Large Hadron Collider Science: Goals and Objectives

Anadi Canepa
Fermilab Strategic Planning Workshop
9 November 2017
Five compelling lines on inquiry with great promise for discovery over the next 10 to 20 years were identified by the Particle Physics Project Prioritization Panel (P5):

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics for dark matter
- Understand cosmic acceleration
- Explore the unknown

The HL-LHC is the highest priority near-term project (P5 report)

CMS is researching on 3 out of the 5 science drivers

Fermilab is essential to the discovery program at the LHC and at CMS
The LHC started exploring the ENERGY FRONTIER in 2009
The historical discovery of a Higgs boson was announced in 2012 (10/fb, 7-8 TeV)
The HL-LHC will produce 3000/fb at 14 TeV till 2038
In 10 years, Fermilab will continue to be the leading U.S. center for CMS, and the second leading center in the world after our partner CERN.

**Lab Goals (5 years)**

1. Maximize science from LHC Runs 2 and 3
2. Complete CMS phase 1 upgrade and execute HL-LHC CMS upgrade projects
3. Execute AUP and the high-luminosity LHC upgrade project
4. Continue R&D and physics studies for future colliders
5. Maintain technical expertise and facilities to support the LHC program
The FNAL group is leader in

Data analysis
Operations
Phase 1 and Phase 2 upgrades
Computing
CMS SW R&D and Maintenance

**FNAL is the host laboratory for US-CMS**

Manages Ops Program
Manages Upgrade Projects
Hosts the US Tier 1 (the largest of all T1s)
Hosts the LHC Physics Center
Outstanding center of excellence

FNAL is the largest group in the US
and the 2\textsuperscript{nd} largest in CMS

50 members including \textasciitilde 15 RAs
Over 100 FTEs

Joel Butler, current CMS spokesperson
Greg Rakness, (former) Run Coordinator
Jeff Spalding, Deputy Upgrade Coord.
Boaz Klima, Chair Publication Committee
• FNAL maintains its leading role in the Higgs boson program, searches for Dark Matter, searches for BSM, precision measurements of the SM parameters
  • 4 physicists leading Higgs and SUSY subgroups
  • Contributions to high profile journal publications, selected ones:
    • evidence for the Higgs boson decaying to b quarks
    • first observation of the Higgs boson decaying to a pair of tau leptons
    • first search for the gluon fusion production of Higgs bosons decaying into a collimated pair of b-jets
    • novel searches for dijet resonances at both high and low mass, for dark matter in the final state with one jet + X, for supersymmetry
• FNAL ensures continued support to hundreds LPC users per year
  • Conferences, workshops, tutorials, schools, help-desk
  • Forum for knowledge sharing (Coffee Hour, Topic of the Week,...)
High data taking efficiency and high data quality critically rely on the FNAL participation in the Tracker, HCAL, DAQ, Operations

- L2 for USCMS DAQ Operations / CMS DAQ Deputy Project Manager
- Shifters in the ROC at Fermilab, at P5 at CERN, in the Remote Control Room at CERN
- Experts on call at CERN
- FNAL is responsible to deploy the US CMS T1 at a scale consistent with the commitment to the Worldwide LHC Computing Grid, to operate it as the agreed level of availability, and to enable US-CMS to perform analysis on the LPC resources
- FNAL is leader in the development of the CMS-Software
The upgrade of the CMS Phase 1 Pixel detector is complete

- Built at FNAL in collaboration with 21 universities
- Successfully installed, commissioned, and in operation now

FNAL is on schedule to complete the Phase 1 HCAL electronics upgrade by the end of CY18

University faculty, RAs, and students based at the LPC have been instrumental to the success of the Phase 1 upgrades
GL-00190 Phase 2 Upgrades (HL-LHC CMS Upgrades)

**Trigger/HLT/DAQ**
- Track information at L1-Trigger
- L1-Trigger: 12.5 $\mu$s latency - output 750 kHz
- HLT output = 7.5 kHz

**Barrel EM calorimeter**
- Replace FE/BE electronics
- Lower operating temperature ($8^\circ$)

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

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

**Replace Tracker**
- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout ($P_{T} \geq 2$ GeV) in Outer Tracker for L1-Trigger
- Extend coverage to $\eta \sim 4$ (TFPIX)

**Novel Timing Detector**
GL-00190 HL-LHC CMS Upgrades (I)

- The HL-LHC CMS Upgrade is a Joint DOE and NSF project
  - US-CMS HL-LHC Project Manager: Vivian O’Dell (Fermilab)
  - $\sim$235 M$
  - FNAL will build 50% of the US CMS Outer Tracker modules and the entire Flat Barrel
  - FNAL will assemble $\sim$30% cassettes of the entire HGCAL
  - FNAL is leading the R&D of the timing detector and will contribute to the trigger upgrade
- US-CMS has successfully undergone 5/6 Independent Technical Reviews in preparation for the director’s review and CD1, planned in FY18: Outer Tracker, FPIX, Muons, Trigger/DAQ, Barrel Calorimeter
  - HGCAL planned in December 2017
- FNAL has contributed to the TDRs of the Tracker/HGCAL/Timing
Changes with respect to the objectives set in 2016:

- The scope of FNAL and US CMS is now defined
- The R&D is being finalized
- Each FNAL Upgrade project is now a separate objective:
  - Outer Tracker
  - High Granularity Calorimeter
  - Trigger
  - Timing Detector (*to be reviewed by the LHCC*)
The FNAL group is identifying the needs in technical expertise and facilities in collaboration with the Projects

- Established a team composed of project representatives and detector experts
- Team providing input to the IERC process through a dedicated Scientific Point of Contact

A resource and succession planning is being defined to ensure the successful completion of the CMS projects FNAL is responsible for

- Close collaboration with the laboratory management for hiring planning
- Plan to be finalized during FY18

Over the years the FNAL group has been very effective in educating and mentoring RAs; 2017 hires:

- Dr. Nhan Tran, now Wilson Fellow (recipient of the 2017 URA Tollestrup Award)
- Dr. Rafael Coelho Lopes de Sa, now Professor at UMass Amherst
• **Completed Objectives of LARP**
  - Built full long scale (4m) first Magnet Prototype under testing at BNL
  - Build Coils for second prototype
  - Successfully tested all Crab Cavities at JLAB.

• **Completed Objectives of HL-LHC AUP**
  - Obtained CD-0 and CD-1/CD-3b approval for HL-LHC Acc. Upgrade Project (HL-LHC AUP)
  - Initiated coils for first “tunnelable” magnet
  - Ready for CD-3a scope (\(\text{Nb}_3\text{Sn} \) SuperConductor procurement) as soon as Continuing Resolution is terminated
  - Transition through FY18 will see focus shifting from LARP to HL-LHC AUP Construction.
    - Moderate e-lens R&D effort will be only LARP-funded activity in FY19 and beyond at fellowship level.
• **FY18 Objectives**
  - Test 2\textsuperscript{nd} magnet prototype and complete the third prototype
  - Initiate Nb\textsubscript{3}Sn Procurement
  - Initiate pre-series RFD Cavities Procurement
Fermilab is contributing input (both in regards to machine parameters and to detector specifications) to the FCC@CERN CDR, and the next Snowmass process starting in ~2021 leveraging limited resources and in close collaboration with other US Labs and Universities.

- Publications on the subject have been produced in the past years, fruitful discussions took place at the Scientists Retreat in Spring 2017

**LA-01350, LA-02300 Phenomenology**

- Fermilab is advancing our knowledge of particle physics through model building and studies of collider physics phenomenology
  - Selected FY17 publications: “Exotic Signals of VectorLike Quarks”, “Direct photon Production at NNLO”, “Interference in the ggH into yy on-shell rate and the Higgs boson total width”, ...
In 10 years, Fermilab will continue to be the leading U.S. center for CMS, and the second leading center in the world after our partner CERN.

Lab Goals (5 years)
1) Maximize science from LHC Runs 2 and 3
2) Complete CMS phase 1 upgrade and execute HL-LHC CMS upgrade projects
3) Execute AUP and the high-luminosity LHC upgrade project
4) Continue R&D and physics studies for future colliders
5) Maintain technical expertise and facilities to support the LHC program

The HL-LHC is the highest priority near-term project (P5 report)
CMS is researching on 3 out of the 5 P5 science drivers
Fermilab is essential to the discovery program at the LHC and at CMS
## Large Hadron Collider Science – FY18 Lab Activities

<table>
<thead>
<tr>
<th>Lab Activities (Research)</th>
<th>Primary Lab Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS Higgs Physics Research</td>
<td>1.1 Develop the precision program of the Higgs sector, searches for dark matter, and other new phenomena during Run 2 and Run 3 of the LHC</td>
</tr>
<tr>
<td>CMS Indirect Dark Matter Research</td>
<td>1.1 Develop the precision program of the Higgs sector, searches for dark matter, and other new phenomena during Run 2 and Run 3 of the LHC</td>
</tr>
<tr>
<td>CMS LHC Physics Center</td>
<td>1.3 Support LHC Physics Center Users - Analysis Activities</td>
</tr>
<tr>
<td>CMS New Physics Searches</td>
<td>1.1 Develop the precision program of the Higgs sector, searches for dark matter, and other new phenomena during Run 2 and Run 3 of the LHC</td>
</tr>
<tr>
<td>CMS Research</td>
<td>1.1 Develop the precision program of the Higgs sector, searches for dark matter, and other new phenomena during Run 2 and Run 3 of the LHC</td>
</tr>
<tr>
<td>LARP R&amp;D</td>
<td>3.1 Test first long quadrupole focusing magnet prototype by 2018</td>
</tr>
<tr>
<td>LHC Detector R&amp;D</td>
<td>2.3 Complete R&amp;D for HL-LHC detector upgrades (PROPOSED)</td>
</tr>
<tr>
<td>Phenomenology and Model Building</td>
<td>1.1 Develop the precision program of the Higgs sector, searches for dark matter, and other new phenomena during Run 2 and Run 3 of the LHC</td>
</tr>
<tr>
<td>Phenomenology Collider</td>
<td>1.1 Develop the precision program of the Higgs sector, searches for dark matter, and other new phenomena during Run 2 and Run 3 of the LHC</td>
</tr>
</tbody>
</table>

See [https://go.usa.gov/xnCb3](https://go.usa.gov/xnCb3) for lab goals, objectives, and activities.
### FY18 Lab Activities (Operations, Overhead, Project)

<table>
<thead>
<tr>
<th>Lab Activities (Operations, Overhead, Project)</th>
<th>Activity Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS Detector Operations</td>
<td>Operations</td>
</tr>
<tr>
<td>HL-LHC Accelerator Upgrade Project</td>
<td>Project</td>
</tr>
<tr>
<td>HL-LHC CMS Detector Upgrade Project</td>
<td>Project</td>
</tr>
<tr>
<td>LHC CMS Detector Upgrade Project</td>
<td>Project</td>
</tr>
</tbody>
</table>

See [https://go.usa.gov/xnCb3](https://go.usa.gov/xnCb3) for lab goals, objectives, and activities.
The CMS Scientific Collaboration

- U.S. (DOE+NSF) 27.4%
- Italy (12%)
- CERN (5%)
- All other countries (55%)
- 42 countries, 182 institutes
- 1500 Ph.D. scientists
- U.S. is 27.4% of the CMS scientific collaboration
  - DOE 21.9%, NSF 5.5%

These numbers do **not** include students!
- Including students makes the US ~ 32% of the CMS collaboration