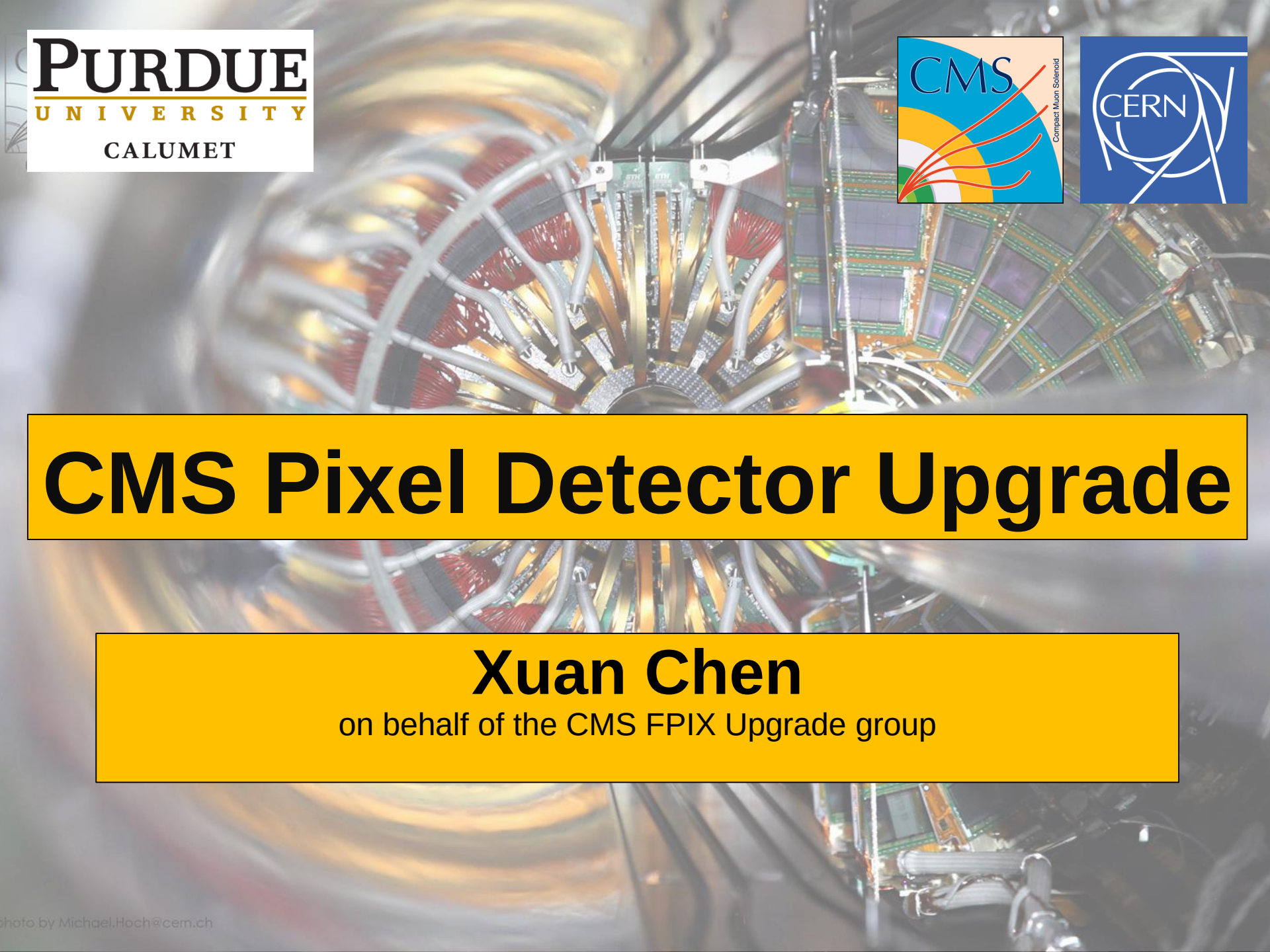


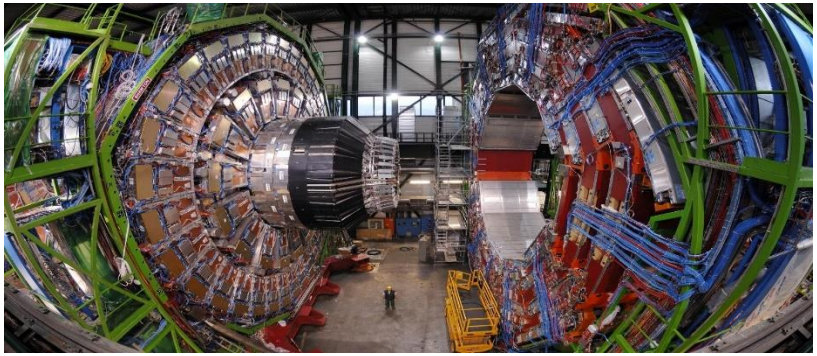
CMS Pixel Detector Upgrade

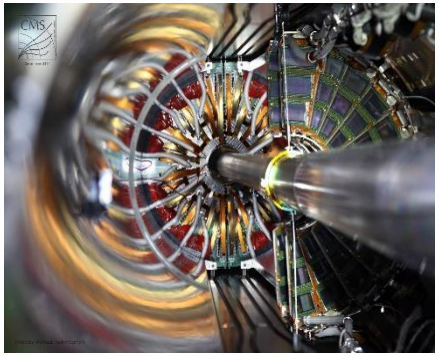
Xuan Chen

on behalf of the CMS FPIX Upgrade group

Outline

- The LHC
- The CMS detector
- The phase 0 pixel detector
- The phase 1 pixel detector upgrade

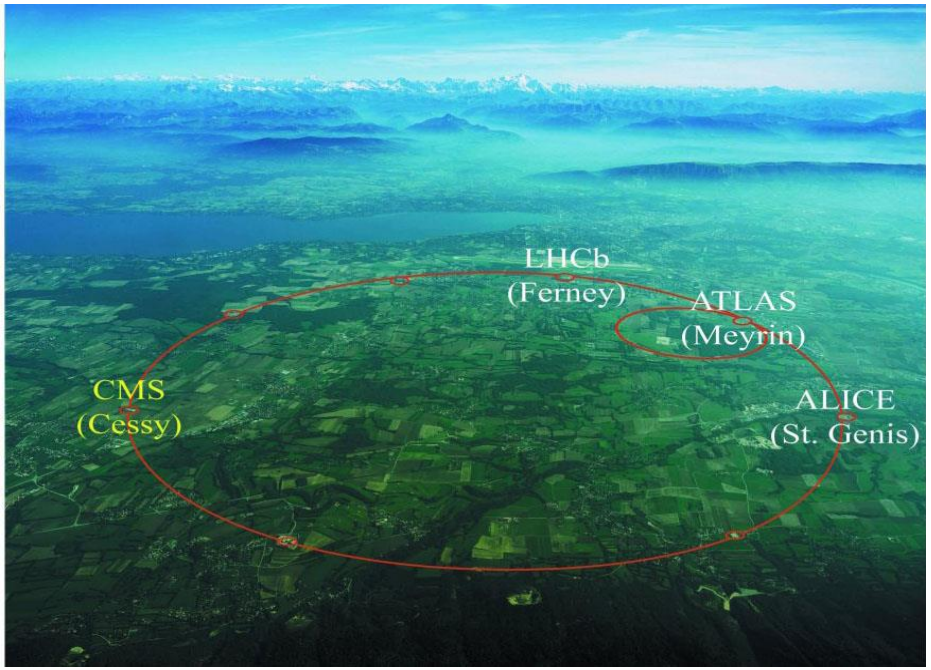




LHC **CMS** **Pixel Detector**

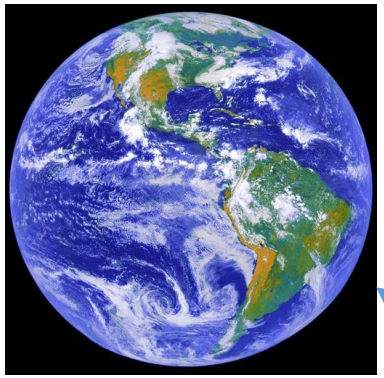
The Large Hadron Collider

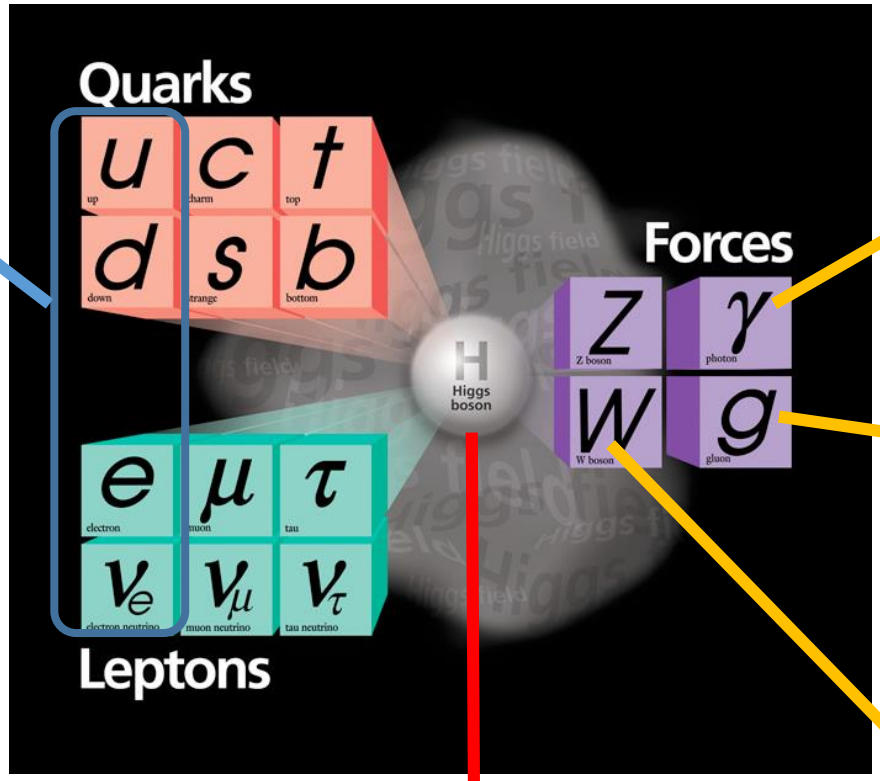
- 17-mile circumference hadron collider across Switzerland and France
- Located at the European Organization for Nuclear Research (CERN)
- 14 Trillion electron-volt (TeV) proton-proton collision design energy

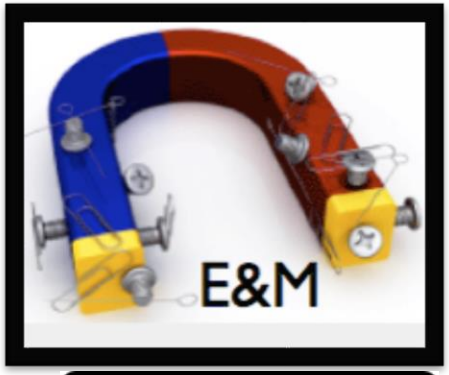


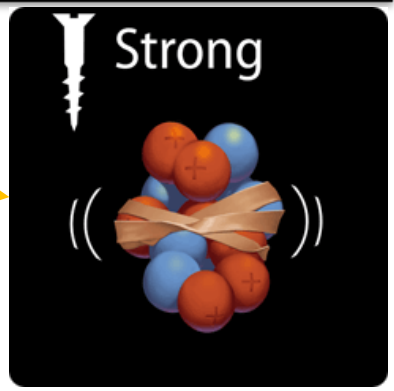
- Accelerates protons to 99.999999% the speed of light
- 4 state-of-the-art particle detectors: CMS, ATLAS, ALICE, LHCb
- Allows precision tests of the Standard Model of Particle Physics, and searches for the Higgs Boson and other New Physics beyond Standard Model

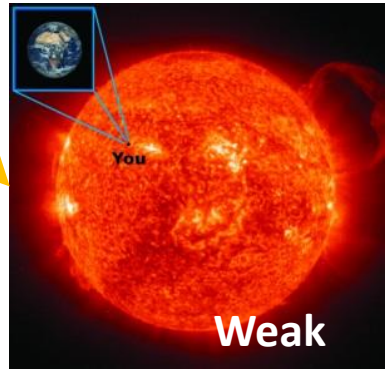
Standard Model



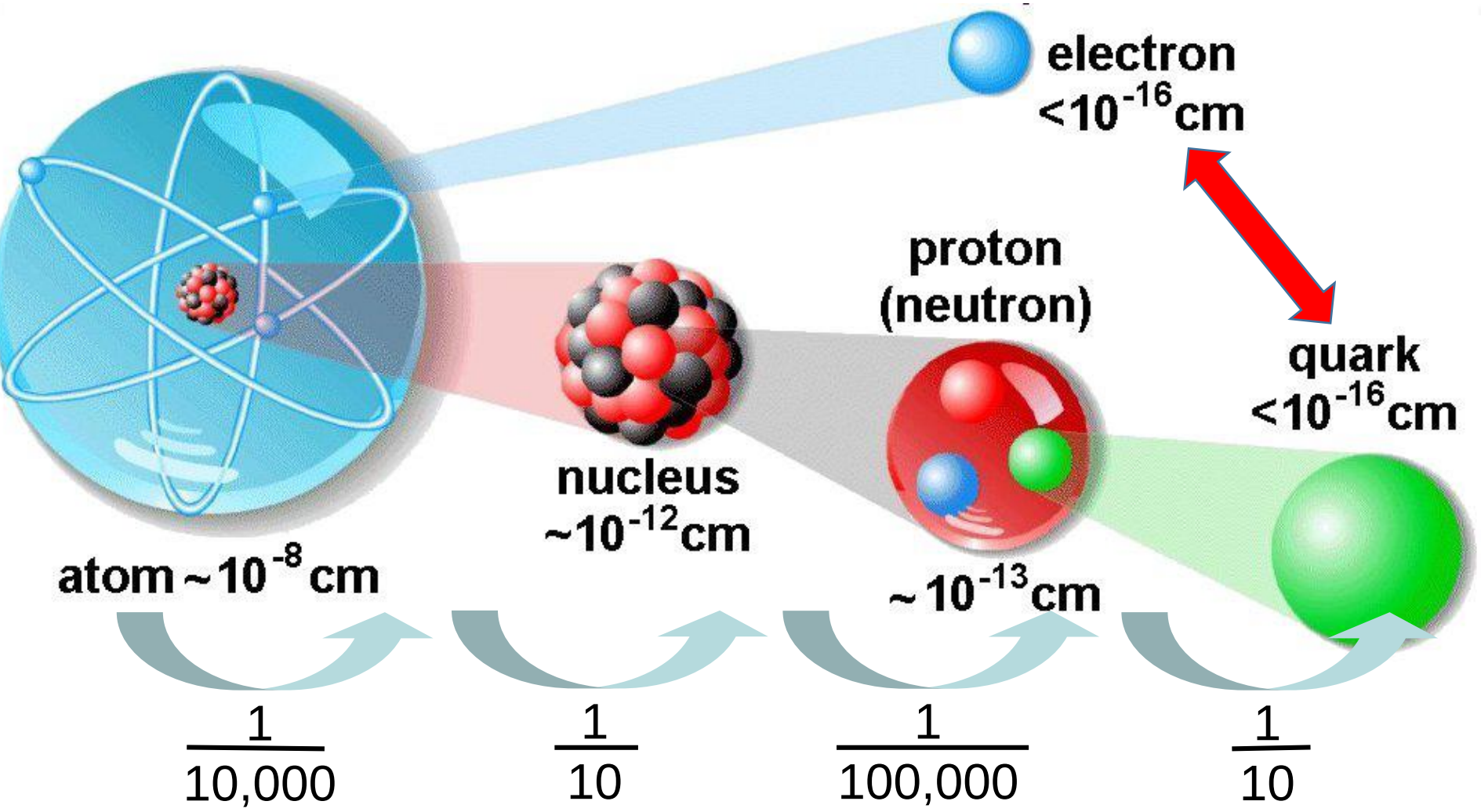




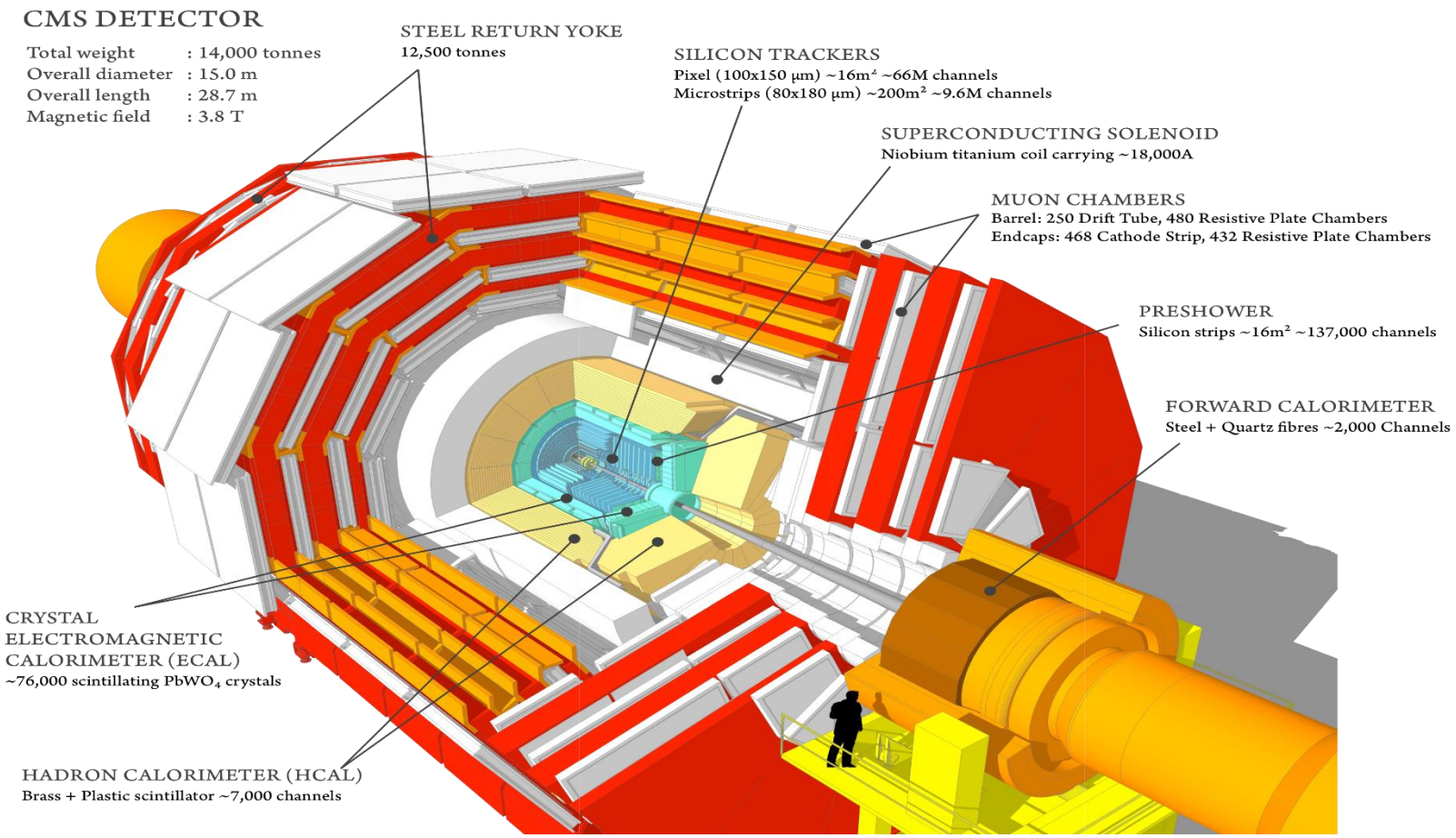




Sense of Scale



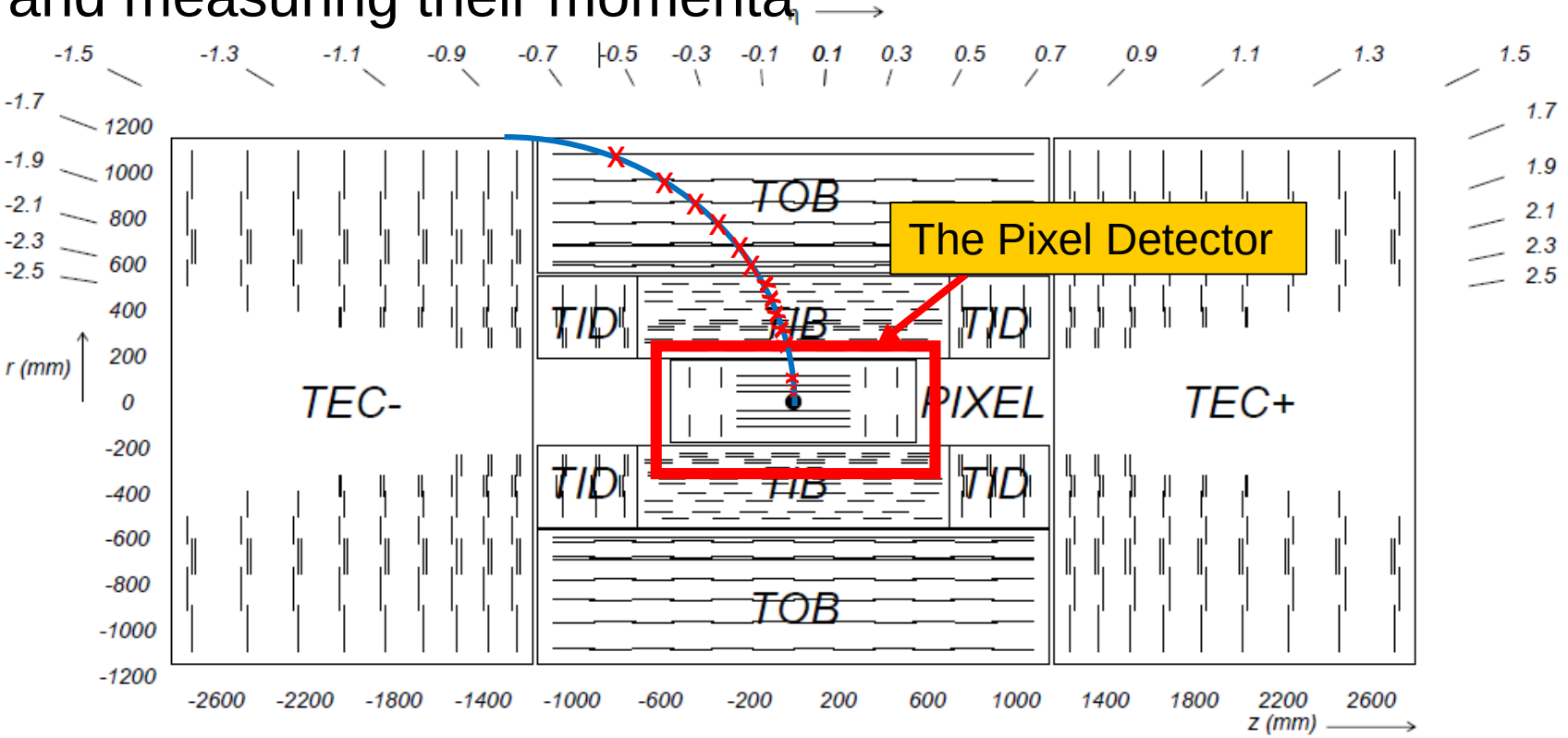
The Compact Muon Solenoid (CMS)



- General purpose, “onion-like” detector to study LHC collisions
- Designed for LHC luminosities of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with 25 ns bunch spacing

Silicon Tracker

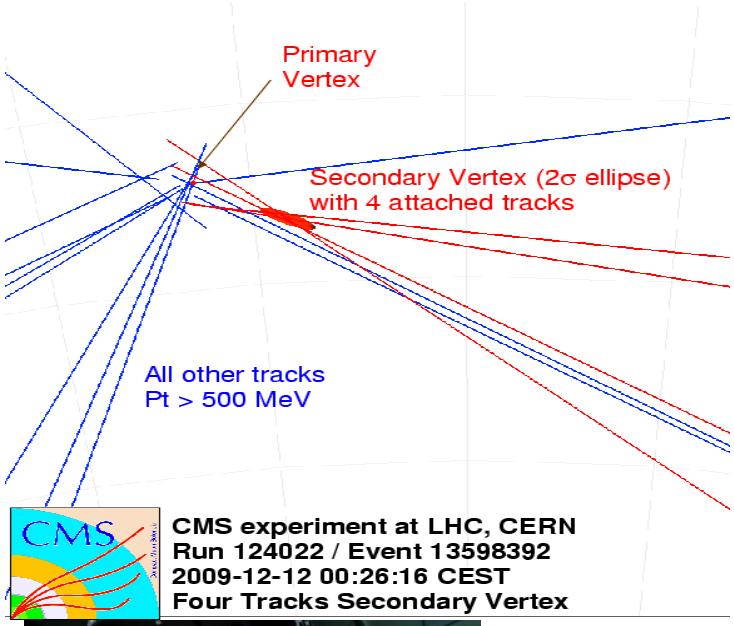
- Responsible for recording the trajectory of charged particles and measuring their momenta



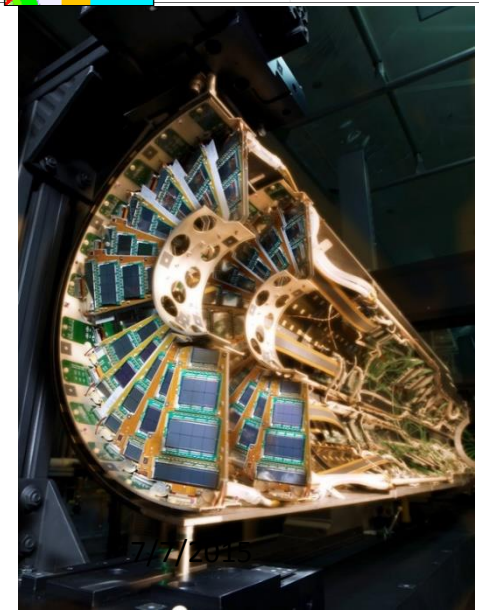
Pixel Detector:
- 3 Barrel Pixel Layers (BPIX), 2 x 2 Forward Pixel Disks (FPIX)

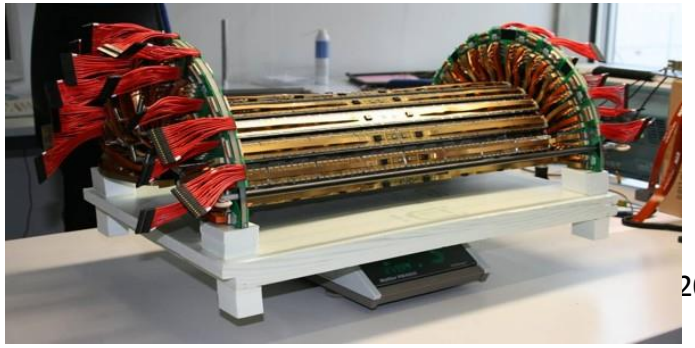
Si Strip Tracker:
- 4 Inner Barrel Layers (TIB), 6 Outer Layers (TOB)
- 3 x 2 Forward Inner Disks (TID), 9 x 2 Outer Disks (TEC)

Current Pixel Detector – Phase 0



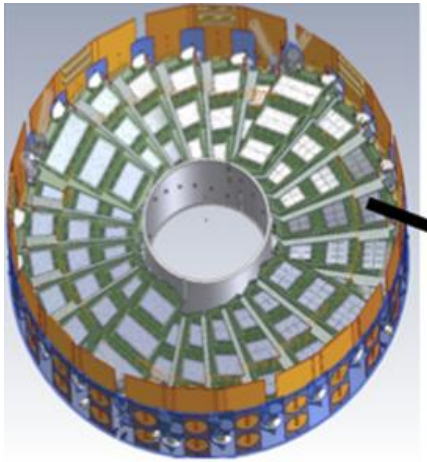
- The pixel detector is the closest detector to the interaction point
- Provides precise track and vertex reconstruction
- Integral part of the Tracker
- Made of silicon with 65 million pixels
- Pixels record the passage of charged particles
- Precise 3D position measurement
  - Each pixel is 100 µm by 150 µm
- Hit resolution of 10 µm
- 40 MHz analog readout



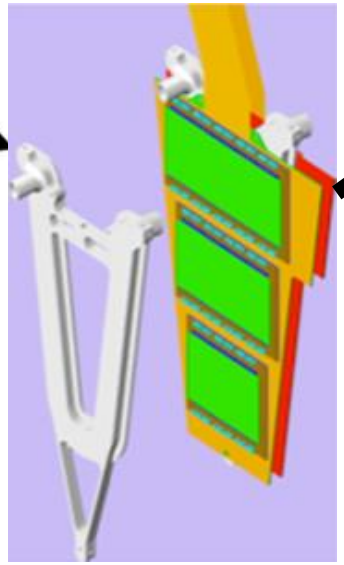


Phase 0 FPIX Detector

- 4 Forward/Endcap Disks (FPIX)
- Populated with 672 pixel modules (called plaquettes), with five different types (with 2 to 10 ROCs)

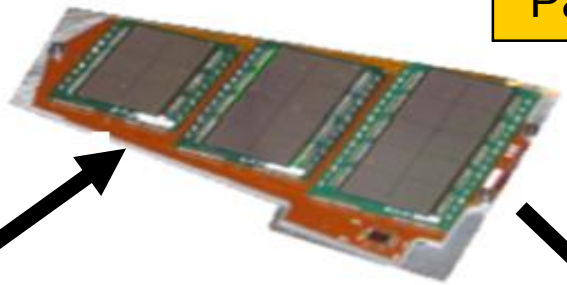


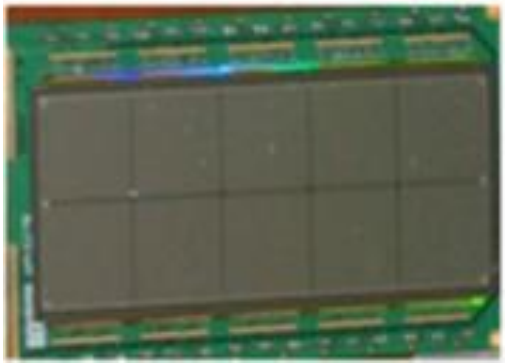
Disk



Blade

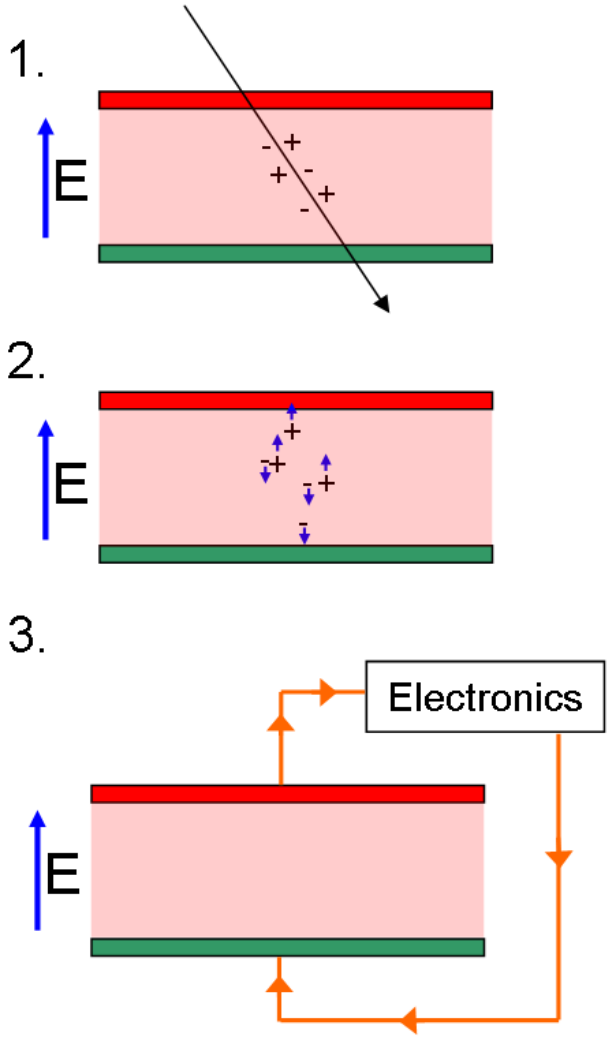
Panel





Plaquette

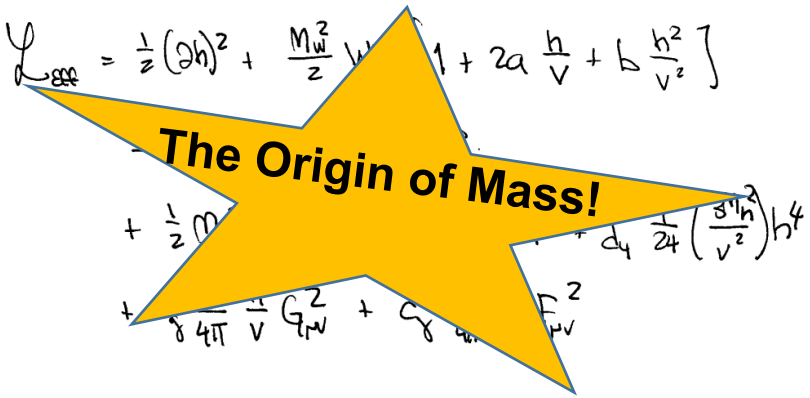
Pixel Detector

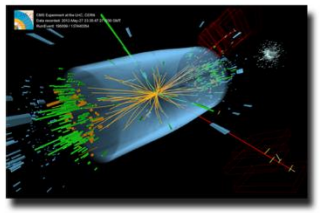


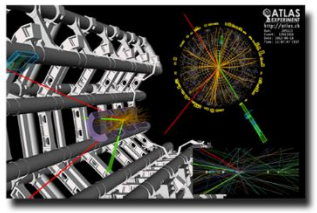
- When a particle passes through pixel detector, it knocks loose electron-hole pairs and doesn't stop at all.
- The electron-hole pairs are pulled in opposite directions by an electric field, and pulled into "contacts."
- The charge built up on those contacts produces a current that flows into electronics

Higgs Boson Discovery

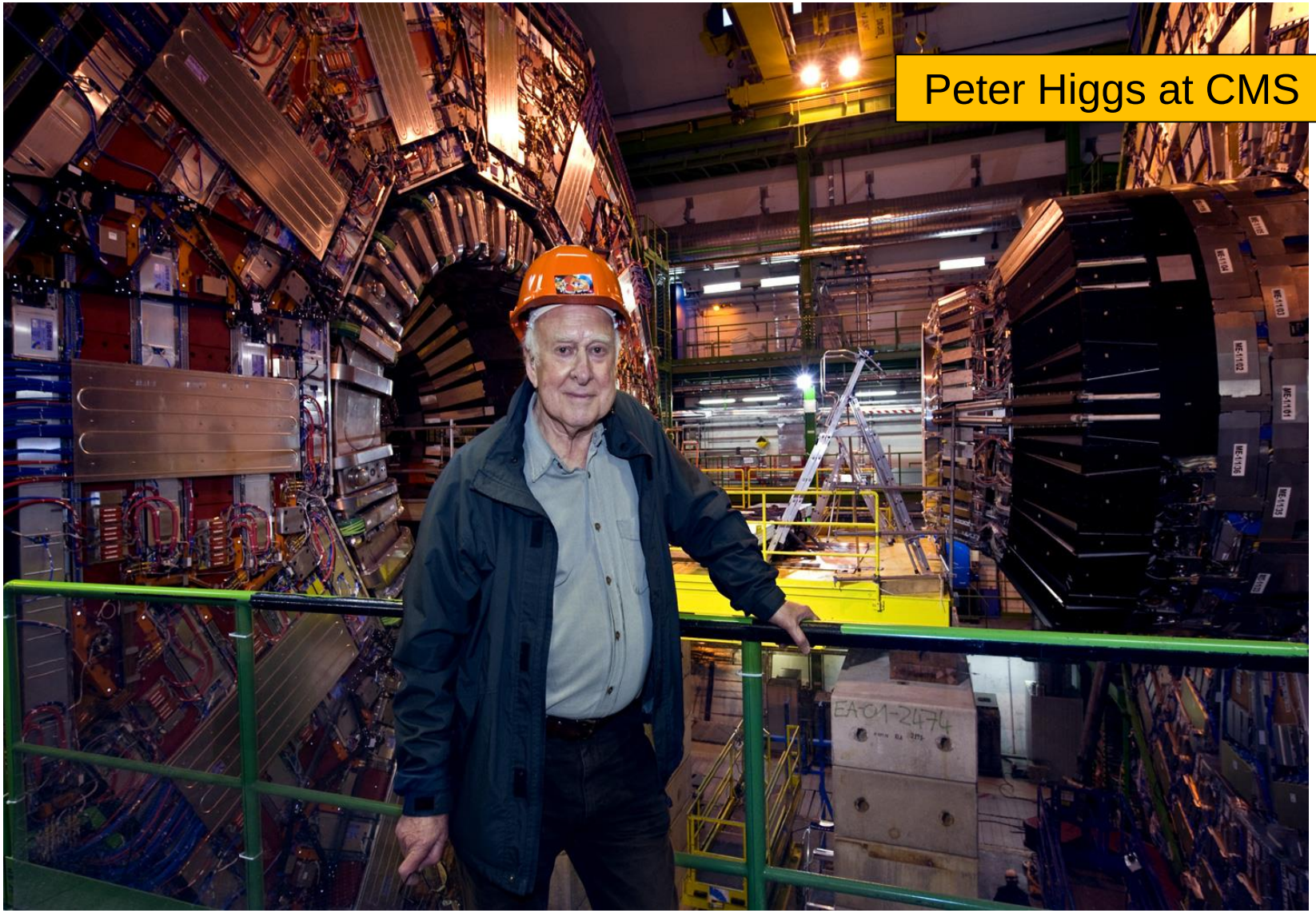
- CMS and ATLAS collaborations at the LHC discovered the Higgs Boson in 2012, confirming the theory proposed by the 2013 Nobel Prize winners



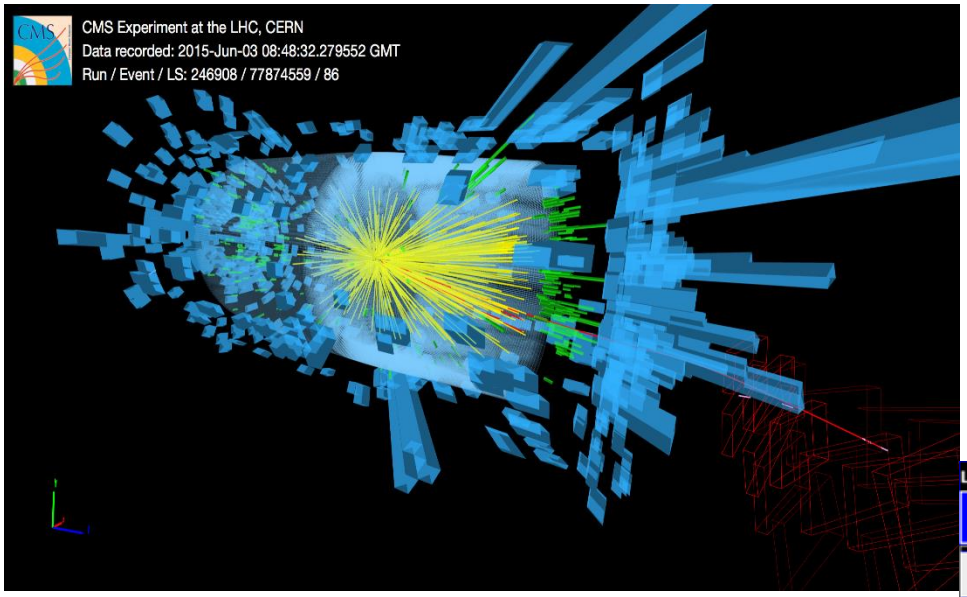




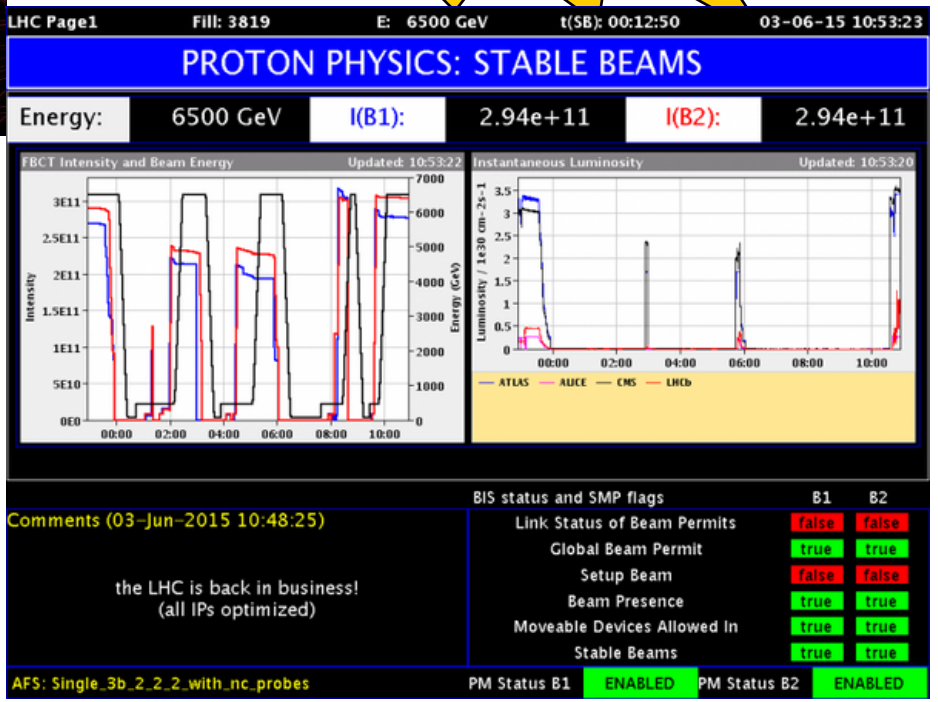
Higgs Boson Discovery



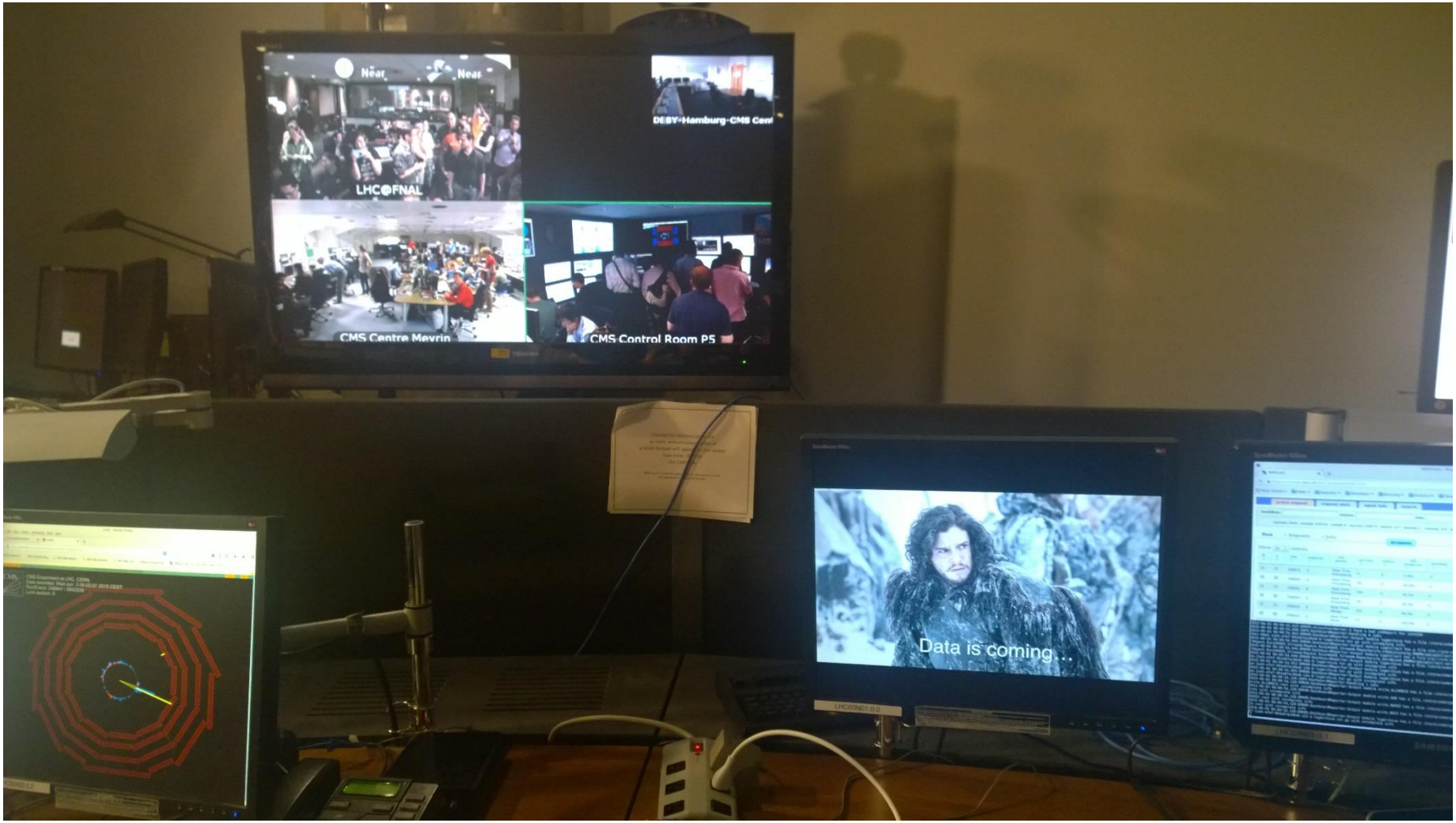
The LHC Run II



First Collision at 13 TeV!!!

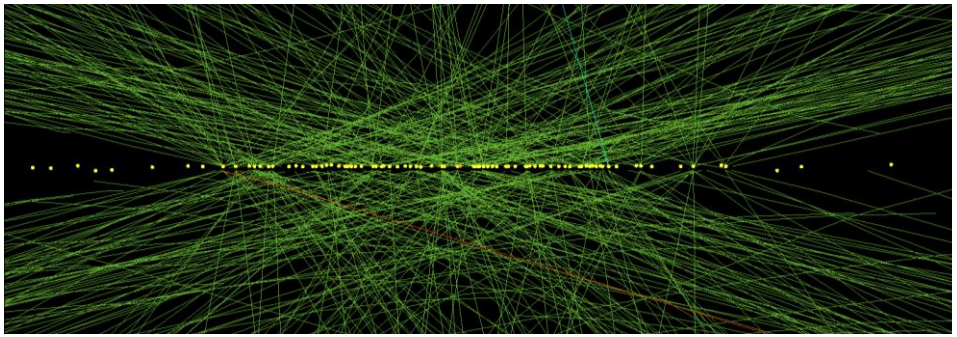


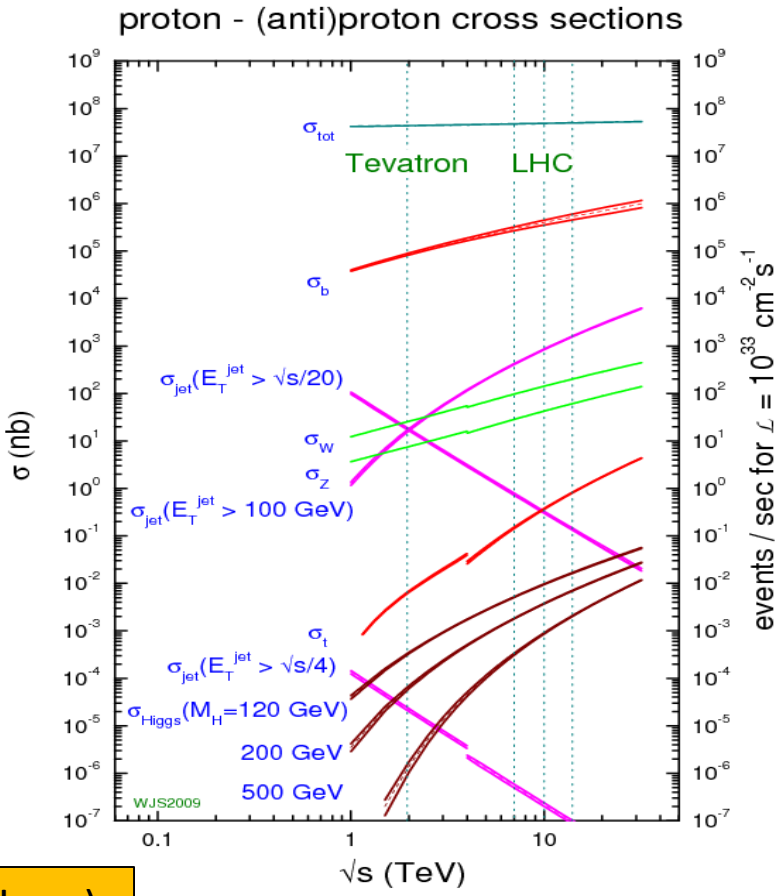
The LHC Run II



The LHC Run II

- Increased energy and luminosity offer unique potential for historic discoveries
  - Precision Higgs physics
  - Additional Higgs bosons
  - Dark Matter
  - Extra spatial dimensions
  - SuperSymmetry
  - Etc…

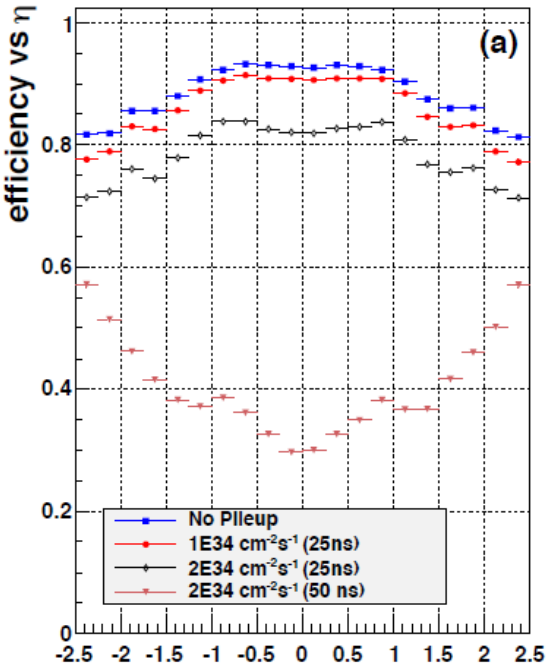


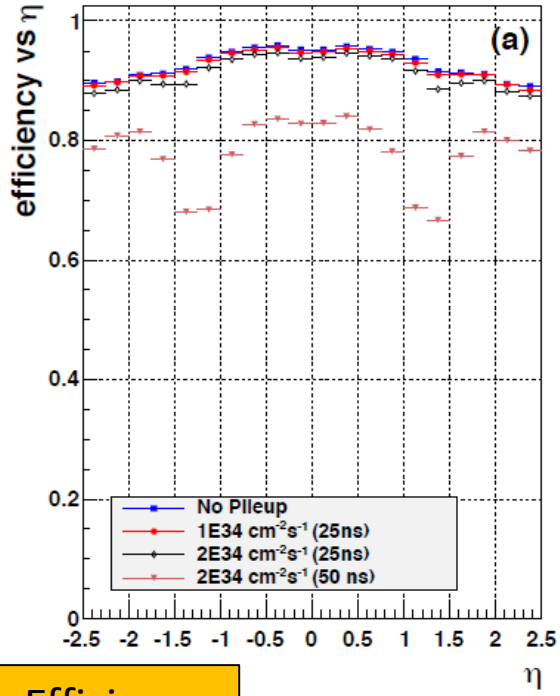


Many Simultaneous overlapping soft interactions (pileup)

Challenges

Current Detector



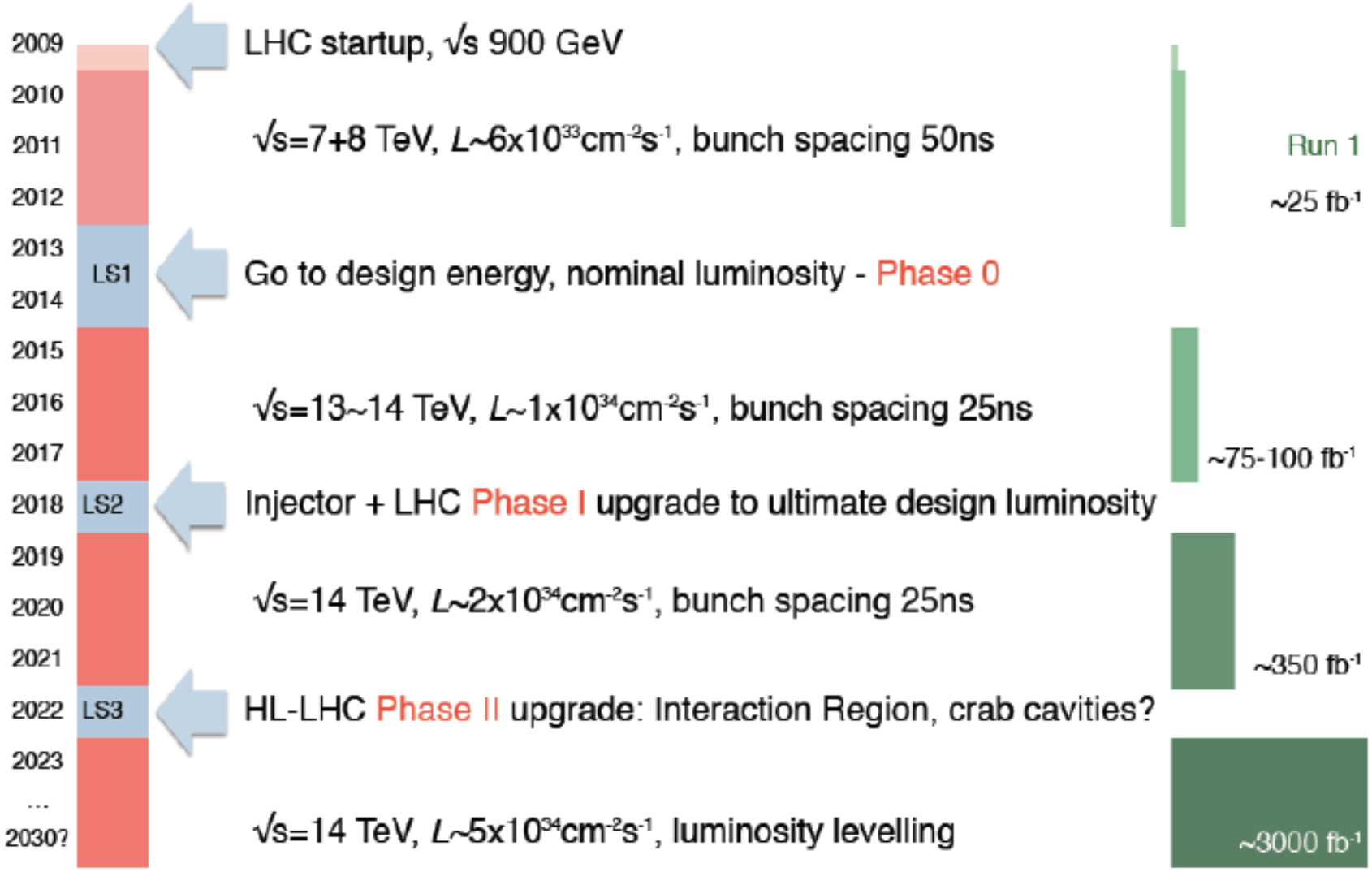


Upgrade Detector

Tracking Efficiency

- **High energy and luminosity brings new challenges**
  - Extreme pile-up conditions
  - High hit rate and data transfer requirements, which the current pixel detector can't satisfy

The LHC Upgrade

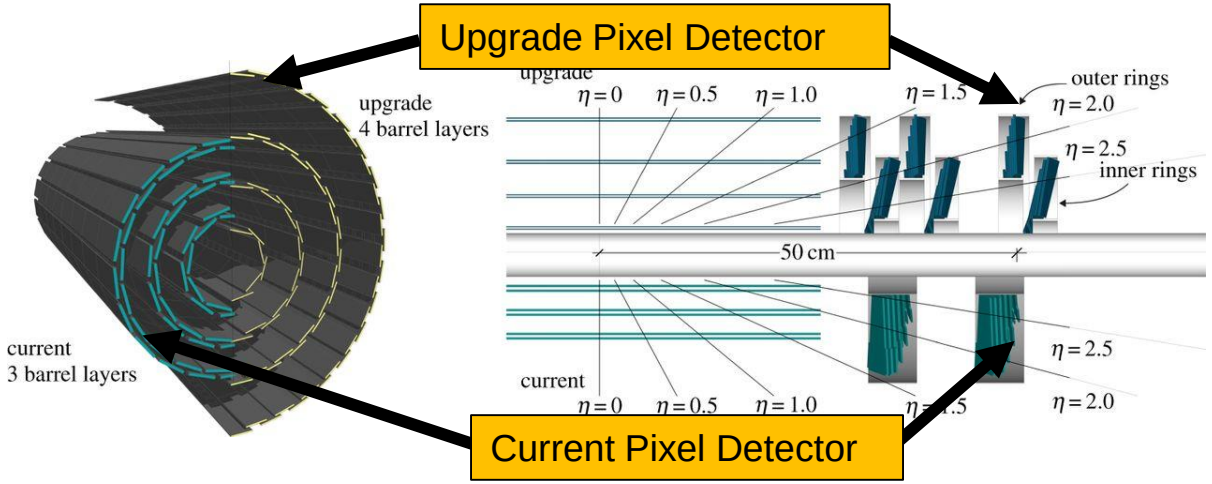


The Pixel Detector – Phase I Upgrade

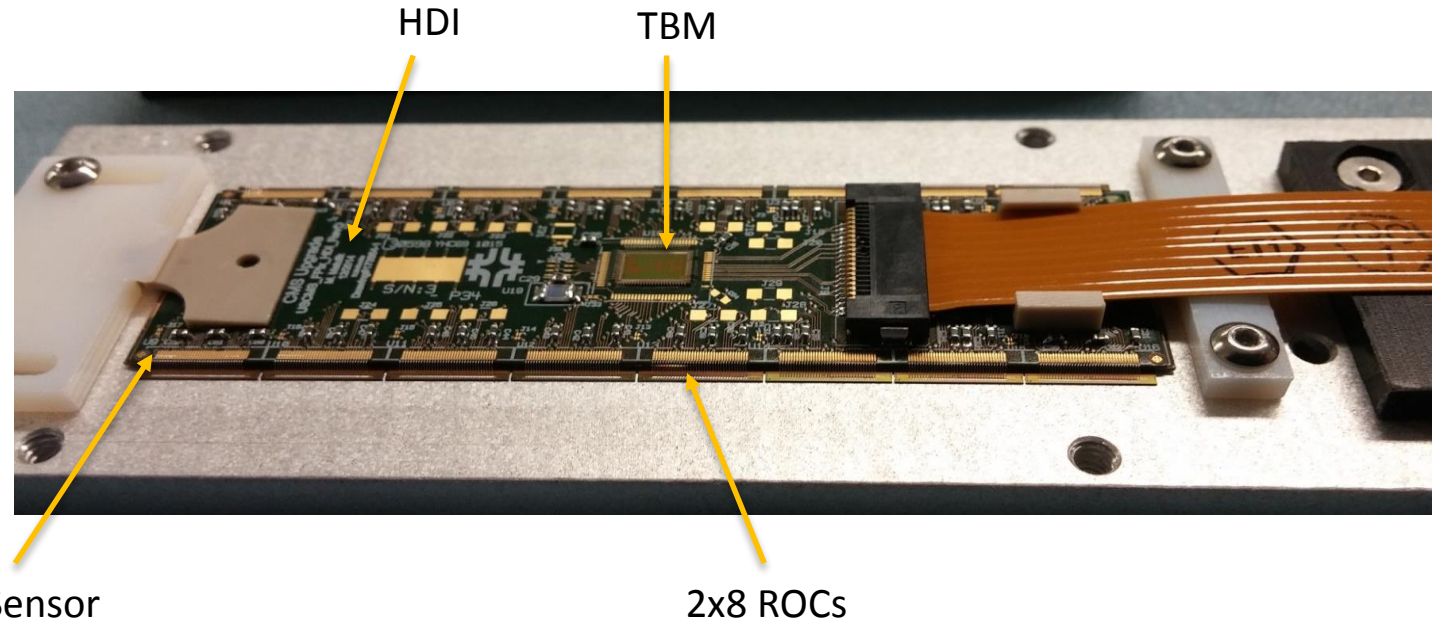
- Maintain or improve current level of performance under extreme pile-up conditions
  - Sustain the high efficiencies and low fake rates of the current detector
  - Preserve hit resolution of current detector
- Improve radiation hardness
- Minimize data loss due to latencies

The Pixel Detector – Phase I Upgrade

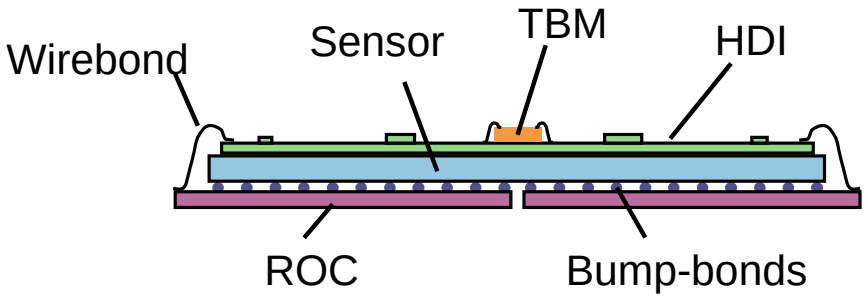
- Optimized detector layout for 4-pixel-hit coverage over the full tracker acceptance
  - Barrel layers from 3 to 4; Forward disks from 4 to 6
- Reduced material budget
  - New cooling system based on two-phase CO_2
- New pixel readout chip (ROC) and token bit manger (TBM), digital readout (160MHz)
- Improved pattern recognition and track reconstruction



FPIX Module

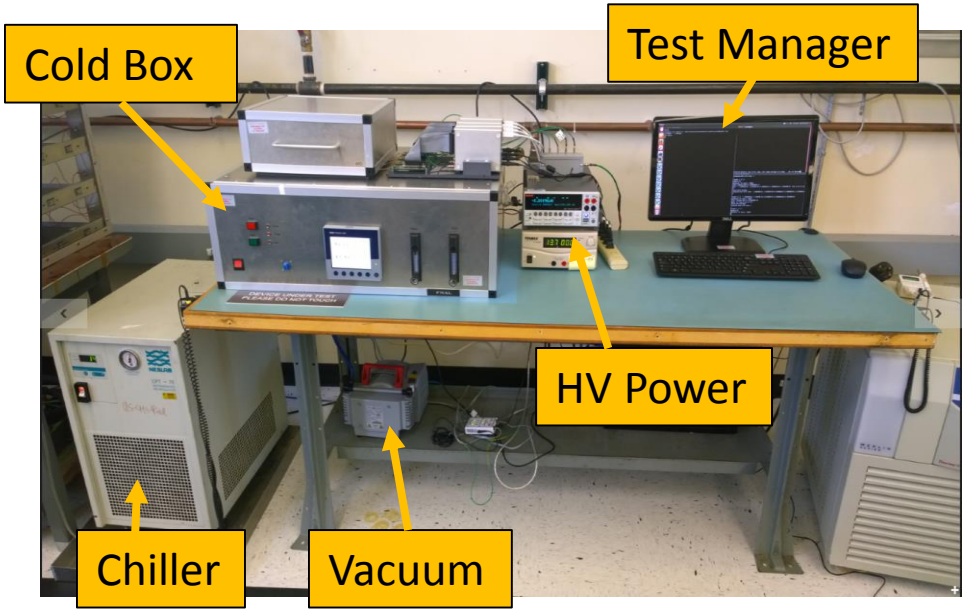


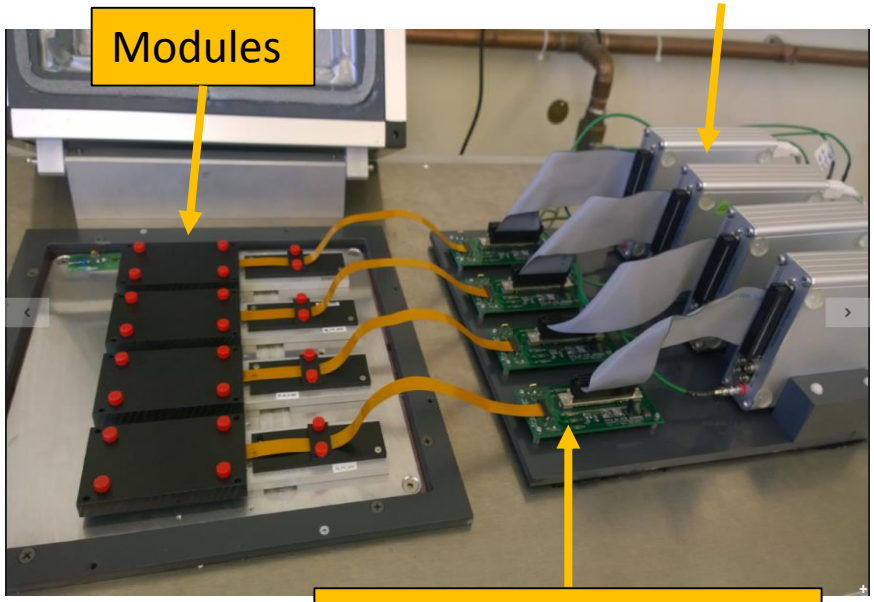
Schematic cross section:



Module Testing & Qualification

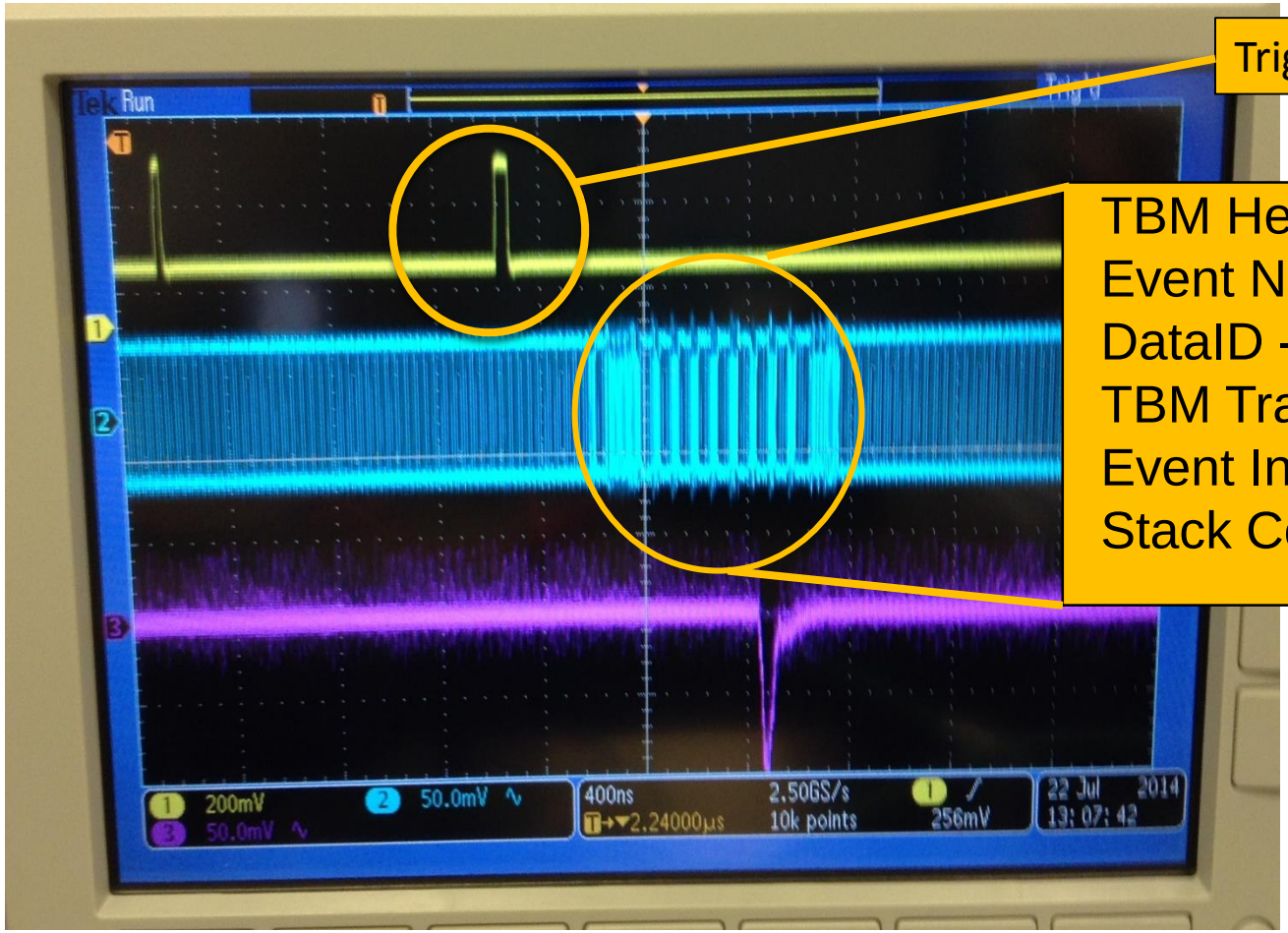
- The bulk of the module testing will be performed at Fermilab
- Two stations with cold boxes
  - Test 4 modules in parallel
- Expect to test 8 modules / day (average)
- Finish testing ~1000 modules around April 2016





TBM Decoding Test

- The TBM decoding test issues a single trigger to the TBM

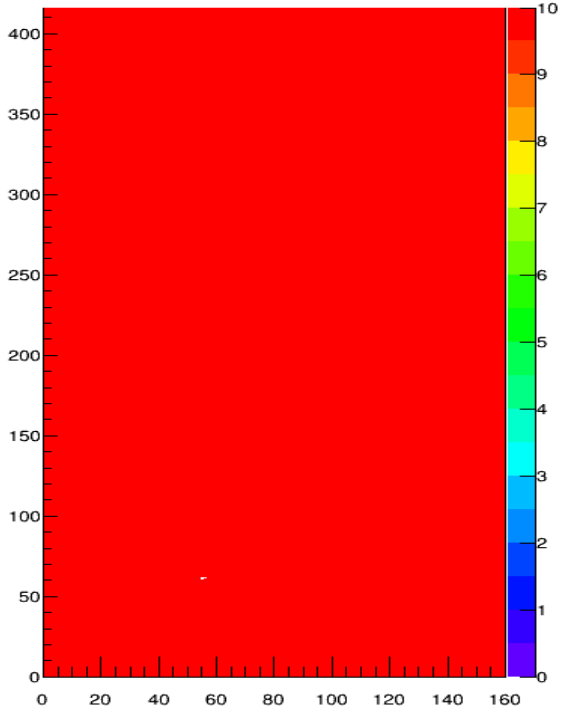


Triggers

TBM Header - 011111111100
Event Number - 00000001
DataID - 10110000
TBM Trailer - 011111111110
Event Info - 0110001000
Stack Count - 000001

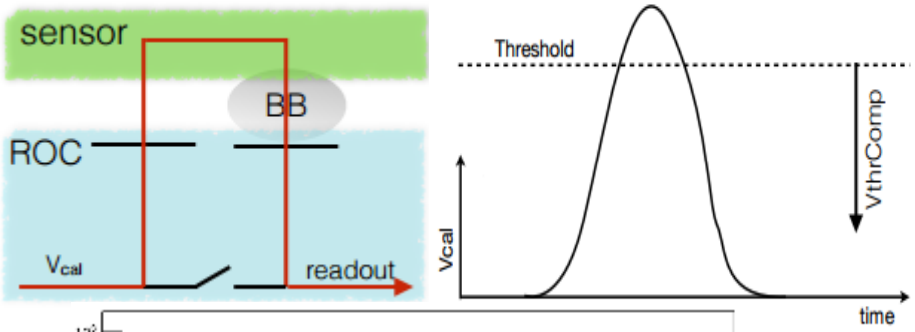
Pixel Alive Test

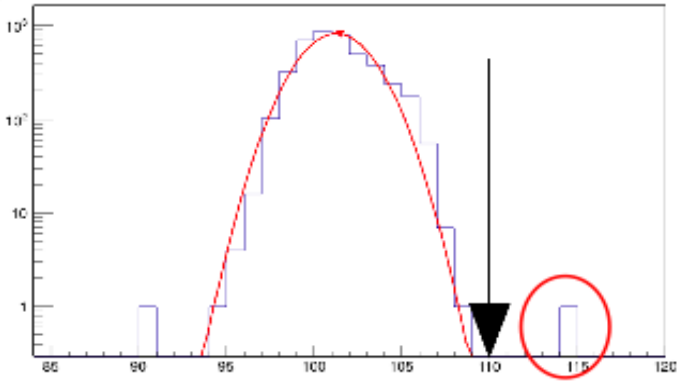
- Pixel alive is a three-fold test that measures the functionality of the pixel unit cell
  - Inject calibration charge 10 times and measures the number of hits
  - Inject calibration charge into each individual pixel and verify that the correct pixel responds
  - Check that pixels can be disable

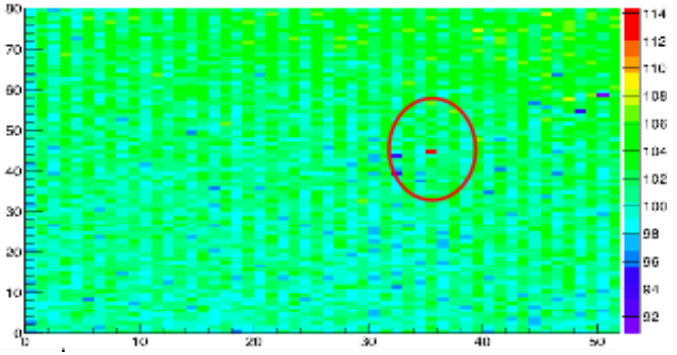


Bump Bonding Test

- Check the number of bad/damaged bump bonds
  - Inject calibration charge across air gap
  - Check comparator threshold at which pixel turns on
    - Bad/damaged bonds require a lower threshold







Summary

- The pixel detector is an integral part of the Silicon Tracker
- The current pixel detector performs well under current run conditions
  - Under future run conditions will experience performance degradation
- An upgraded pixel detector is under construction to be installed in the winter of 2016/2017
  - Will maintain the current performance under extreme pileup conditions
- Module testing and qualification procedures established and validated

Thank you!