# Large Hadron Collider: from LHC-Run2 to the HE-LHC

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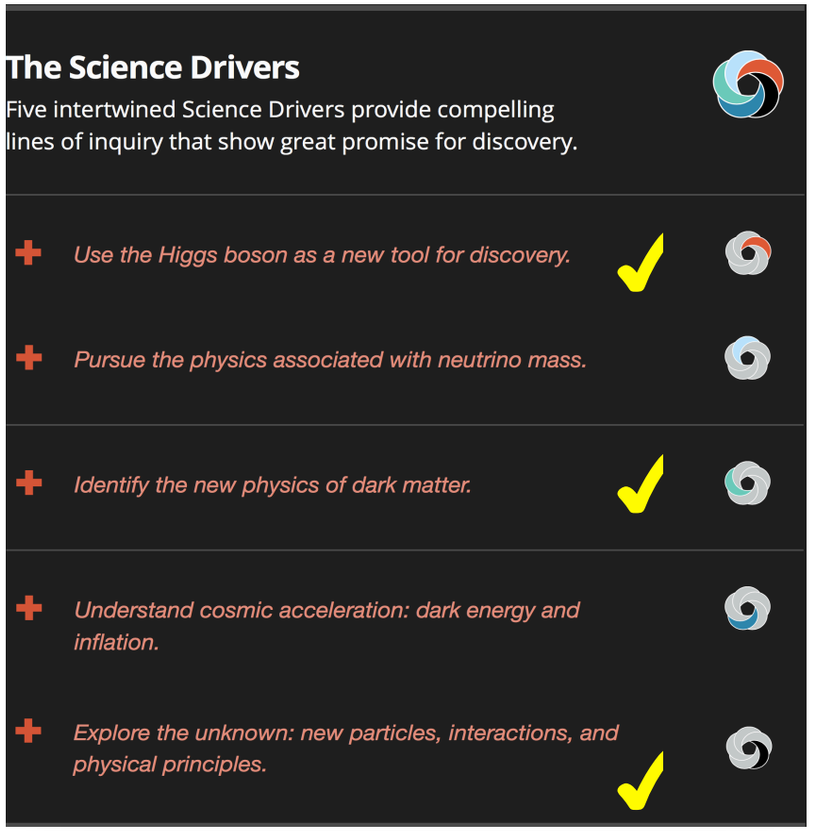
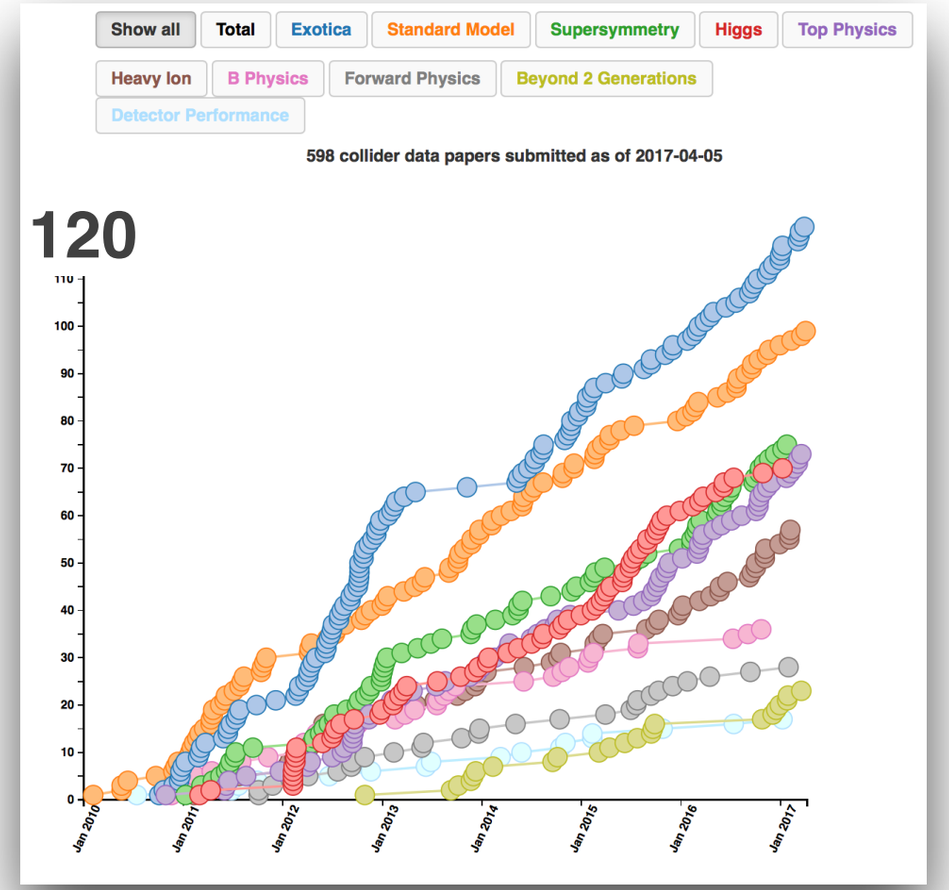
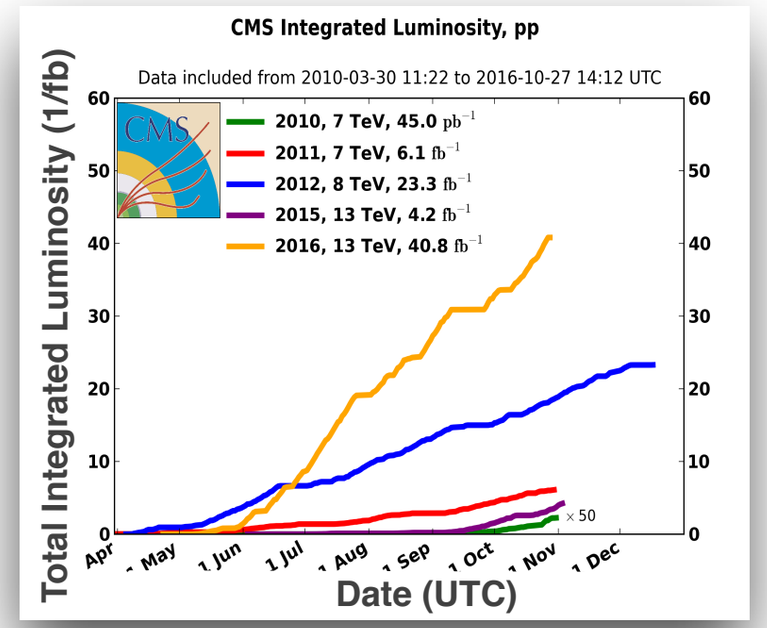
# The LHC

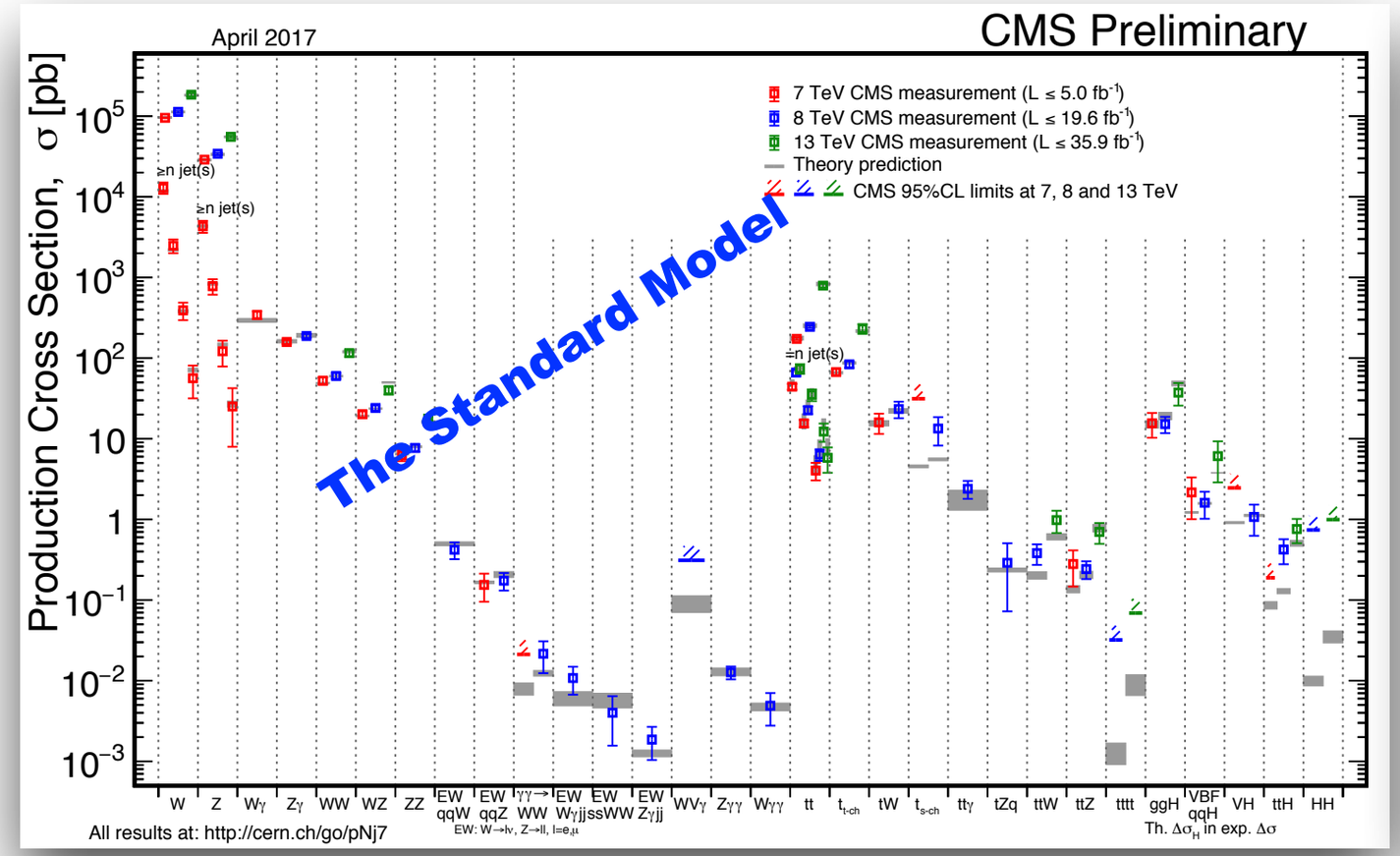
- **The LHC addresses three out of the five science drivers identified by P5**
- **The broad and diverse physics program allows to explore the energy frontier**
  - **CMS and ATLAS > 1000 journal publications**

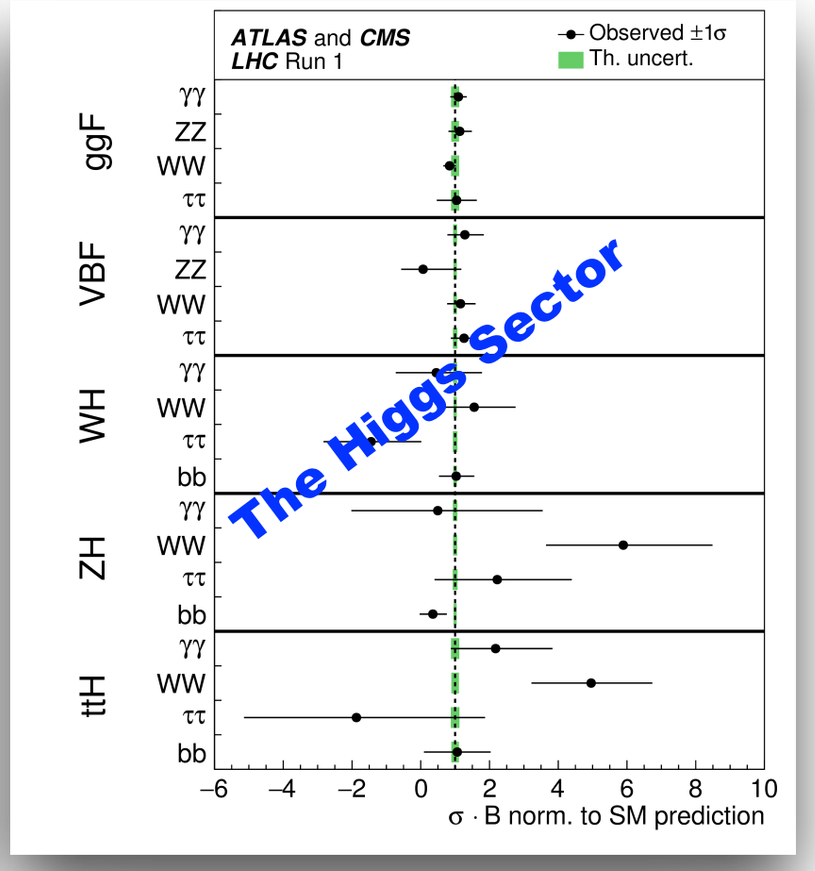


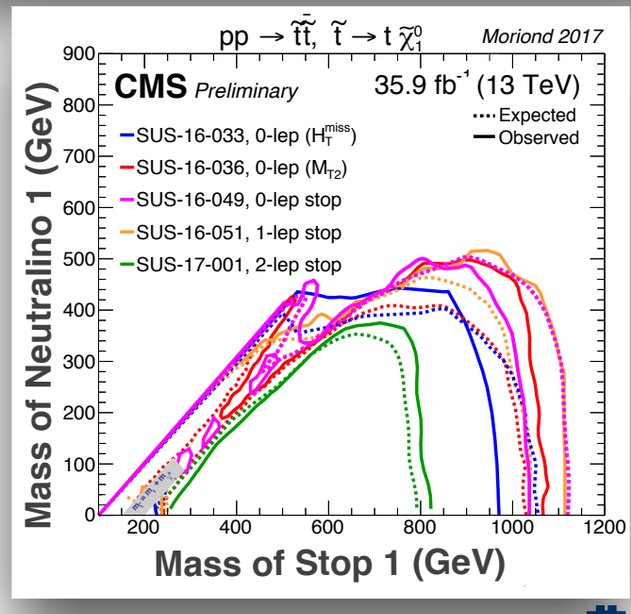
# Physics Today




- **Direct searches for New Physics**
  - **SUSY as an example**
- **Indirect searches for New Physics via precision measurements of the Higgs sector**

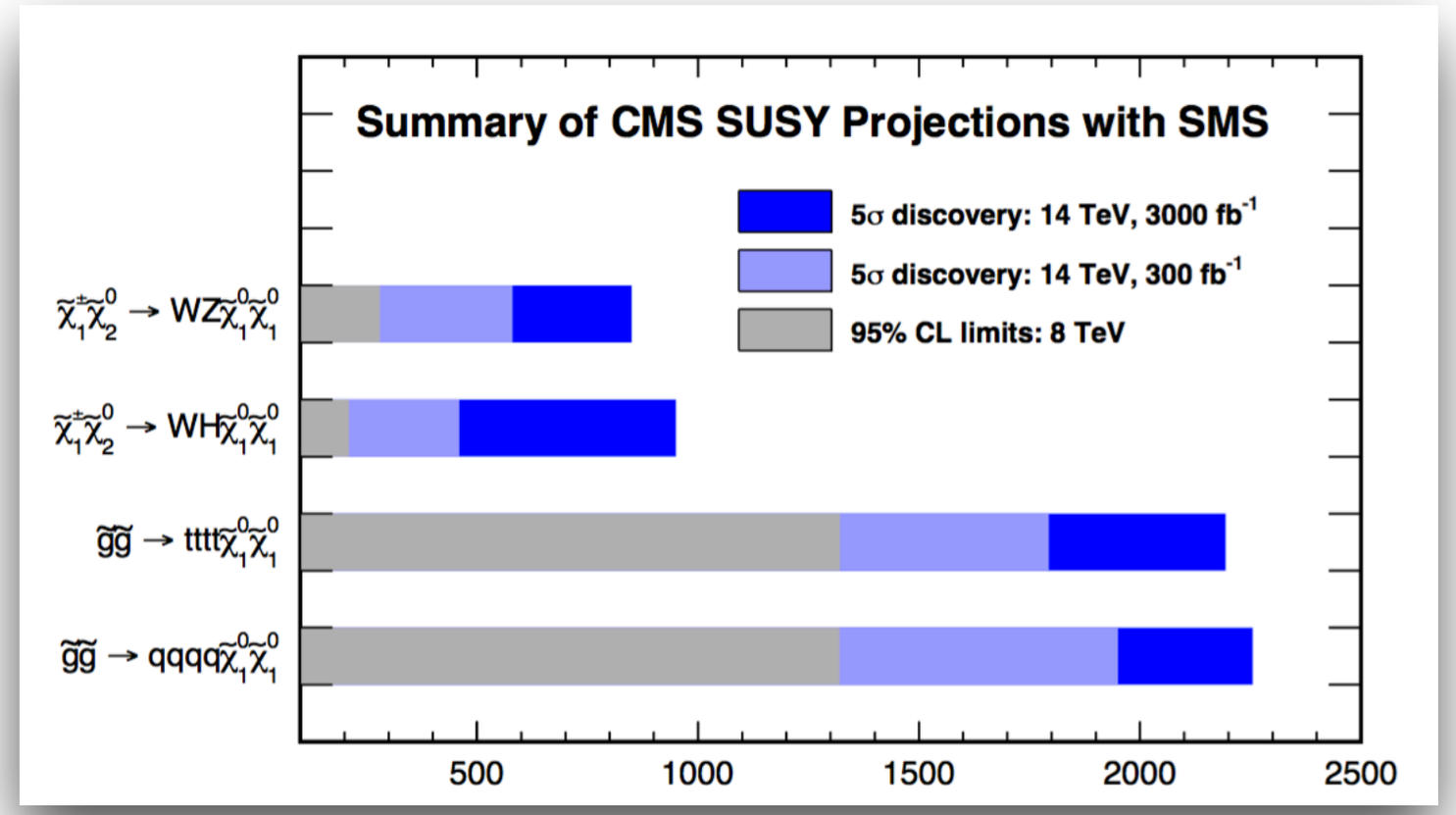
(and EWK, top, B, etc. sectors)

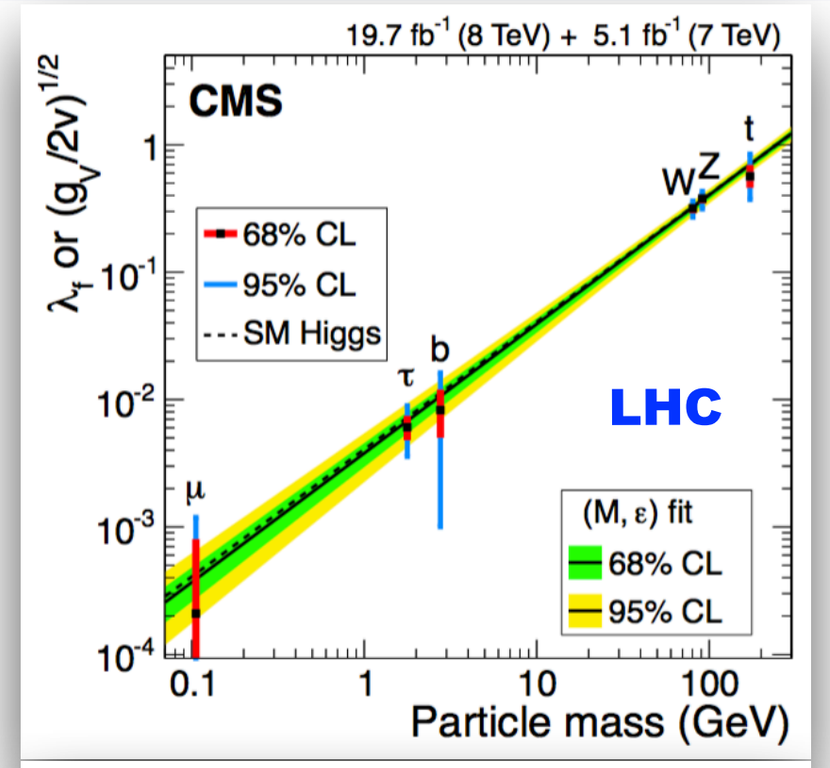


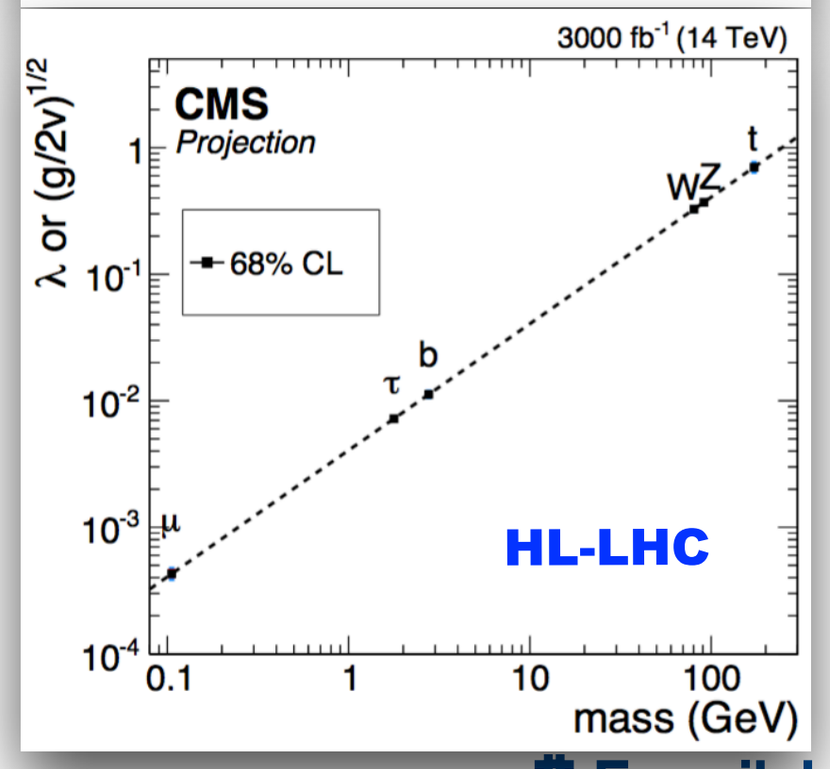
# Why HL-LHC?

## Extend the LHC discovery potential

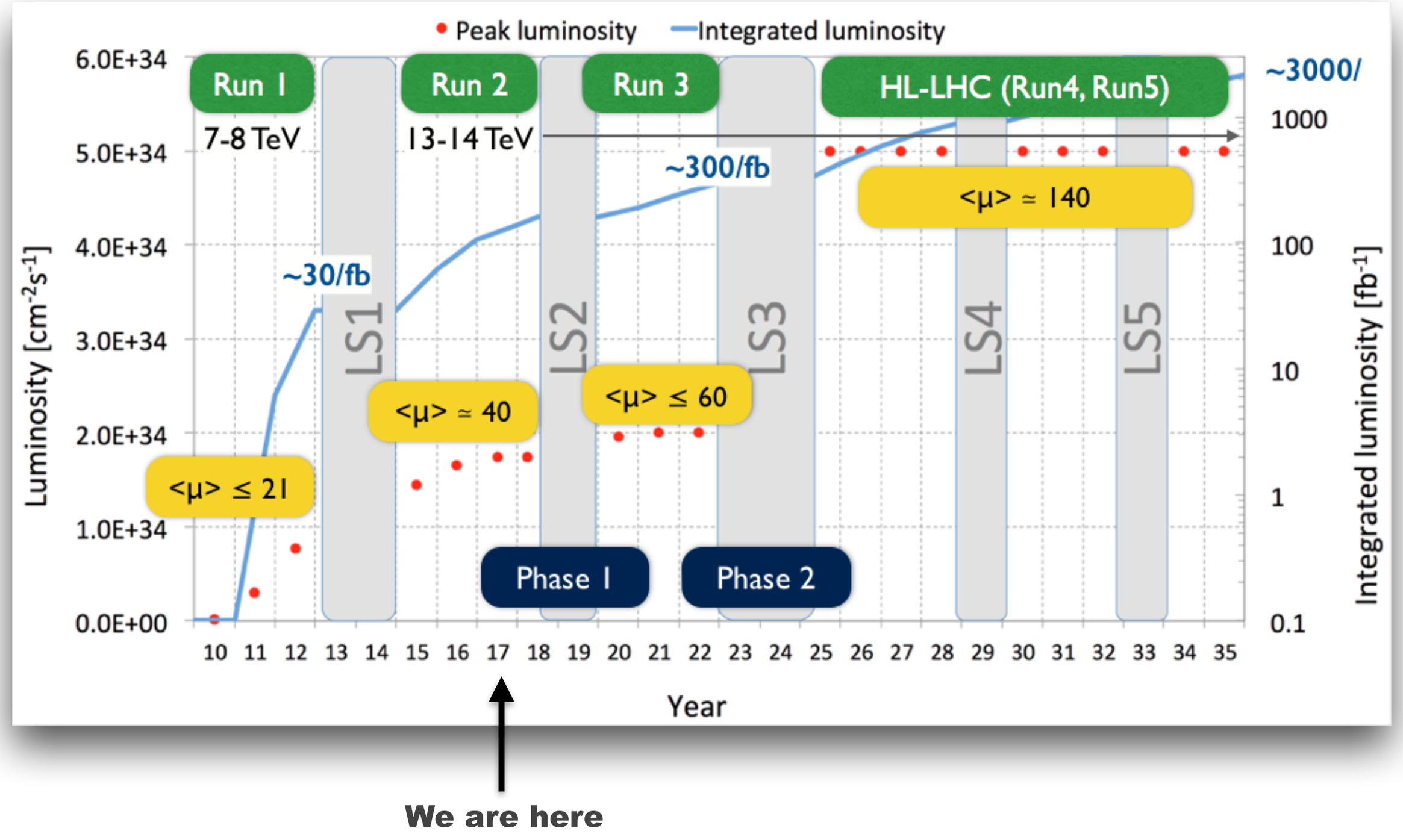
- measurements of the Higgs couplings (from % to sub-% level)
- direct searches for few-TeV New Physics



# The Evolution of the LHC into the HL-LHC



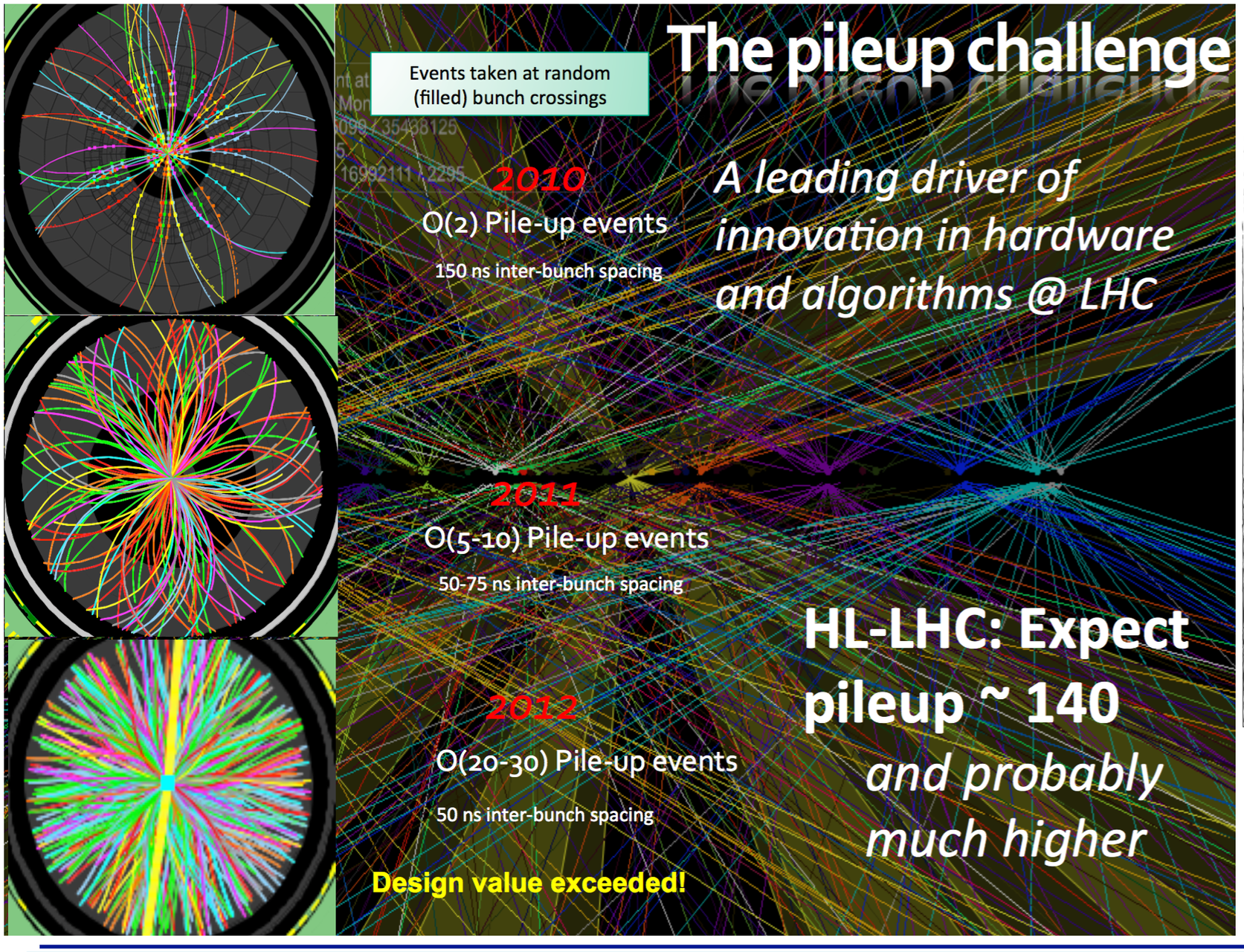
# Fermilab at the LHC

- **Superconducting magnets for the accelerator**
- **Construction and upgrade of the CMS detector**
- **Comprehensive physics program**
- **Host of US-CMS LHC Physics Center**
- **Host of Tier-1 center**
- **Host of Remote Operations Center**
- **Project management of the US-CMS**

# The technological challenge at the HL-LHC

**Unprecedented number of collisions per bunch crossing (up to 200)**

**and radiation dose / neutrino fluence**



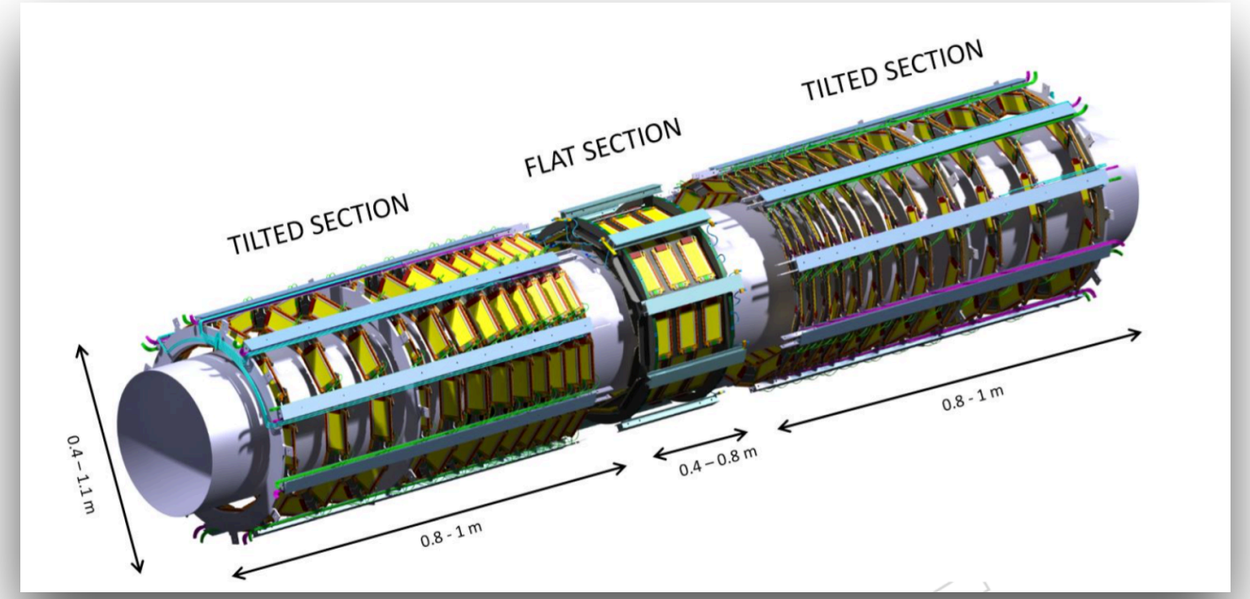

**Extreme radiation hardness and very high granularity detectors are the keys to enable particle identification at CMS in this challenging environment**

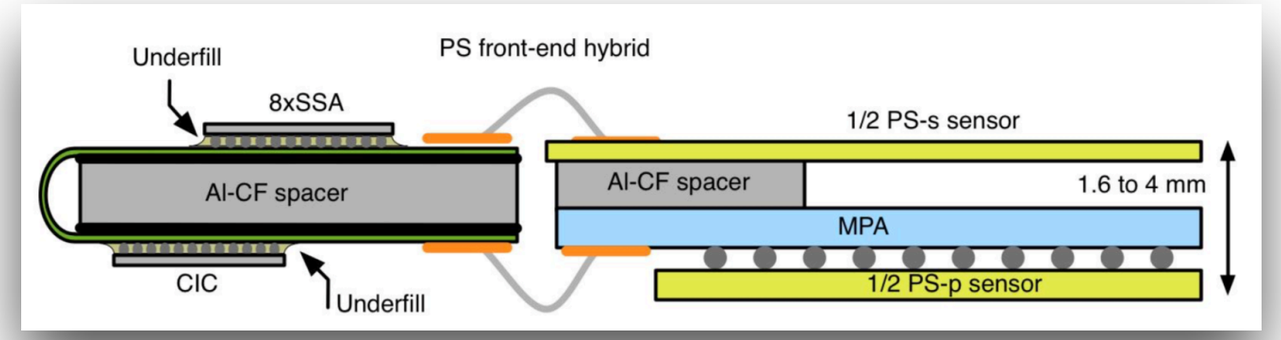
Courtesy of J. Incandela

# Tracking at 40MHz: the Phase 2 Tracker of CMS

**New >200 $m^2$ silicon tracker:**

- **silicon sensors with 10x radiation hardness**
- **4x granularity & larger coverage (>250M channels)**
- **capability to provide tracking info at 40 MHz for the first time at Hadron Colliders (setting the basis for future machines)**




**pT Module**

**Local measurement of track momentum done by 'pT' modules at 40MHz (high density folded hybrids, digital front-end electronics)**

# Triggering at 40MHz: the Phase 2 Track Trigger of CMS

**The performance of current Level-1 trigger will be highly compromised by high pileup**

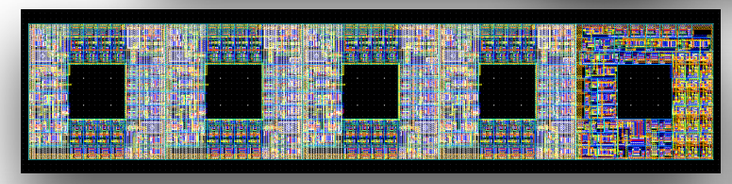
- **higher thresholds leaving interesting physics out**

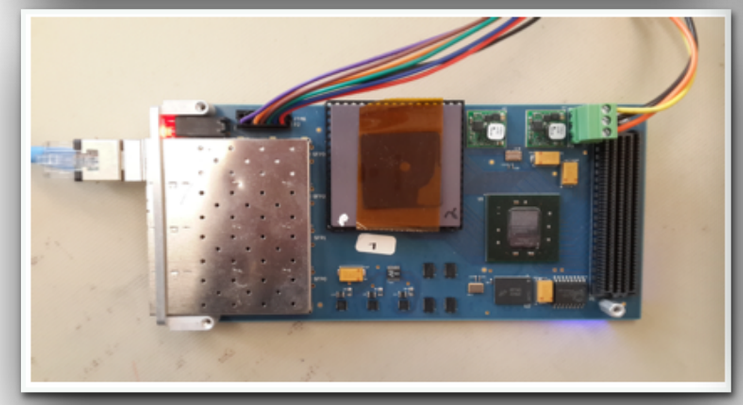
**Use Silicon Tracker data and Particle Flow reconstruction in Level-1 trigger**

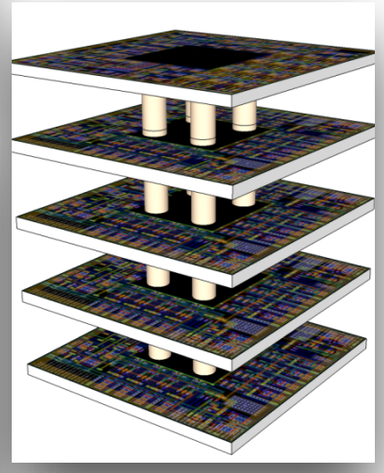
- **Large bandwidth (~100 Tbps)**
- **small latencies (~10 microseconds)**
- **R&D in high speed electronics and fast pattern recognition**

**High speed links, modern FPGAs etc.**

**Technology useful for future high energy/intensity**

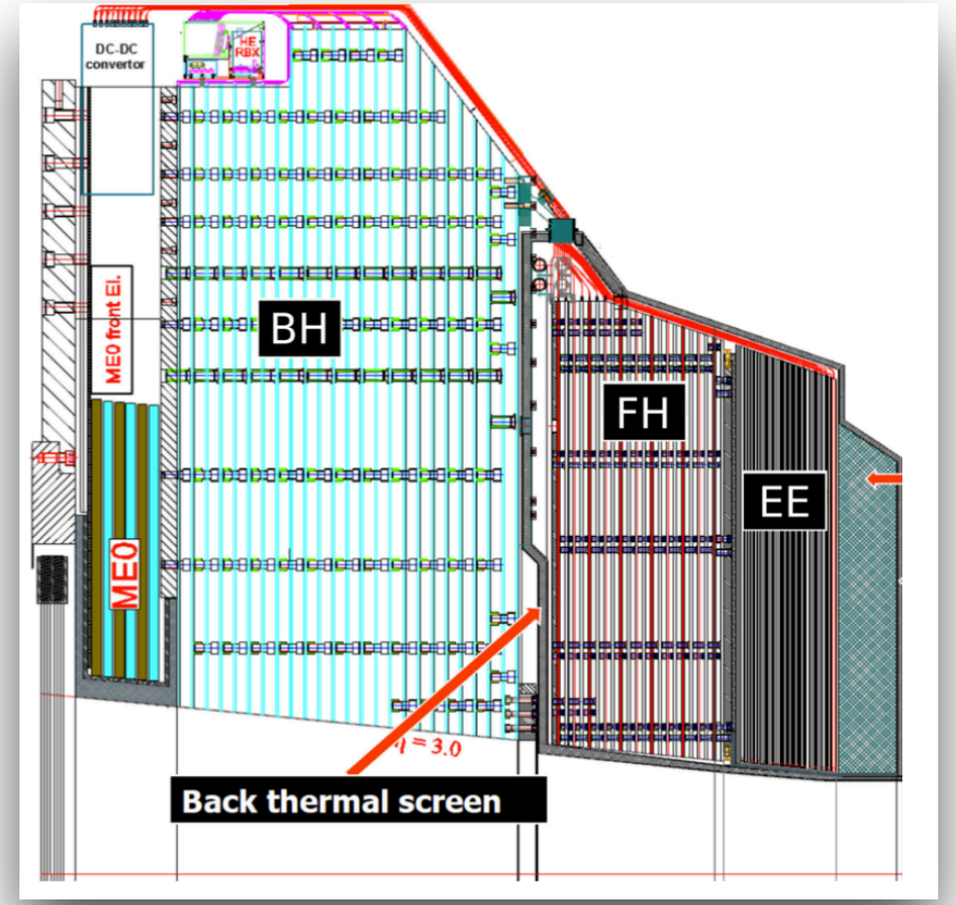


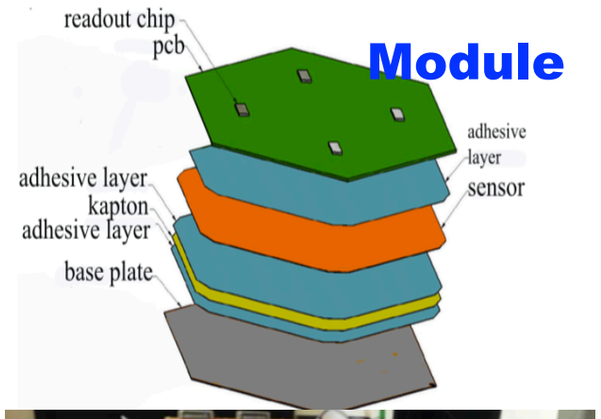


# Imaging Jets: the Phase 2 High Granularity Calorimeter of CMS

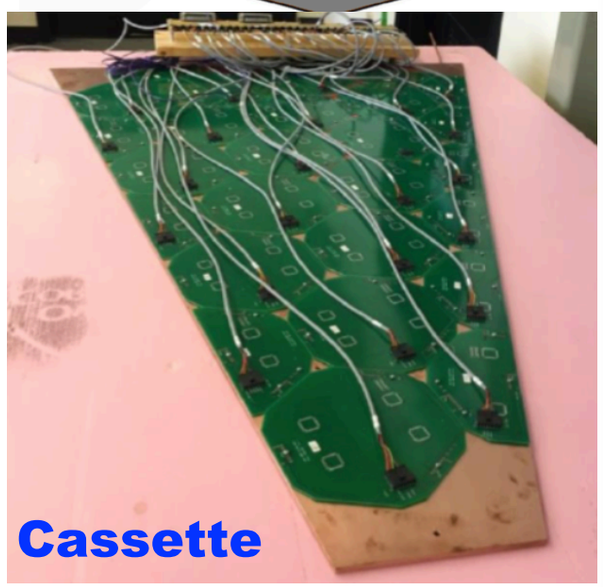
**Innovative choice, a 6M-channel silicon based calorimeter:**

- **radiation hard sensors**
- **providing timing information for pile up suppression**
- **extending tracking to calorimetry with 3D reconstruction of showers**

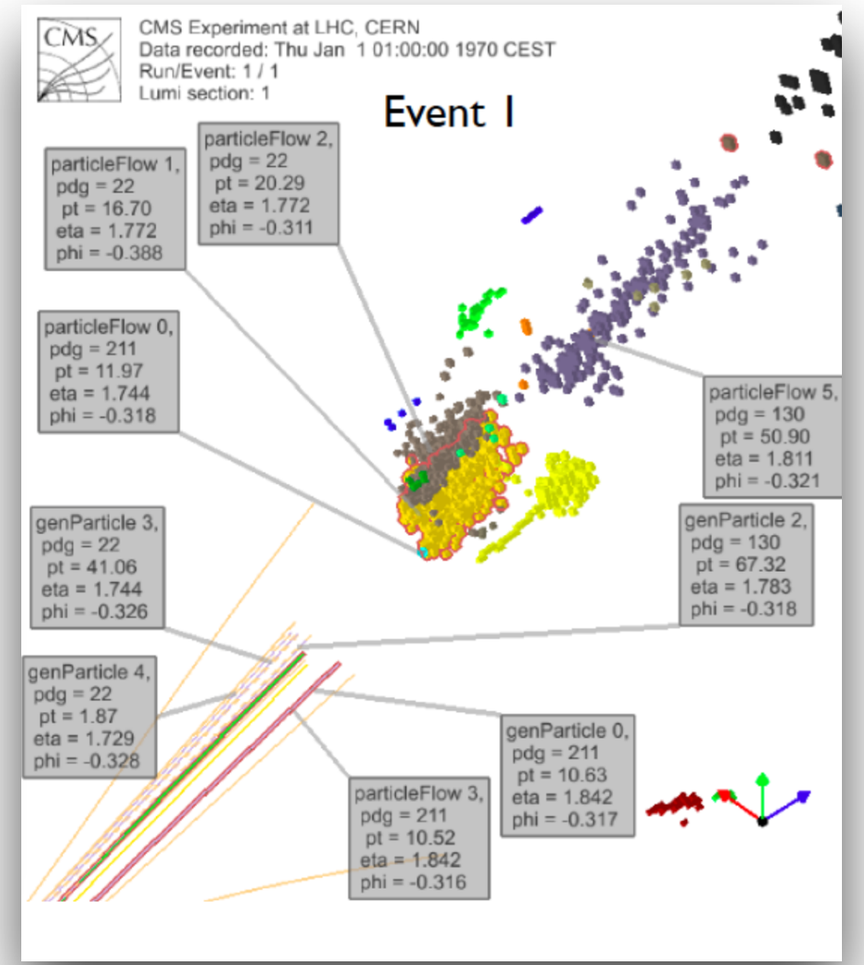



**Module**



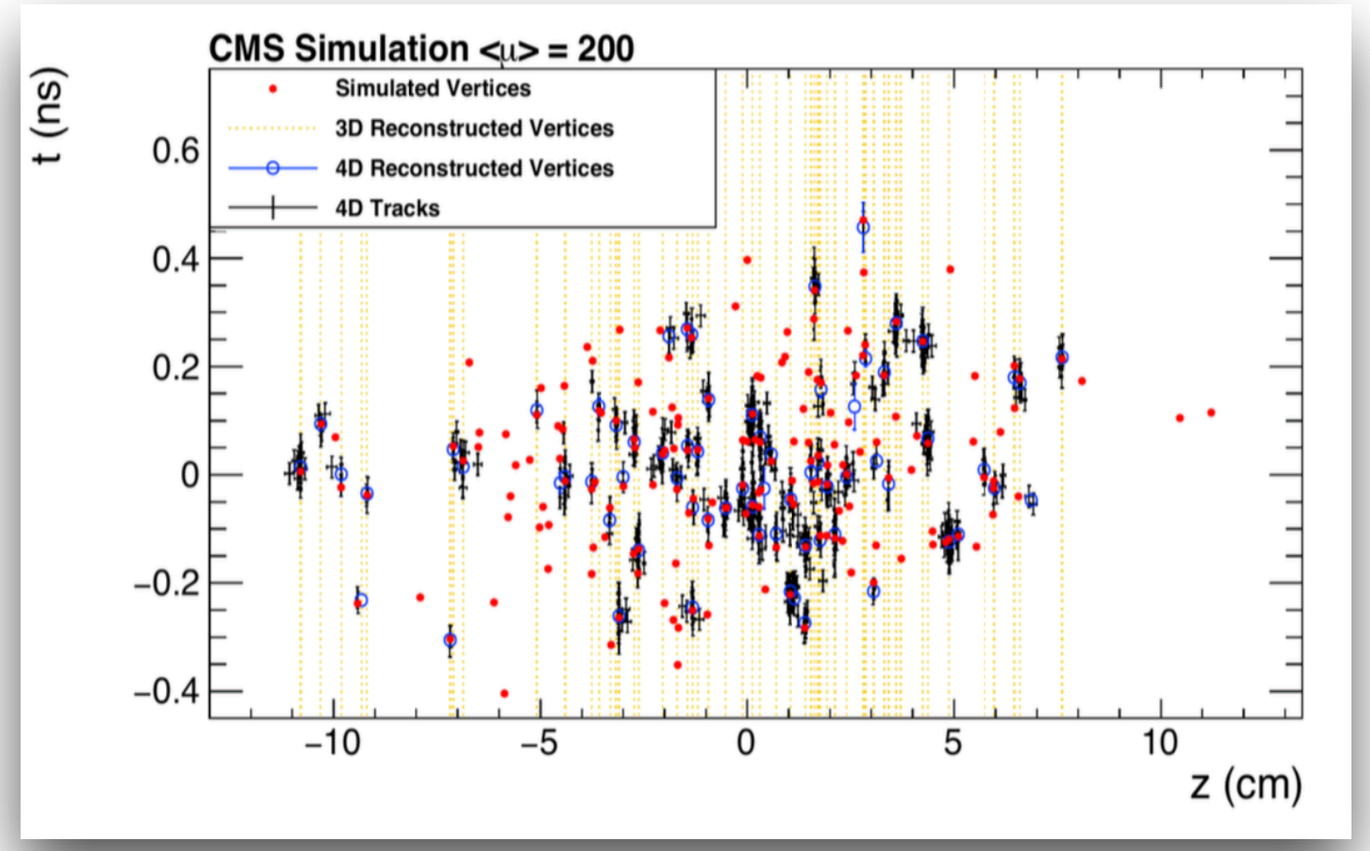
**Cassette**

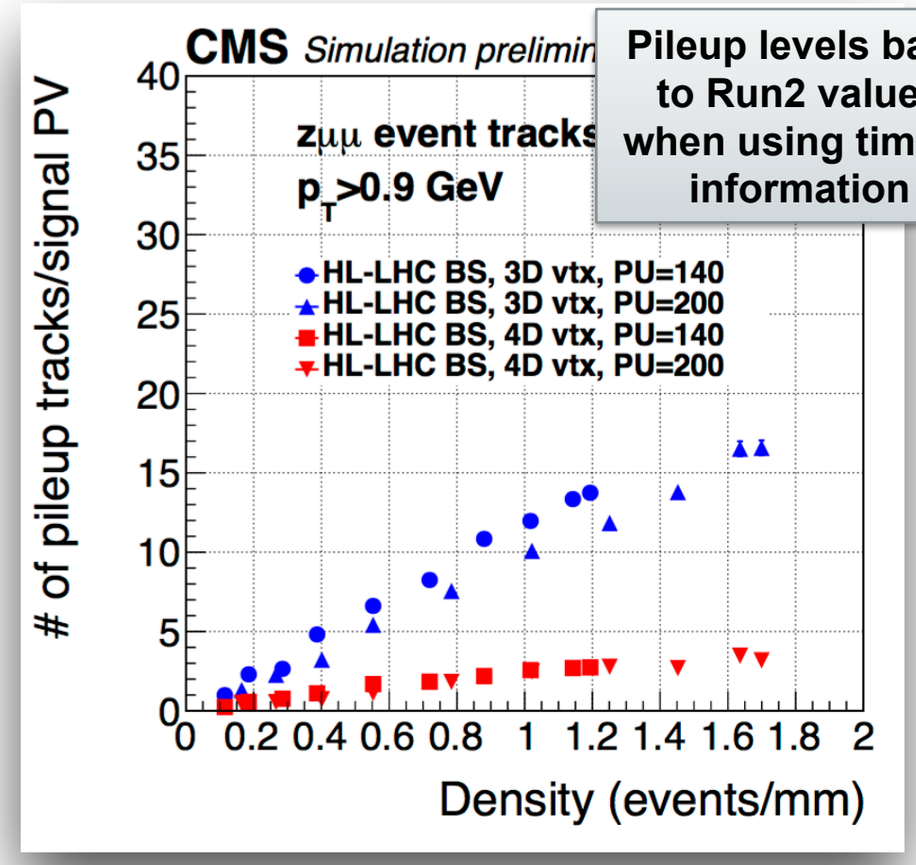


# Timing at the HL-LHC: a timing detector at CMS

**Pile-up is THE challenge at the HL-LHC**

**Timing information allows to further separate hard-scatter collisions from pileup collisions happening close by in z**




**Pileup levels back to Run2 values when using timing information**

**Technological challenges: radiation hardness of sensors and stability of clock distribution, could be revolutionary for hadron collider detectors**

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# LARP

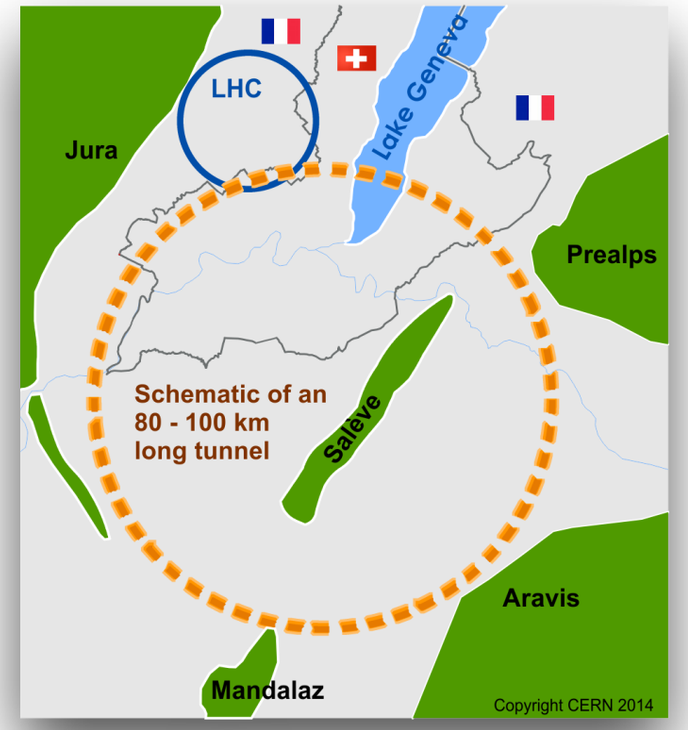
**Main objectives of HL-LHC: operate the machine up to 2035-37 and produce 10x the luminosity reach of first 10 years of LHC operation**

- **Contributions of the US: Large Aperture IR Quadrupoles and Crab Cavities**
- **LARP achieved excellent performances on short/long coils and magnets**
- **Recently the LARP/JLAB Collaboration demonstrated good successes on the front of completion & testing of DQW and RFD Crab Cavities for HL-LHC**

# HE-LHC

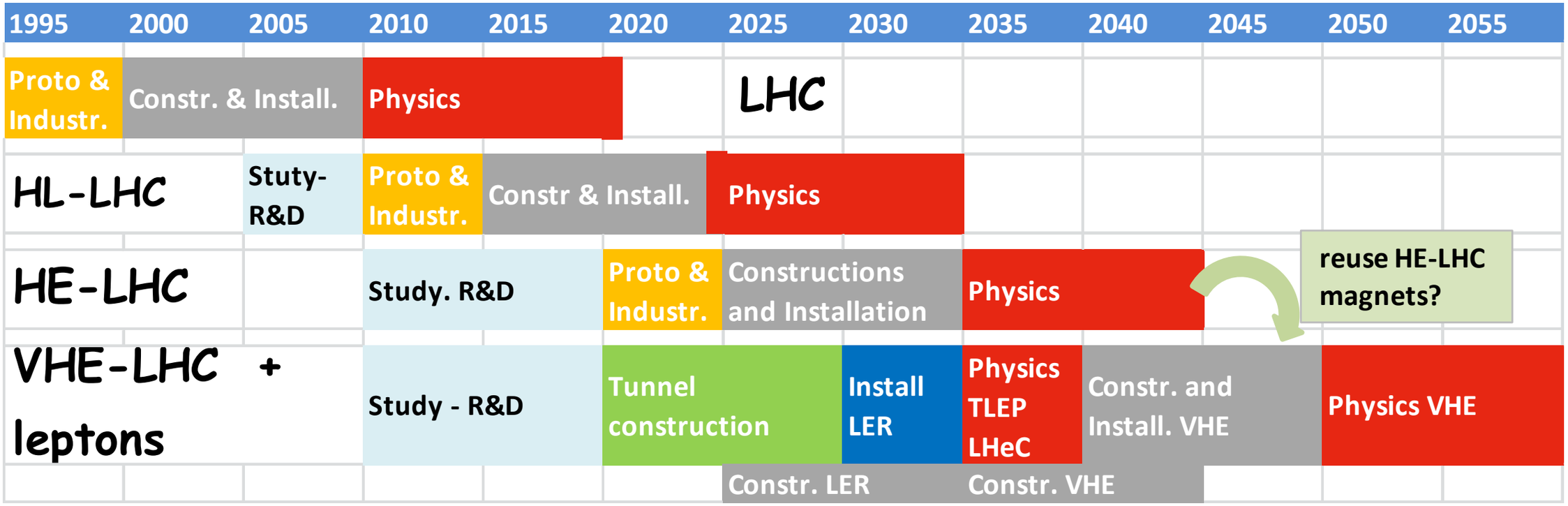
**Future Circular Collider collaboration continues effort on high-field collider in LHC tunnel (2035-)**

- **Yellow Report CERN-2011-1**
- **Energy of 25+ TeV, Luminosity 25x10$^{34}$ cm$^{-2}$s$^{-1}$**
- **Based on 16-T dipoles developed for FCC-hh**
- **Extrapolation from (HL-)LHC and from FCC developments**
- **Extend reach for new physics by approximately a factor of 2 in masses**
- **Can detectors be largely reused ?**
- **Goal for the FCC collaboration to complete CDR by the next European Strategy update in 2018/2019**



# Sketch schedule

From presentation by F. Zimmermann in 2013



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# Additional Material

# Phase 1 Upgrade of the CMS detector

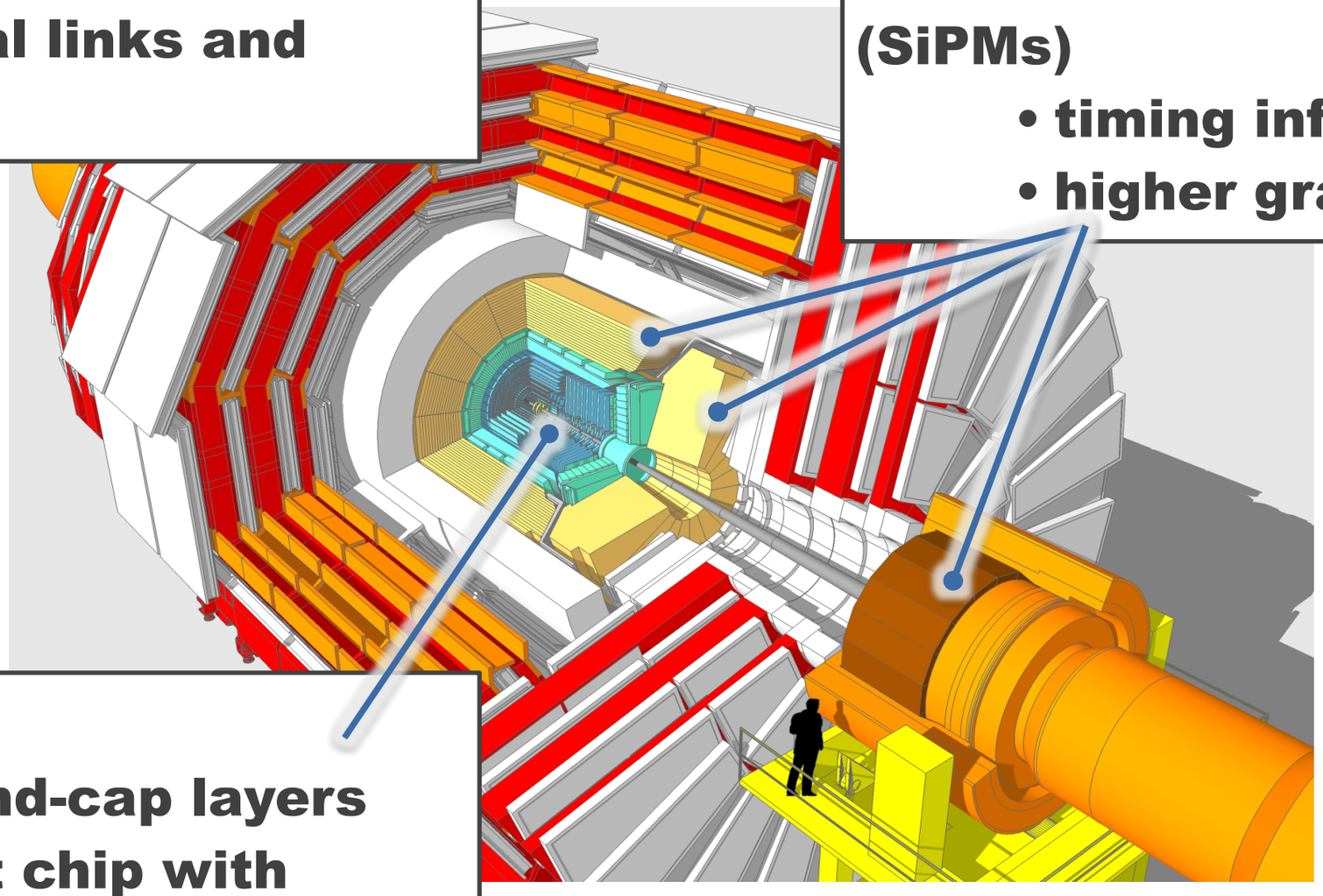
**Level 1 trigger**

**Conversion from VME to uTCA system (optical links and FPGAs)**

**Hadron Calorimeter**

**New "front-end" photosensors (SiPMs)**

- **timing information**
- **higher granularity**

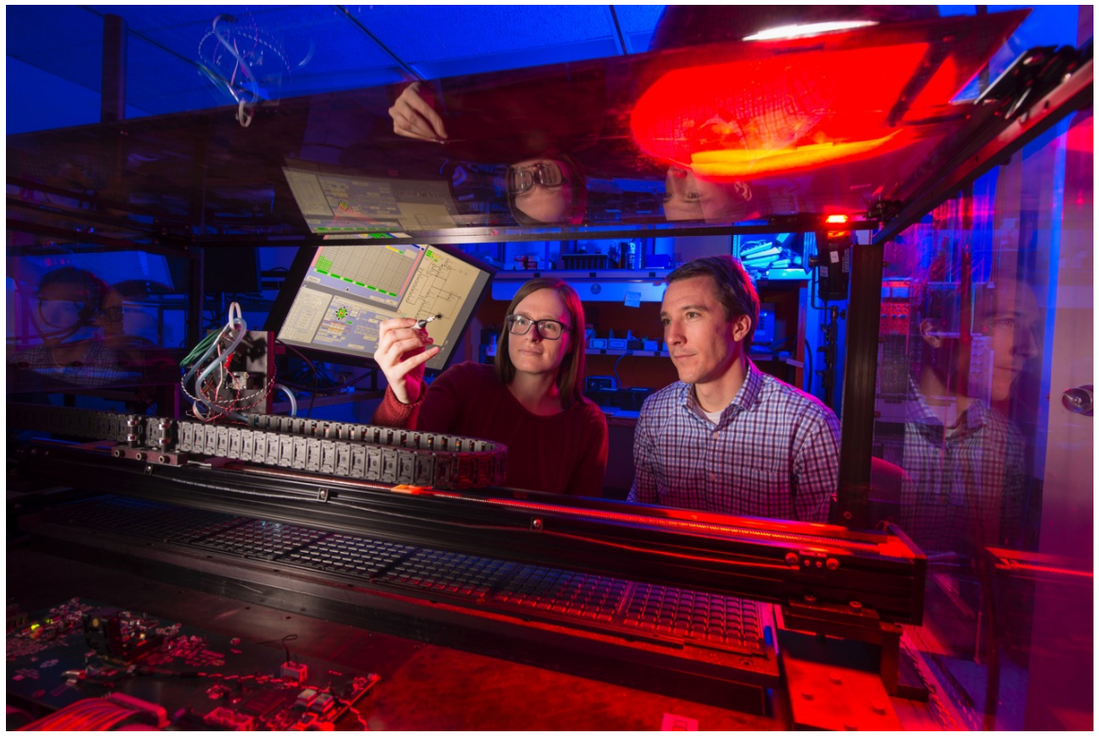


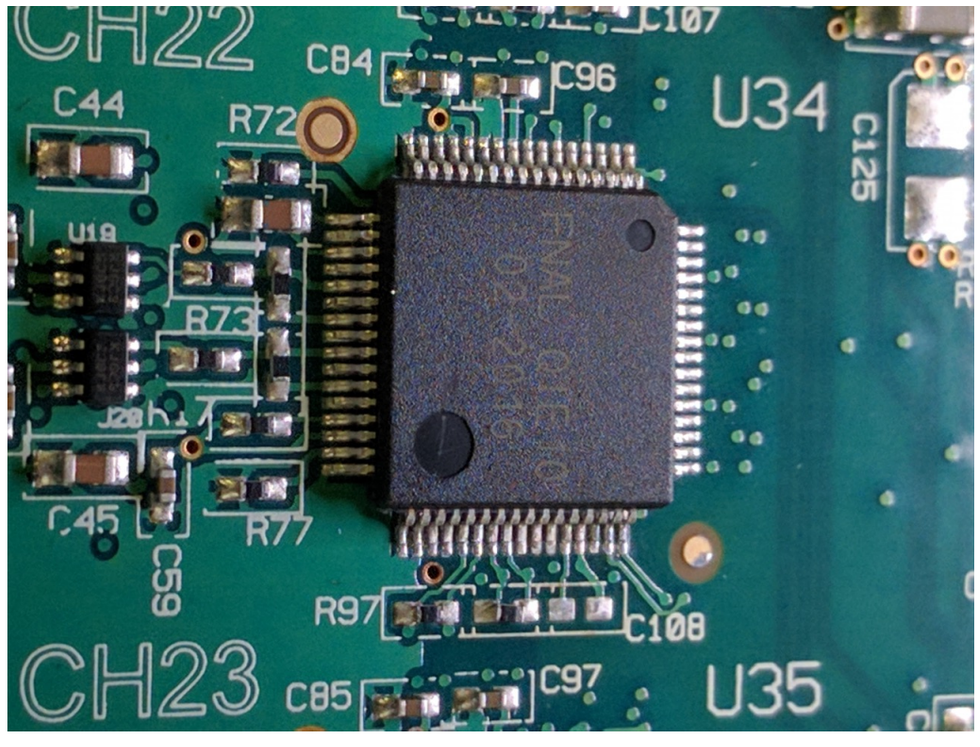
**Pixel Detector**

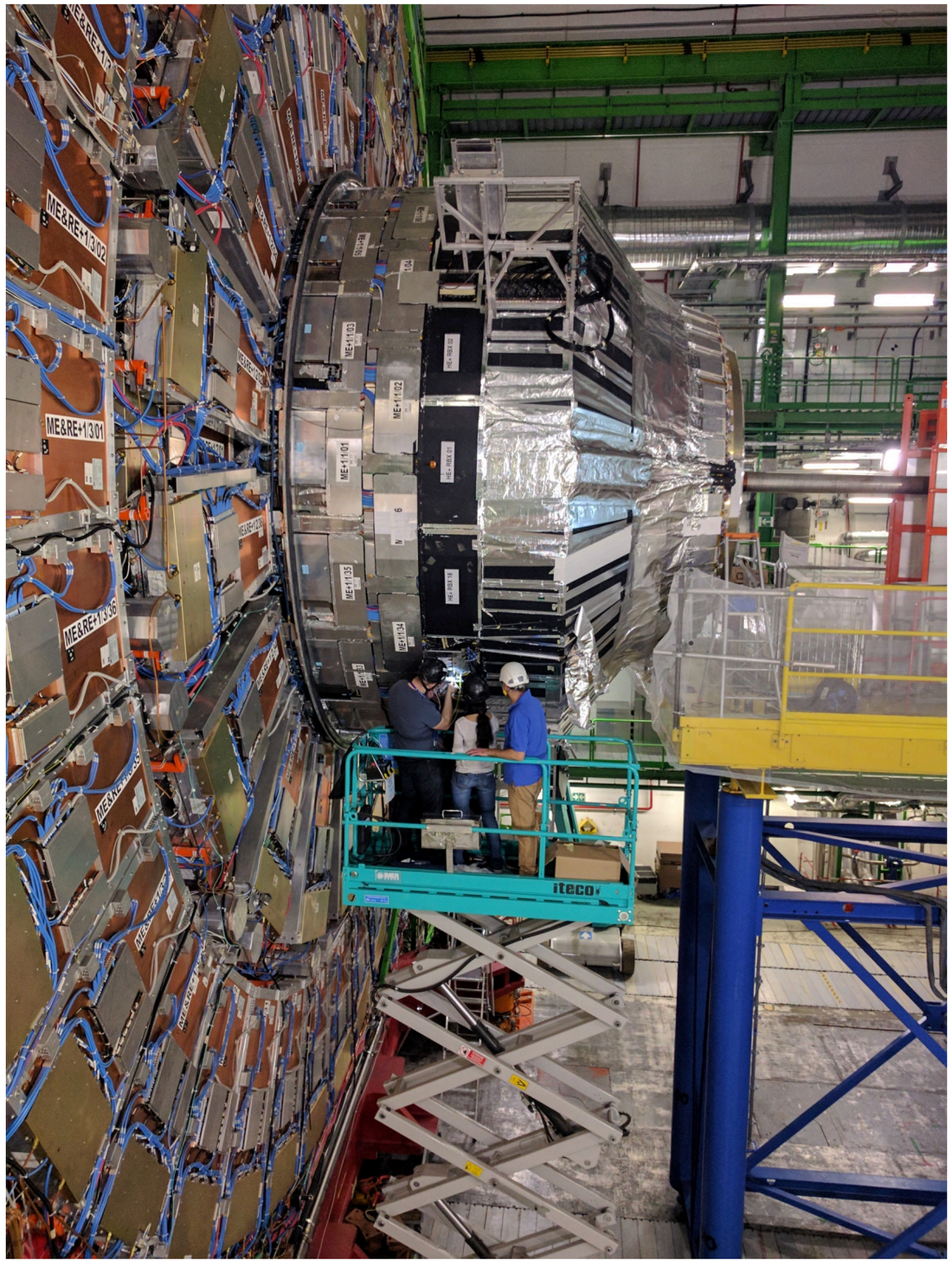
**4 barrel & 3 end-cap layers**

- **readout chip with deeper buffers, higher speed**
- **less mass**

# Phase 1 Upgrade of the CMS detector





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# Phase 1 Upgrade of the CMS detector

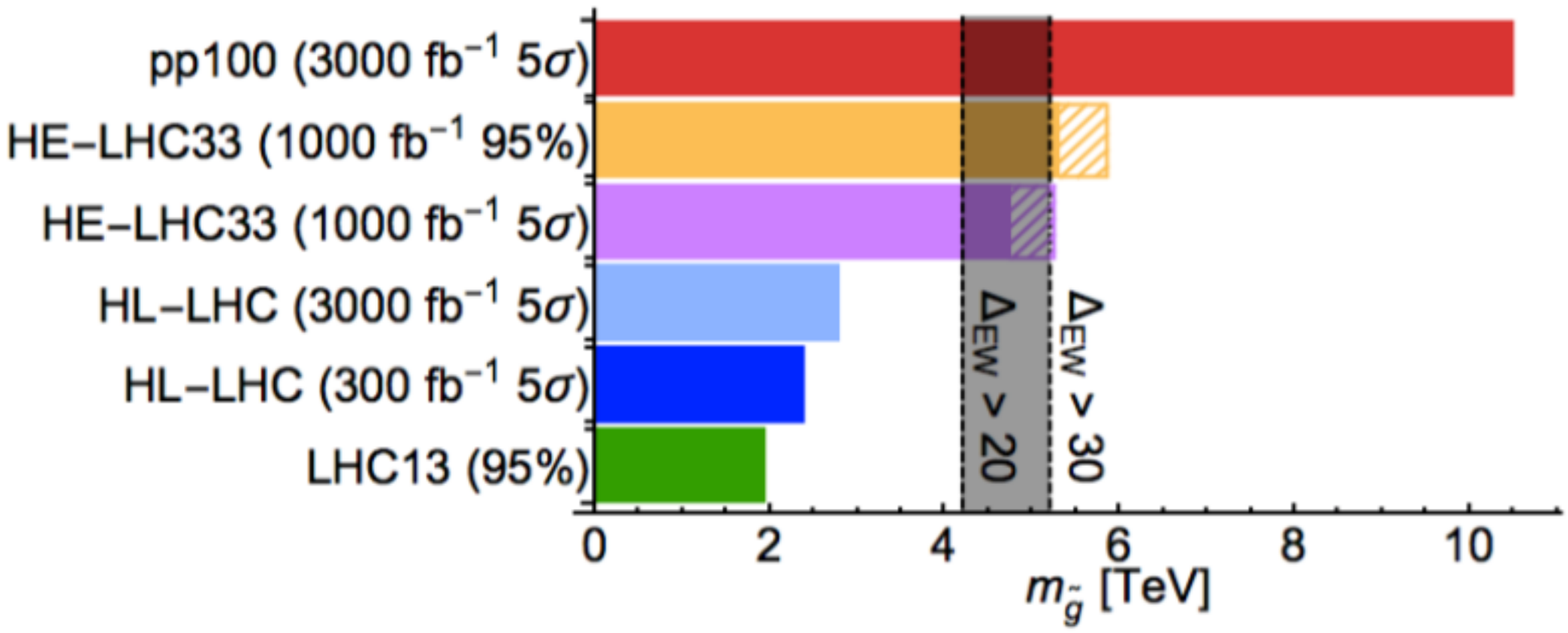
G. Apollinari

# HL-LHC AUP

- HL-LHC Accelerator Upgrade Project (AUP) has received formal CD-0 (Mission Need) Approval in March 2016.
- HL-LHC AUP Management Team in TD
- HL-LHC AUP gearing up for CD-1 (Cost & Schedule Range) Review in August 2017.
  - HL-LHC AUP Production Plans for both Magnets and Cavities foresee major involvement from TD technical resources
    - Coil Production, Magnet Cold Mass Assembly, Cryostat Assembly and Final Test
    - Crab Cavities Production, processing and testing

US HL-LHC AUP

# Collider reach for Gluinos in Natural SUSY



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