**Tough Question:**

*What is the physics motivation for the high-luminosity LHC run? Do we need to be involved in both ATLAS and CMS experiments? What should we do next if LHC13 does not find new physics?*

# Higgs Case for HL-LHC

| Facility | LHC | HL-LHC | ILC | ILC LumiUP | CLIC | TLEP (4 IPs) |
|---|---|---|---|---|---|---|
| Energy (GeV) | 14,000 | 14,000 | 250+500+1000 | 250+500+1000 | 350+1400+3000 | 240+350 |
| $\int \mathcal{L}dt$ (fb$^{-1}$) | 300/expt | 3000/expt | 250+500+1000 | 1150+1600+2500 | 500+1500+2000 | 10000+1400 |
| $N_H$ ($\times 10^6$) | 17 | 170 | 0.37 | 1.05 | 2.2 | 3.2 |

$pp \to H + X$ at $\sqrt{s} = 14$ TeV for $m_H = 125$ GeV

| | ggF | VBF | VH | $t\bar{t}H$ | Total |
|---|---|---|---|---|---|
| Cross section (pb) | 49.9 | 4.18 | 2.38 | 0.611 | 57.1 |
| | Numbers of events in 3000 fb$^{-1}$ | | | | |
| $H \to \gamma\gamma$ | 344,310 | 28,842 | 16,422 | 4,216 | 393,790 |
| $H \to ZZ^* \to 4\ell$ | 17,847 | 1,495 | 851 | 219 | 20,412 |
| $H \to WW^* \to \ell\nu\ell\nu$ | 1,501,647 | 125,789 | 71,622 | 18,387 | 1,717,445 |
| $H \to \tau\tau$ | 9,461,040 | 792,528 | 451,248 | 115,846 | 10,820,662 |
| $H \to b\bar{b}$ | 86,376,900 | 7,235,580 | 4,119,780 | 1,057,641 | 98,789,901 |
| $H \to \mu\mu$ | 32,934 | 2,759 | 1,570 | 403 | 37,667 |
| $H \to Z\gamma \to \ell\ell\gamma$ | 15,090 | 1,264 | 720 | 185 | 17,258 |
| $H \to$ all | 149,700,000 | 12,540,000 | 7,140,000 | 1,833,000 | 171,213,000 |

**HL-LHC is a Higgs factory!**

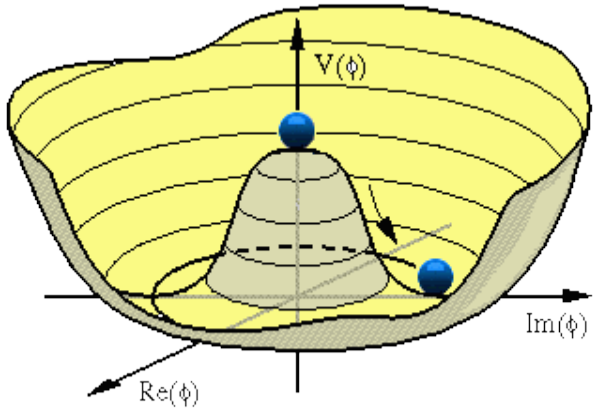
**HL-LHC is at the intensity frontier !**

# Higgs Case for HL-LHC

**Study Higgs self-coupling:**

At the heart of the theory is the Higgs potential

$$V = -\mu^2 \Phi^\dagger \Phi + \lambda \left(\Phi^\dagger \Phi\right)^2$$




Spontaneous symmetry breaking leads to

$$\Delta\mathcal{L} = -\frac{1}{2} m_H^2 H^2 - \frac{1}{3!} g_{HHH} H^3 - \frac{1}{4!} g_{HHHH} H^4$$

**Searches for BSM Higgs bosons:**

- Electroweak singlet
- Composite model
- 2 Higgs doublet model
- MSSM

Extend the mass reach to ~1 TeV in most of the models

# What if no new physics found in 300 $fb^{-1}$?

Should go ahead with the HL-LHC upgrade regardless what we see in 300 $fb^{-1}$ for the following reasons:

- The program to study the 126 GeV Higgs boson is sufficient appealing by itself. No future lepton colliders can compete in statistics with HL-LHC for the channels with electrons, muons and photons.
- Extend the reach for BSM Higgs from 100s GeV to several TeV, not to mention other discovery potentials and precision measurements beyond the Higgs sector.
- For the most part, the detectors will maintain good performance and the community interests remain strong. People follow physics.
- Important to capitalize the past major investments to maximize its physics with relatively small incremental improvements.

# Why both ATLAS and CMS Experiments?

**Why two experiments?**

At (circular) colliders, historically there are always two or more experiments:

Strong community interests, healthy competition, cross checks, increase statistics, and insurance, ...

Allow experiments to utilize physicists' different expertise and explore different and sometimes risk technologies, …

**Why should US participate in both ATLAS and CMS upgrades for HL-LHC?**

US is the largest contributor to both experiments (20% of ATLAS and 30% of CMS). The success of the two experiments are heavily dependent on the US participation.

Without US participation, the experiment will be in jeopardy financially as well as technically. The US expertise and leadership in detector, computing, software and physics will be lost. The experiment likely won't be strong enough to be competitive.

Potentially it could be the end of US participation in the LHC if US choses to contribute to one detector upgrade only, cause irreparable harm to global cooperation in an era of global Science. Ultimately the Science will suffer.

Many US physicists have devoted 10+ years in their chosen experiments and formed strong bond with their international collaborators, forced pulling out will be infringing PI's freedom and demoralizing for US physicists.