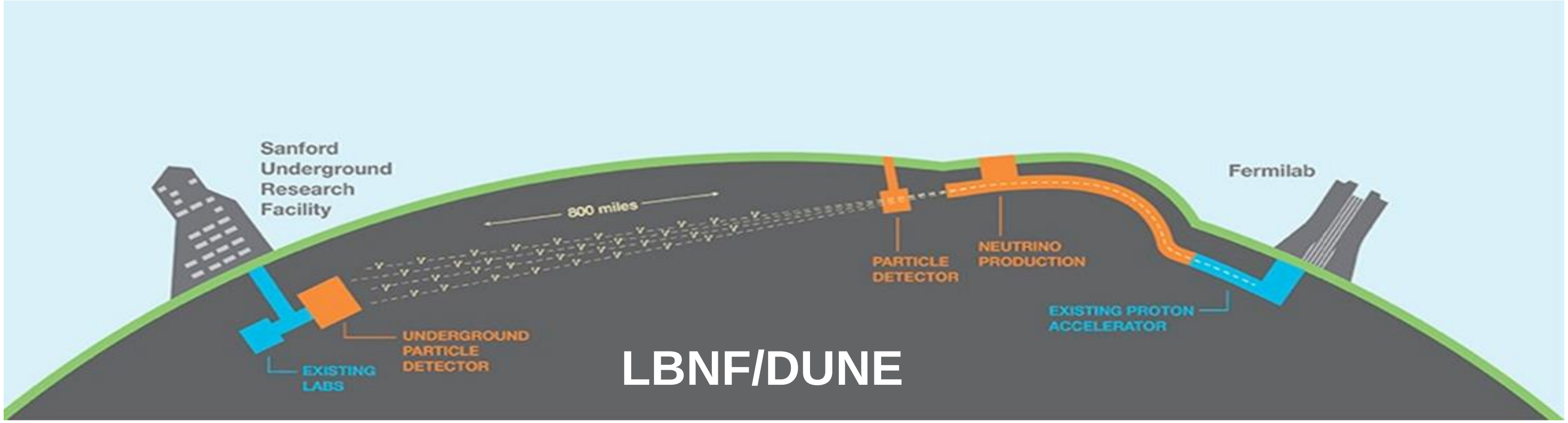
Three detectors:

- **ICARUS – brought from Gran Sasso, Italy via refurbishment at CERN. Now at FNAL.**
- **SBND – Short-Baseline Near Detector**
- **MicroBooNE - operating**



Long-Baseline Neutrino Program – LBNF/DUNE

Long-Baseline Neutrino Facility / Deep Underground Neutrino Expt.



- **Identified by P5 as the highest priority large project in its time frame.**
- **Centerpiece of a U.S.-hosted, international neutrino program.**
- **The 1st international science facility hosted in the U.S.**

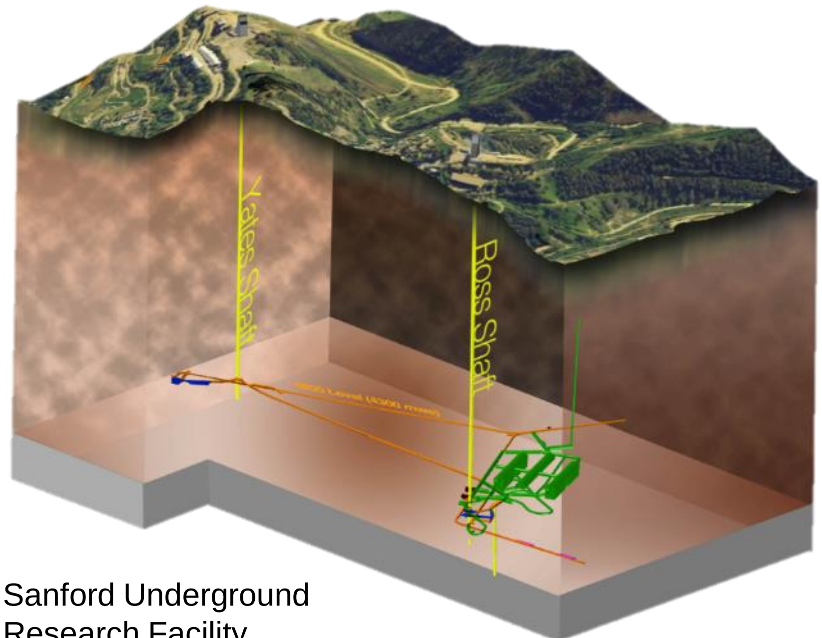
1065 collab.
177 inst.
31 nations

UK-U.S. S&T Agreement
20 Sept 2017

Some recent agreements

US DOE – India DAE
S&T Agreement for
neutrino physics
16 April 2018

LBNF/DUNE



Sanford Underground
Research Facility

Anode Plane Assembly

See F. Cavanna presentation.

International Project Milestones	Date
Start Main Cavern Excavation	2019
Start Detector #1 Installation	2022
Neutrino beam on with two detectors	2026

Proton Improvement Plan II (PIP-II)

Goal - 1.2 MW proton beam power DUNE in 2026

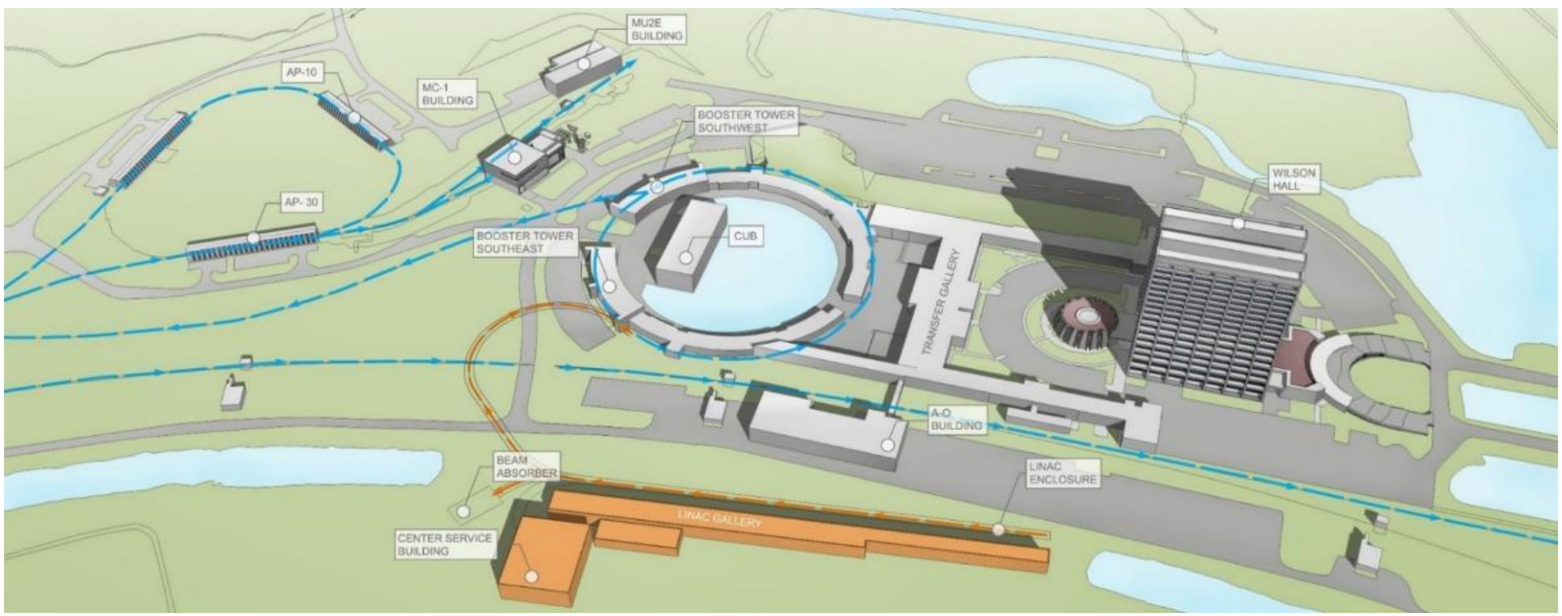
Will also support other research goals by providing increased beam power and high reliability to future Fermilab experiments.

Replace existing 50-year-old linac with a high-power, 800-MeV SRF linac.

Based on LCLS-II experience (and ILC R&D)

Being built with international partners, incl. India, UK, Italy, France.

CD-1 planned for June 2018.



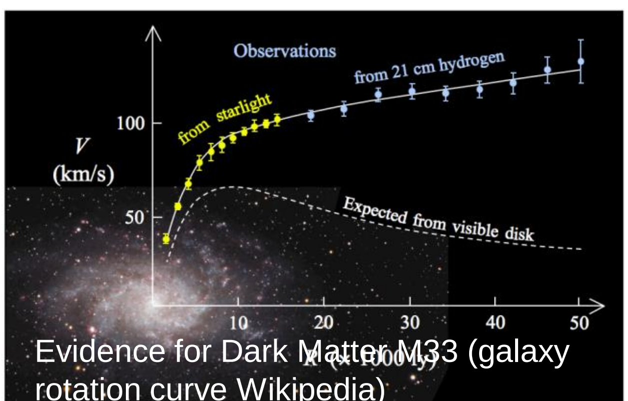
Ultimate goal for upgrade of proton complex is >2 MW to LBNF. (PIP-III?)

Identify the new physics of dark matter.

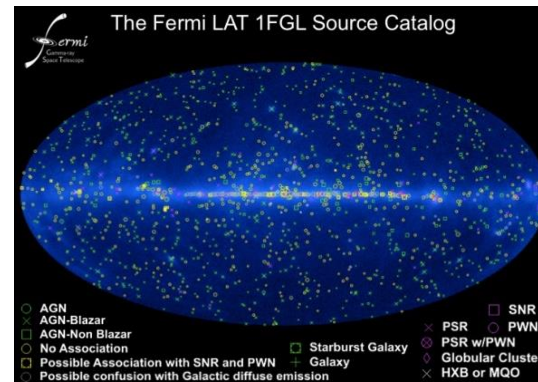
P5: "It is imperative to search for dark matter along every feasible avenue."
4 complementary experimental approaches, each providing essential clues:
- direct detection,
- indirect detection,
- observation of large-scale astrophysical effects,
- dark matter production at accelerators.

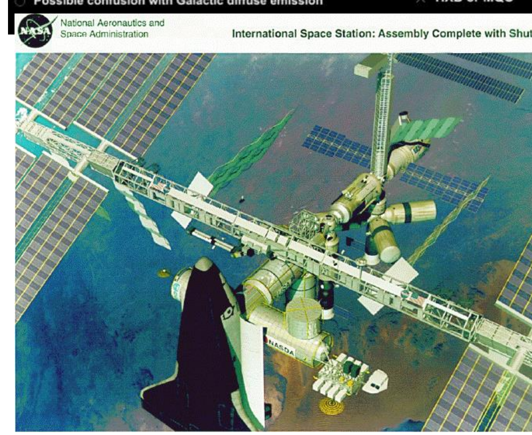
Indirect detection:
- Research continuing with Fermi-LAT & AMS-02.
- HAWC sensitive to very heavy DM particles.
- DOE has no new initiatives planned.

Large-scale astrophysical effects:



Evidence for Dark Matter M33 (galaxy rotation curve Wikipedia)



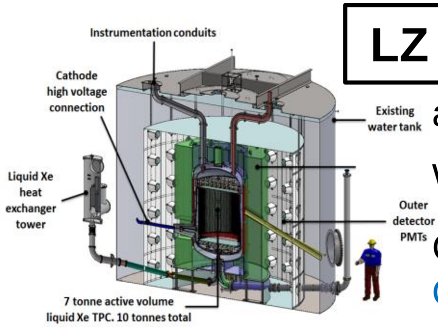


Direct detection searches for dark matter

DOE completed support for operations of DM-Generation 1 experiments in FY16/17.

ADMX-II, LUX, CDMS-Soudan, DarkSide-50, COUPP/PICO, DAMIC

DM-G2 program: 3 complementary experiments



LZ

at SURF (South Dakota)

WIMP search LXe

CD-3 - Feb 2017

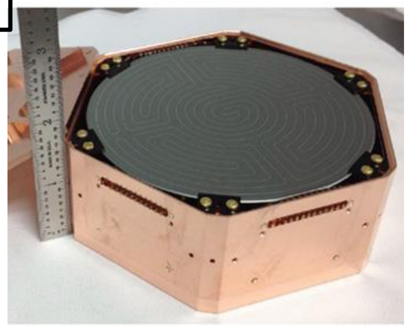
Operations – FY2021

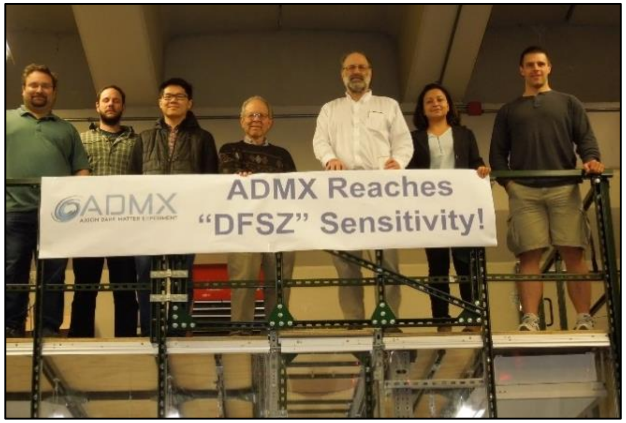
SuperCDMS-SNOLab

NSF-PHY partnership

WIMP search Si/Ge at SNOLab

CD-1 – Dec 2015
in final design phase
CD-2/3 – *Spring 2018*
Operations – FY2021



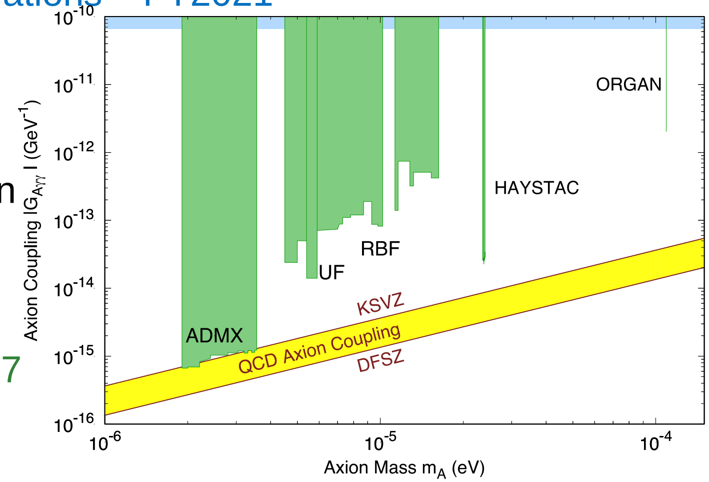


ADMX-G2

at Univ. of Washington

Axion search

Operations – Jan 2017



Looking further forward, P5 also recommended one or more DM-G3 experiments.

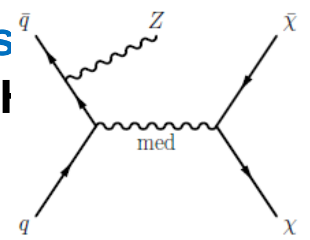
Dark matter production at accelerators

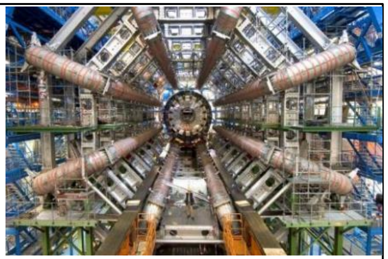
Dark matter production with particle colliders

Many US-led Dark Matter searches at the LH

- **“Mono-*X*” searches**
- **searches in the SUSY context**

Program will continue with HL-LHC.



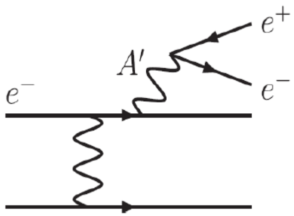


Dark matter production in intense particle beams

Current experiments in *e* beam at Jefferson Lab:

- **Heavy Photon Search** (physics runs 2015-2016)
- **APEX** (first data 2018)

Many new concepts under study, including at other labs.



Future planning via Cosmic Visions Dark Matter community group.

New concepts, for all experimental techniques, were explored at a broad workshop on Dark Matter in 2017.

Whitepaper on most important scientific opportunities:

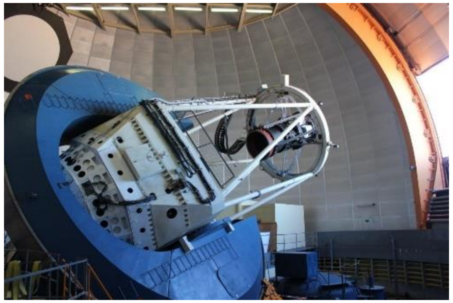
U.S. Cosmic Visions: New Ideas in Dark Matter 2017: Community Report

arXiv:1707.04591 [hep-ph]

Understand cosmic acceleration: dark energy and inflation.

Dark energy: complementary imaging & spectroscopic surveys

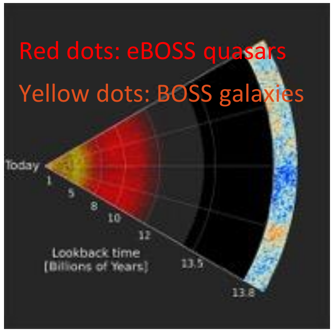
DES
Dark Energy Survey



DOE & NSF-AST
Producing excellent results
Now in 5/6 yrs operations

eBOSS
Extended Baryon Oscillation Spectroscopic Survey

Now last year of operations
Producing excellent results

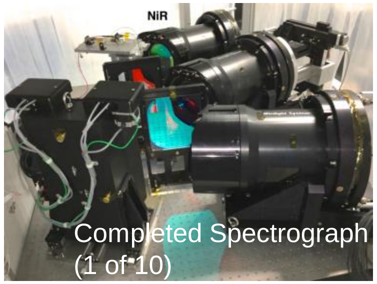


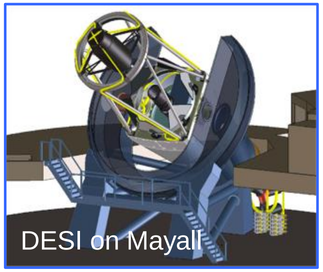
LSST
Large Synoptic Survey Telescope
DOE & NSF-AST

NSF MREFC - Aug 2014;
CD-3 - Aug 2015
Operations - 2022

DESI
Dark Energy Spectroscopic Instrument

CD-3 - Jun 2016
Commissioning - 2019





Understand cosmic acceleration: dark energy and inflation.

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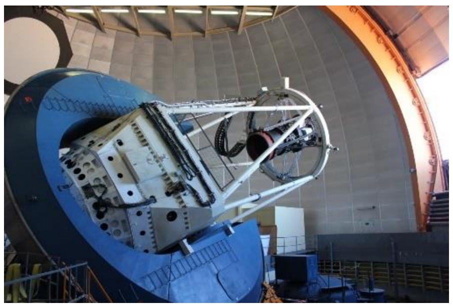
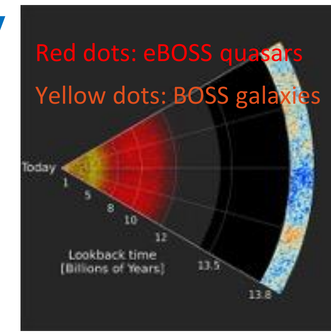


eBOSS
Extended Baryon Oscillation Spectroscopic Survey



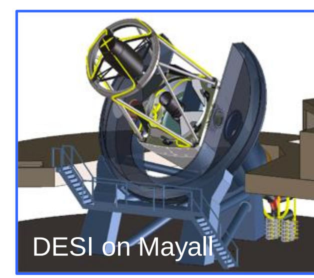
Stage III

Stage IV

LSST
Large Synoptic Survey Telescope

DOE & NSF-AST

DESI
Dark Energy Spectroscopic Instrument



Understand cosmic acceleration: dark energy and inflation.

Inflation: Cosmic Microwave Background (CMB)

SPT-3G

Operating Stage 3:
South Pole Telescope
Operations began Feb 2017;
DOE-NSF partnership
Research also on several other CMB exp'ts

Planning for next generation:

- **CMB Stage 4 (CMB-S4)**
- **DOE-NSF partnership**
- **Science book** – Oct 2016.
- CMB-S4 **Concept Definition Taskforce Report** approved Oct 2017.
  - science goals, technical requirements, strawman concept
- Note: P5 suggested international collaboration and coordination on Stage 4.

Explore the unknown.

Explore the unknown: new particles, interactions, and physical principles.

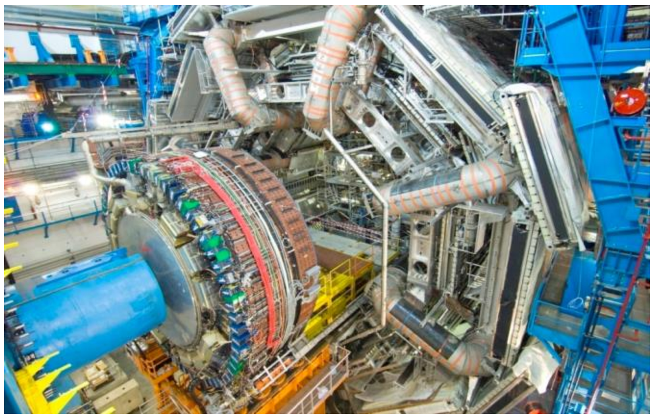
Some approaches to exploring the unknown as outlined by P5:

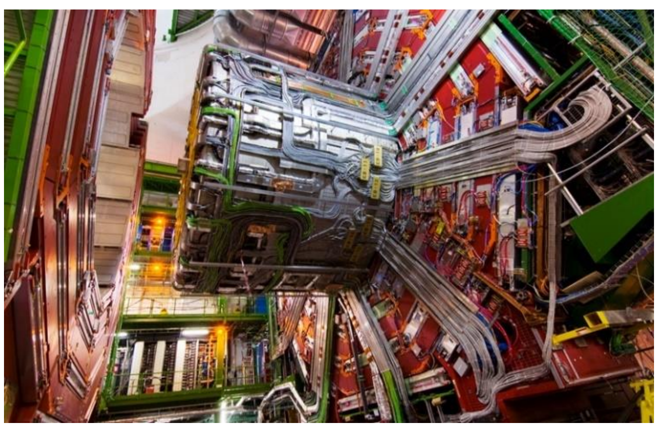
- *High energy colliders*
- *Precision physics & rare processes*
  - *Heavy quarks & tau leptons*
  - *Rare kaon decays*
  - *Rare muon decays and processes*
  - *Muon magnetic moment*
  - *Baryon number violation*
  - *Electric dipole moments*
- *Cosmic particles*
- *Low-mass particles*

Explore the unknown.

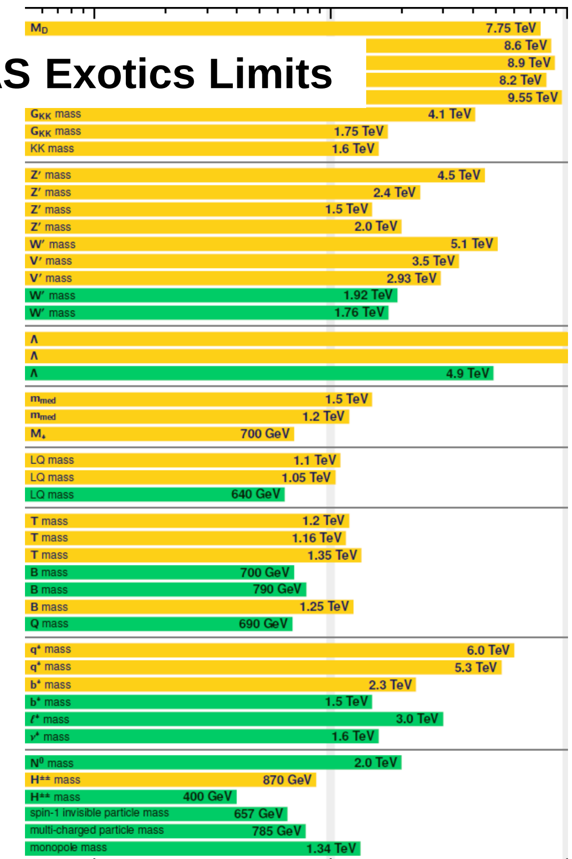
Explore the unknown: New particles, interactions, and physical principles.

High energy colliders are one of the approaches to exploring the unknown.





ATLAS Exotics Limits

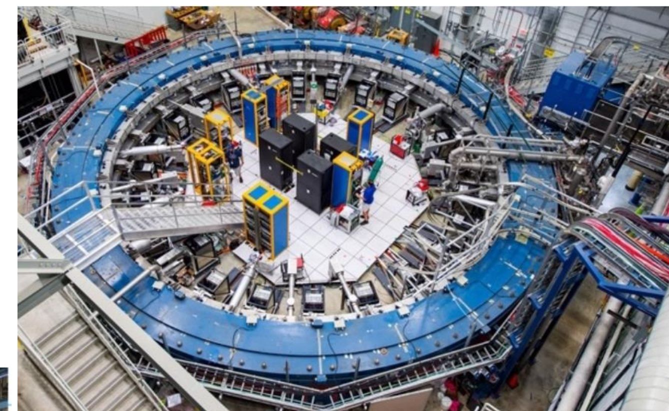


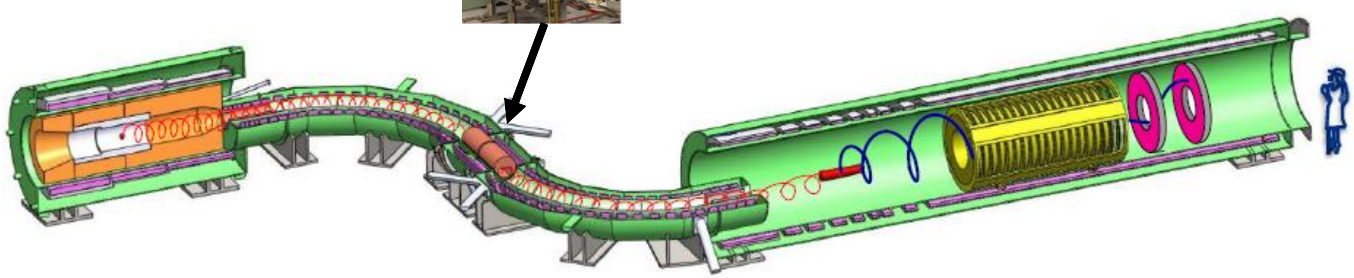
HL-LHC => Up to 40% larger discovery potential for new physics than that accessible prior to upgrades

Fermilab muon program

Explore the "unknown" thru precision measurements

- *Ongoing precision experiments:*
  - Collaboration with Japan on *K* meson, heavy quark, and *τ* lepton precision studies with **KOTO** and **Belle II**
- *In the future:* The FNAL muon program
  - **Muon g-2**
    - First beam in May 2017
    - First physics in 2018; BNL-size data set by summer
    - Full statistic results in 2020
  - **Mu2e**
    - CD-3 construction start – July 2016
    - First beam – 2020
    - Physics data - 2022





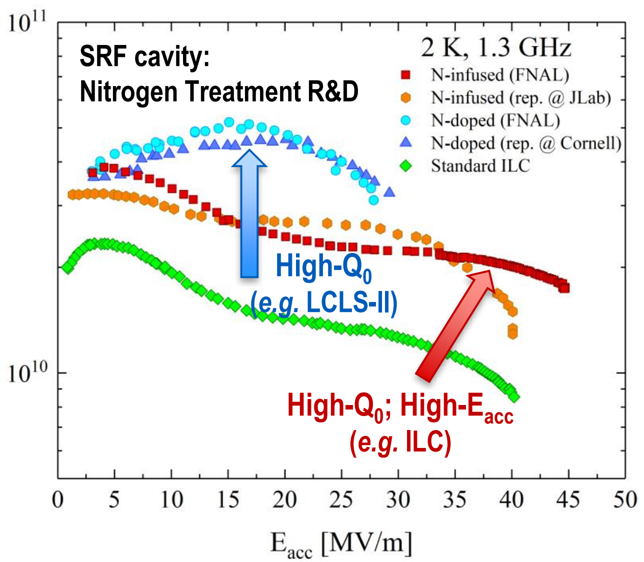
Accelerator R&D

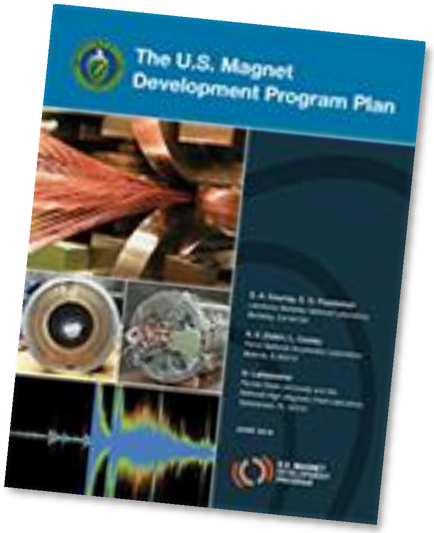
Accelerator R&D roadmaps

- **Recommended by 2015 HEPAP Accelerator R&D Subpanel**
- **Roadmaps defined by research community contain:**
  - Pressing challenges to be addressed to move the field forward
  - Prioritized milestones aligned to the most compelling research
- **Subject areas:**
  - **Radiofrequency Acceleration Technology**
    - Superconducting RF, Normal Conduction RF, RF sources
  - **Superconducting High Field Magnets**
    - Produced the U.S. Magnet Development Program Plan
  - **Advanced Accelerator Concepts**
    - Laser-driven plasma wakefield acceleration (LWFA)
    - Particle-beam-driven plasma wakefield acceleration (PWFA)
    - Dielectric wakefield acceleration (DWFA)

Future Colliders

- **DOE has been coordinating with the international community towards the development of the next collider program**
  - The U.S. looks forward to a decision this year by Japan to host the ILC as an international project
  - Global strategy for the next circular collider awaits the 2020 European Strategy Update for Particle Physics
- **Interest from U.S. HEP community to pursue R&D studies for future collider options (*e.g.,* Europe/CERN Future Circular Collider or Japan-proposed ILC)**
  - Current DOE efforts focused on next generation high-field magnet technology to enable higher energy future proton-proton collider
  - For ILC, current DOE efforts focused on cost reduction R&D—for e.g., nitrogen treatment in SRF accelerator cavity technology: potential for up to 10% cost reductions in 3-5 years, up to 15% in 5-10 years
- **Caveat: Under any fiscal budget constraints in the Energy Frontier program, near-term priorities will aim to support the LHC program as well as R&D for the High-Luminosity LHC upgrades**





Canadian Particle Physics and Future Accelerators

Subatomic Physics Long Range Plan 2017-2021

Community-driven planning exercise captures aspirations of Canadian particle and nuclear physics research communities as guide to investment decisions of funding agencies (Long Range Plan available at www.subatomicphysics.ca)

Some Scientific Recommendation highlights:

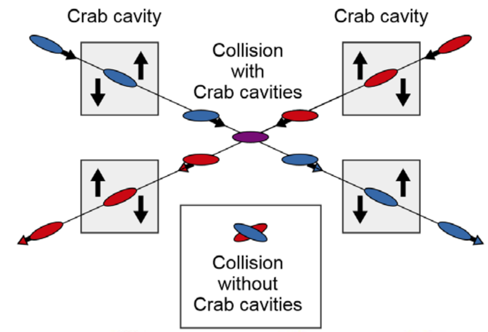
- Provide continued support and resources to:
  ATLAS; T2K; TRIUMF (radioactive beams, ARIEL);
  SNOLAB (dark matter and $0\nu 2\beta$ searches);
- Support strategic, smaller-scale Canadian efforts, giving breadth to the community's programme: ALPHA, JLAB and offshore rare isotope beam experiments, and IceCube.
- Support activities in potential *future* flagship endeavours having significant Canadian participation:
  - ATLAS at the High-Luminosity LHC
  - Belle II at SuperKEKB
  - Hyper-Kamiokande
  - ILD at ILC
  - Moller and SOLID at JLAB
  - nEXO at SNOLAB
  - UCN/nEDM at TRIUMF (w/ significant Japanese contributions)

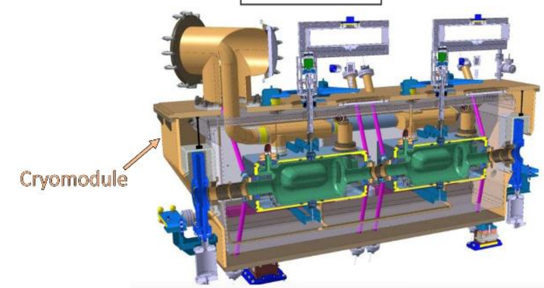
Canadian Particle Physics and Future Accelerators

Canadian HEP community will be engaged in next generation high energy collider projects both detectors and accelerators

e.g. HL-LHC:

- ATLAS detector upgrades have federal funding
- IPP Canadian HEP community working to secure funding of cryomodules for crab (partnerships TRIUMF, FNAL, CERN…)





International partnerships in all regions key to success:

- TRIUMF and KEK have offices in each others labs, joint programs/symposium series
- Long Range Plan recommends:
  - Stakeholders in Canadian government, universities, institutes, labs and industry work towards a more formal relationship between Canada and CERN.
  - Identify an office in federal government responsible for engaging with the international community in moving forward major new science initiatives.
- Canadian government now has a Chief Science Advisor – IPP HEP community working with her on engagement in international projects and partnerships.

Canadian Foundation for Innovation

Project	Lead Institution	CFI Request	Gate 0	Gate 1
ATLAS Upgrade / HL-LHC	Toronto	~$35M	✓	✓
Photodetector Infrastructure	Carleton	~$10M	✓	✓
HyperK/PINGU	Toronto	~$25M	✓	✓
UCN/nEDM	Winnipeg	~$12M	✓	✓
MOLLER	Manitoba	~$4M	✓	✓
TIGRESS Si Tracker	Guelph	~$1M	✓	✓
Muon Beamline Upgrade	SFU	~$10M	✓	✓
Isotope Harvesting	UBC	~$10M	✓	✓

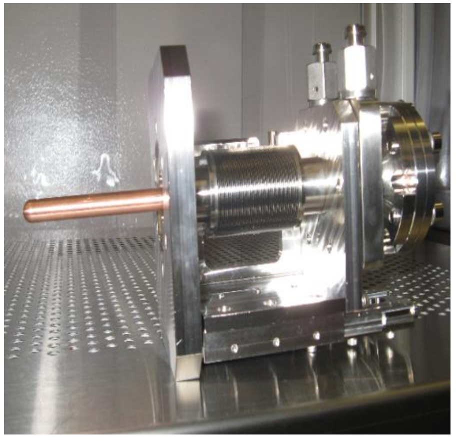
Proposals aligned with Subatomic Physics Long Range Plan

TRIUMF Accelerator Science

Outside projects leverage Accelerator Division core competences, help support/expand infrastructure, grow skills and build reputation

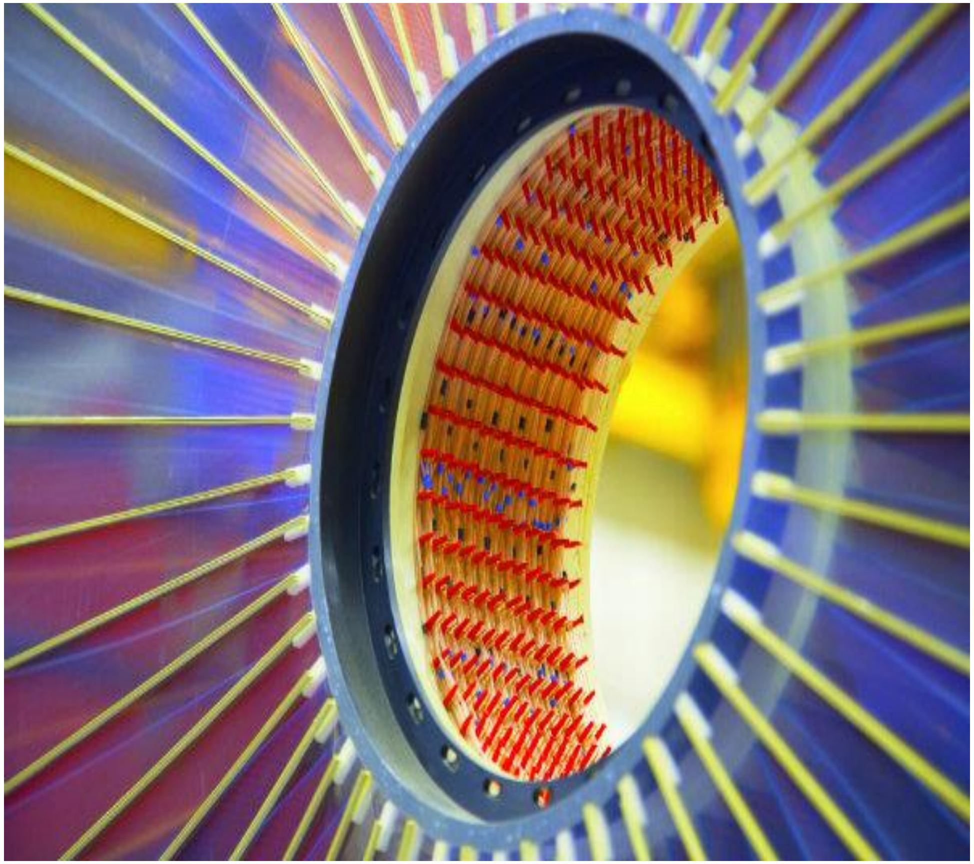
Recent and Ongoing Activities

- ANURIB (VECC-India)
  - Cryomodule and target production - in progress
- RISP (IBS-Korea)
  - SRF cavity testing - complete
  - SRF spoke design/fabrication - in progress
- LCLS-II (SLAC) – SRF coupler conditioning - complete
- FRIB (MSU) – SRV test coupler fabrication - complete
- IMP (CAS-Lanzhou) – LLRF systems - in progress
- RISP (IBS-Korea) – LLRF test system - in progress
- GANIL (France) – Ti/Sa laser systems - complete
- HL-LHC (CERN) – Beam dynamics studies - in progress
- ILC (LCC) – Surface characterization studies - in progress



TRIUMF: Current Major Projects

- Three major projects currently underway
  - UCN: Ultra Cold Neutrons
  - ARIEL II
  - IAMI: Institute for Advanced Medical Isotopes



North American Particle Physics Program

United States

The 2014 P5 Report defines the HEP strategic plan through ~2024.

- The P5 report well accepted, by the HEP community, in DOE, NSF, Congress.
- The P5 plan is still in its early years.

DOE Perspective on future planning: not too early; not too late

The P5 strategic plan needs to be updated in time to impact the FY2025 budget, leading to the notional timeline:

Mid-2020: Begin process, Early 2023: Report to inform FY2025 budg

Continue accelerator R&D needed for next-generation research.
Continue community activities looking to the future.

Canada

Sub-atomic Physics Long Range Plan 2017-2021

- TRIUMF serves as core Laboratory
- Strong, innovative internal physics and technology program
- Strong international partnerships in particle physics and accelerator science

INTERNATIONAL PARTNERSHIP is integrated in both strategies