# CMS, In Brief

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Vanderbilt Quarknet session, July 20, 2015

(disgracefully borrowing from Will Johns)

# CMS, status

- CMS is up and running after Long Shutdown One (LS1).
  - Yes, there will be an LS2
- CMS Run 1 (2011-2013) was an unqualified success
  - > 300 publications and counting
  - One Higgs Boson, $m_H$ = 125.6 $\pm$ 0.4 $\pm$ 0.2 GeV,

    $\Gamma_H$ < 17.3 MeV (resonance width)
- Run 2 started in May 2015 (? first Stable Beams)
- Goals of Run 2
  - What are the rest of the Higgs Properties?
  - What makes it so light?
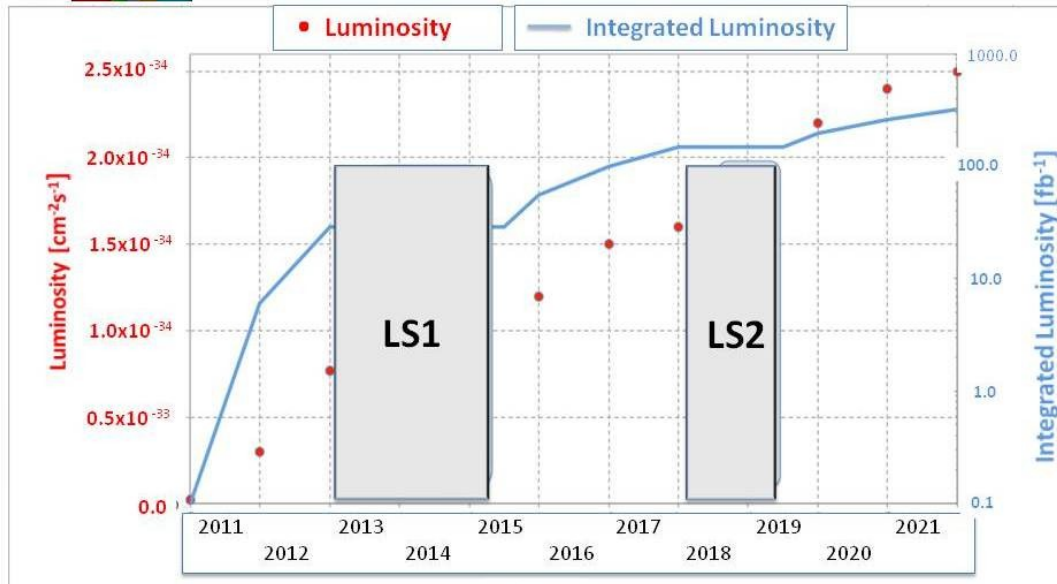  - **New Physics at higher Energies found with higher Luminosity**

# Challenge of Run 2
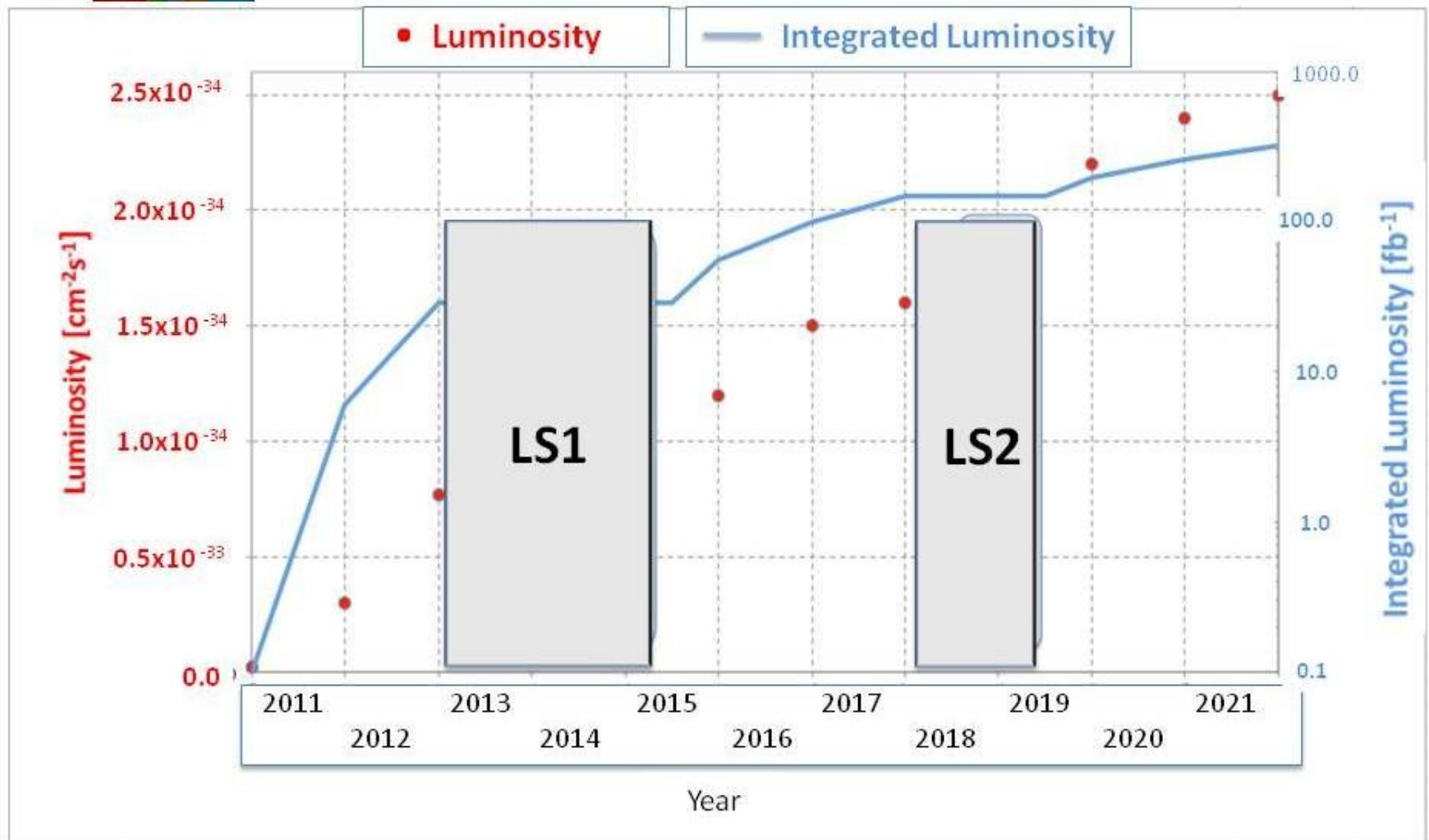
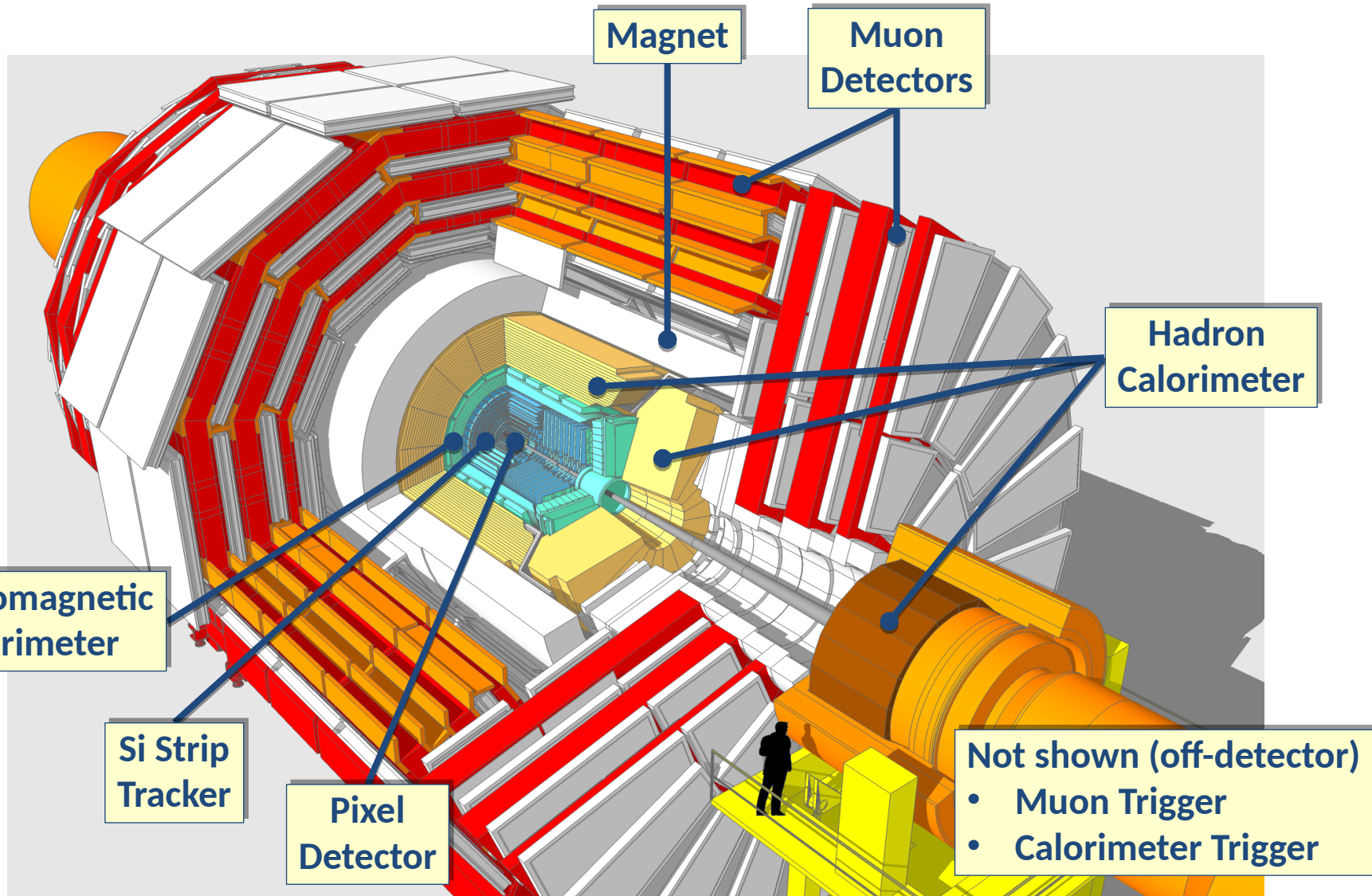# Current Luminosity, still ramping up
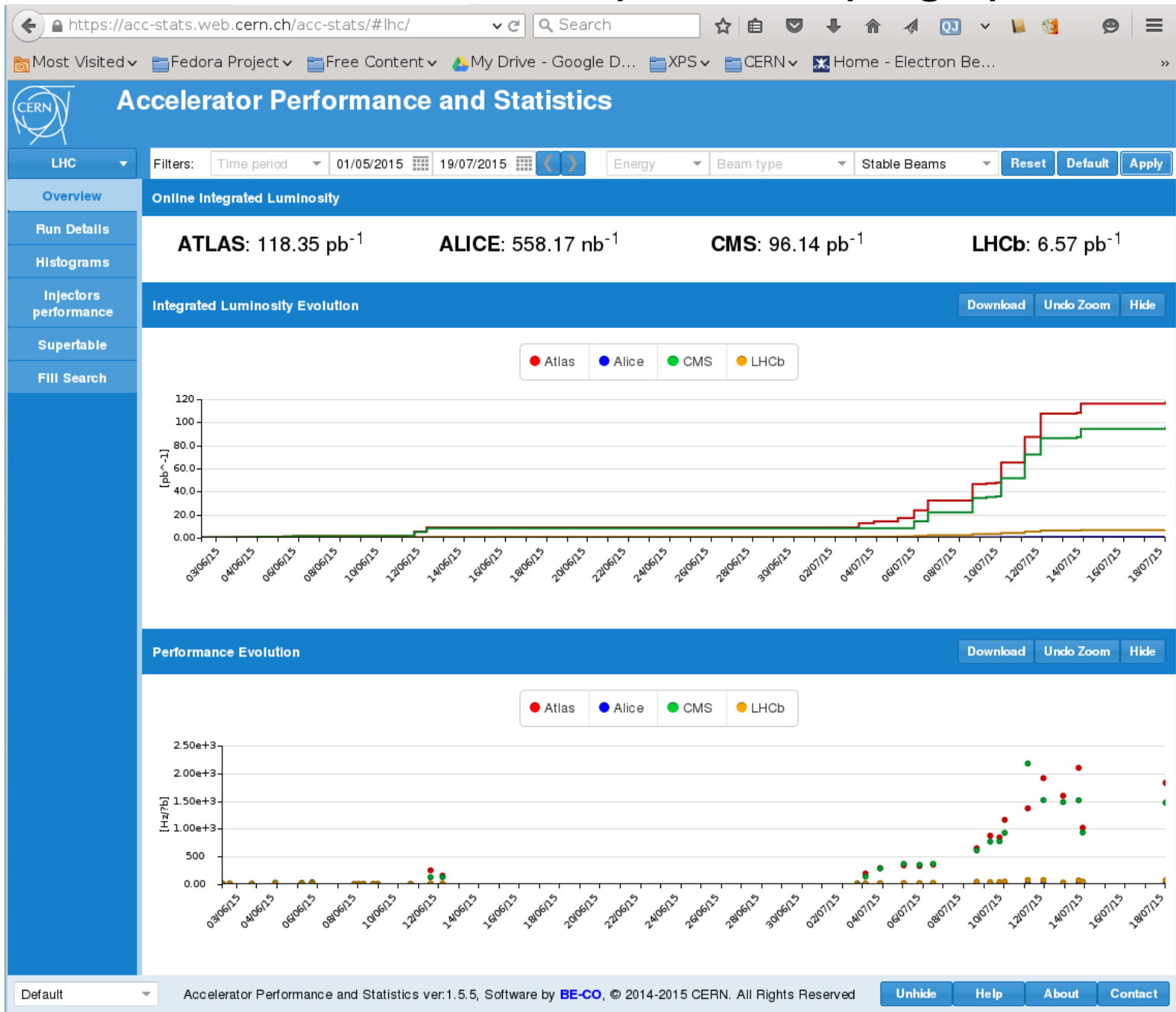
# Challenge of LHC Run 2



- Increased Luminosity
  - Instantaneous increases by ×2 by LS2, more beyond
  - Integrated increases ×10 by LS2, ×25 to ~ 500 fb$^{-1}$ by LS3

- Criteria for Upgrade
  - Operate with a baseline "pileup" (PU) of 50 events/crossing, tolerate maximum of 100
  - Maintain low trigger thresholds with increased event rate
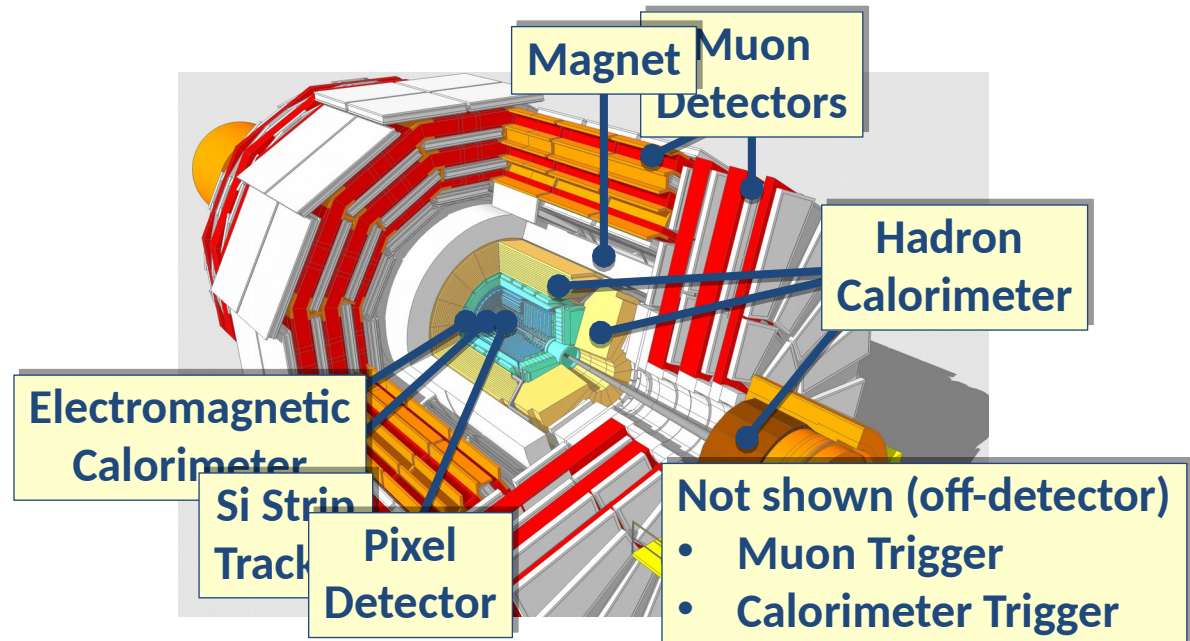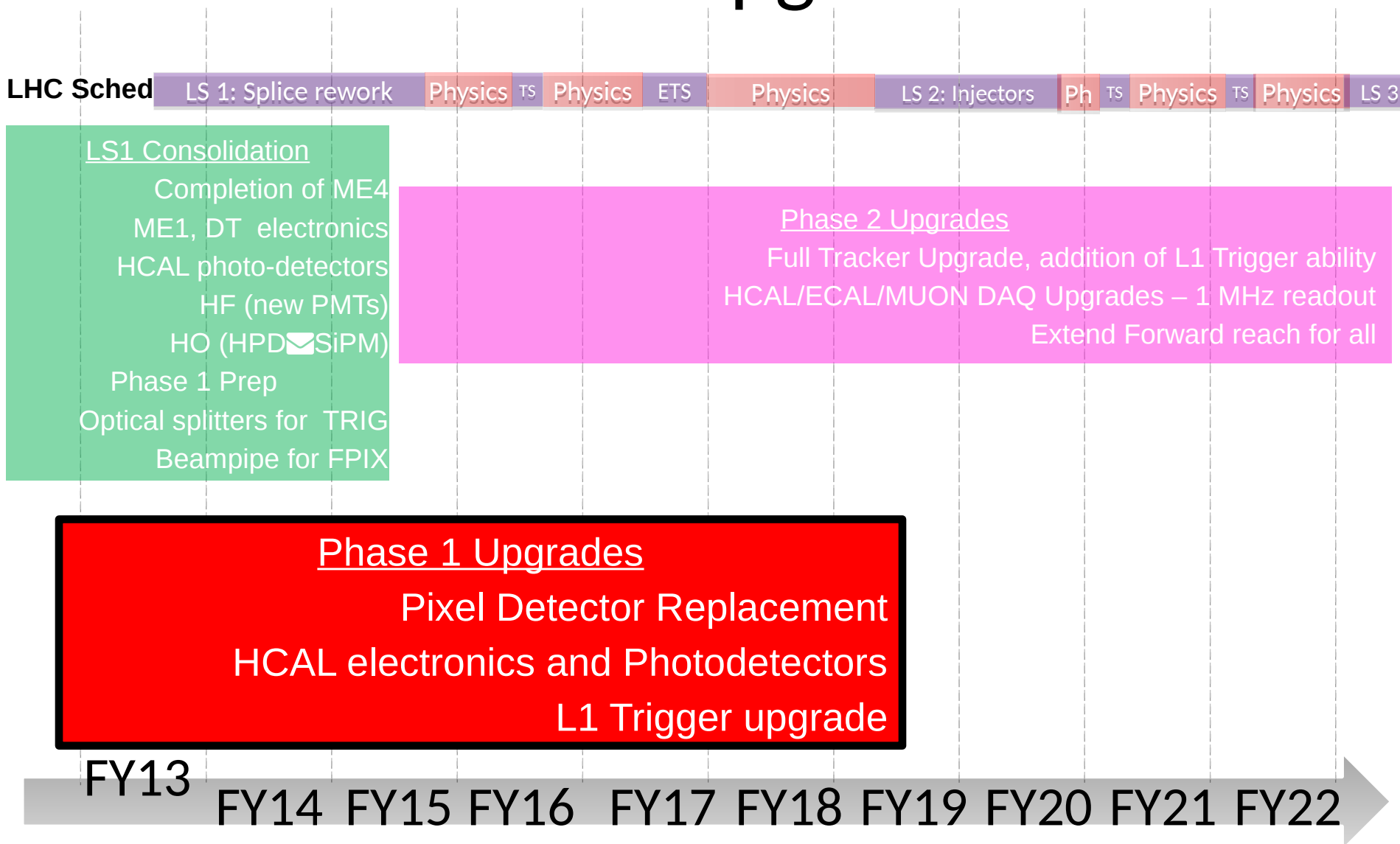  - Survive doses ≥ 500 fb$^{-1}$

# CMS Detector

Magnet

Muon Detectors

Hadron Calorimeter

Electromagnetic Calorimeter

Si Strip Tracker

Pixel Detector

Not shown (off-detector)
- Muon Trigger
- Calorimeter Trigger

# CMS Detector, Animation

- CMS Detector Animation at

- CMS pieces animation, 1 min, at https://www.youtube.com/watch?v=BG37424NWWE

- Processing LHC Data, 5 min, at https://www.youtube.com/watch?v=jDC3-QSiLB4

- aa

**Magnet**

**Muon Detectors**

**Hadron Calorimeter**

**Electromagnetic Calorimeter**

**Si Strip Tracker**

**Pixel Detector**

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# Phases of CMS Upgrades/Work

**LHC Sched**

| LS 1: Splice rework | Physics | TS | Physics | ETS | Physics | LS 2: Injectors | Ph | TS | Physics | TS | Physics | LS 3 |

**LS1 Consolidation**
Completion of ME4
ME1, DT electronics
HCAL photo-detectors
HF (new PMTs)
HO (HPD✉SiPM)
Phase 1 Prep
Optical splitters for TRIG
Beampipe for FPIX

**Phase 2 Upgrades**
Full Tracker Upgrade, addition of L1 Trigger ability
HCAL/ECAL/MUON DAQ Upgrades – 1 MHz readout
Extend Forward reach for all

**Phase 1 Upgrades**
Pixel Detector Replacement
HCAL electronics and Photodetectors
L1 Trigger upgrade

FY13  FY14  FY15  FY16  FY17  FY18  FY19  FY20  FY21  FY22

# Phases of CMS Upgrades/Work

**LHC Sched**

| LS 1: Splice rework | Physics | TS | Physics | ETS | Physics | LS 2: Injectors | Ph | TS | Physics | TS | Physics | LS 3 |

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HCAL photo-detectors
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**Doing**

**Preliminary Planning**

**Phase 2 Upgrades**
Full Tracker Upgrade, addition of L1 Trigger ability
HCAL/ECAL/MUON DAQ Upgrades – 1 MHz readout
Extend Forward reach for all

**Phase 1 Upgrades**
Pixel Detector Replacement
HCAL electronics and Photodetectors
L1 Trigger upgrade

**Planning/ Prototpes**

**Construct Install**

FY13 FY14 FY15 FY16 FY17 FY18 FY19 FY20 FY21 FY22

# Vanderbilt Involvement

Current Pixel

Proton Beam

FPiX

Barrel
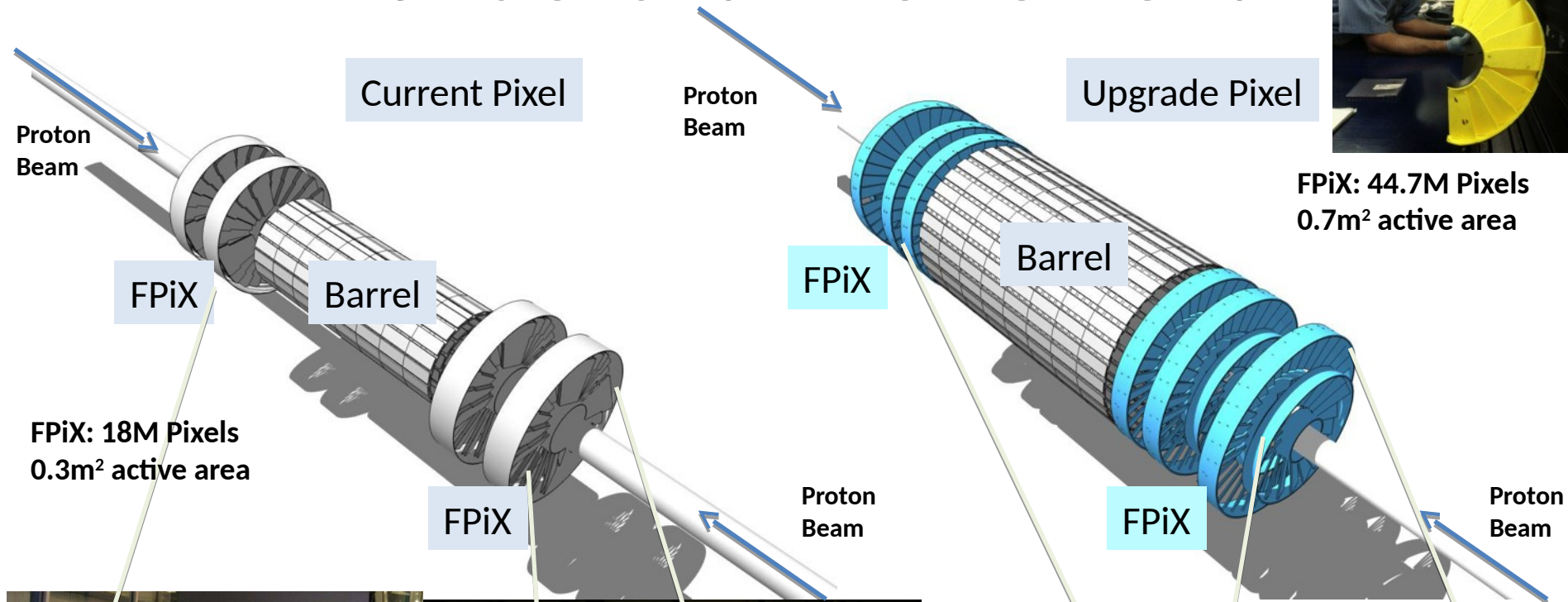
FPiX

**FPiX: 18M Pixels 0.3m² active area**

Proton Beam

Proton Beam
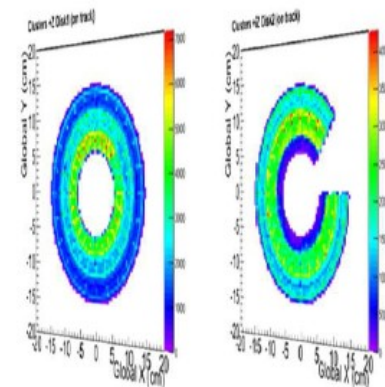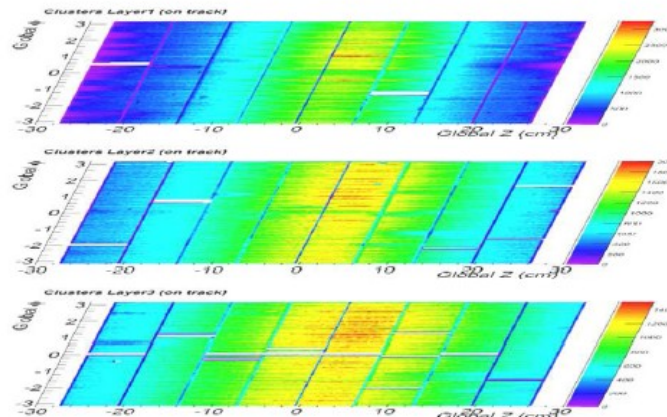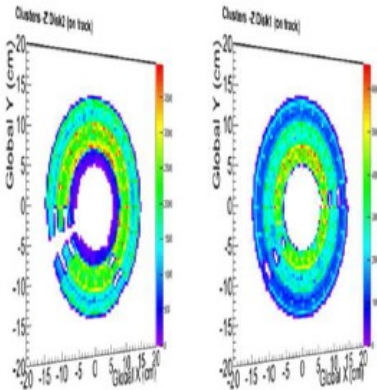
Upgrade Pixel

FPiX

Barrel

FPiX

Proton Beam

**FPiX: 44.7M Pixels 0.7m² active area**
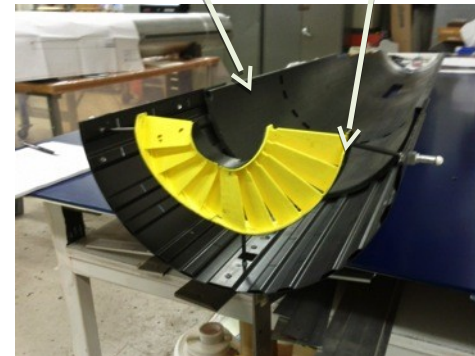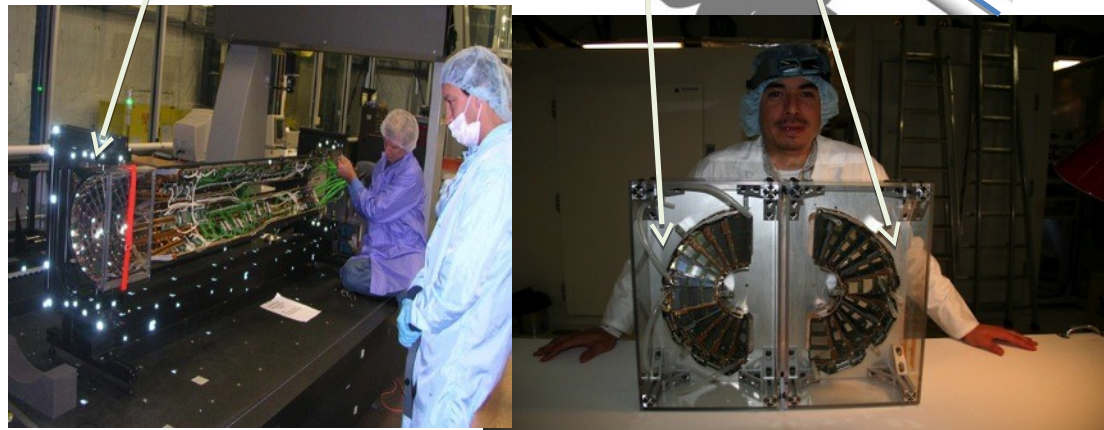
# Current Detector

- Vanderbilt Provides the overall leadership for the Forward Pixel Detector
- In LS1, the Forward Pixel Detector was removed for a refurbishment.
  - We had several places where readout no longer worked

# Why is efficiency important

- With hits in2 planes, you can make a straight line, no?
- The problem here is muli-faceted
  - The pixels are used for the main pattern recognition of the CMS tracking software
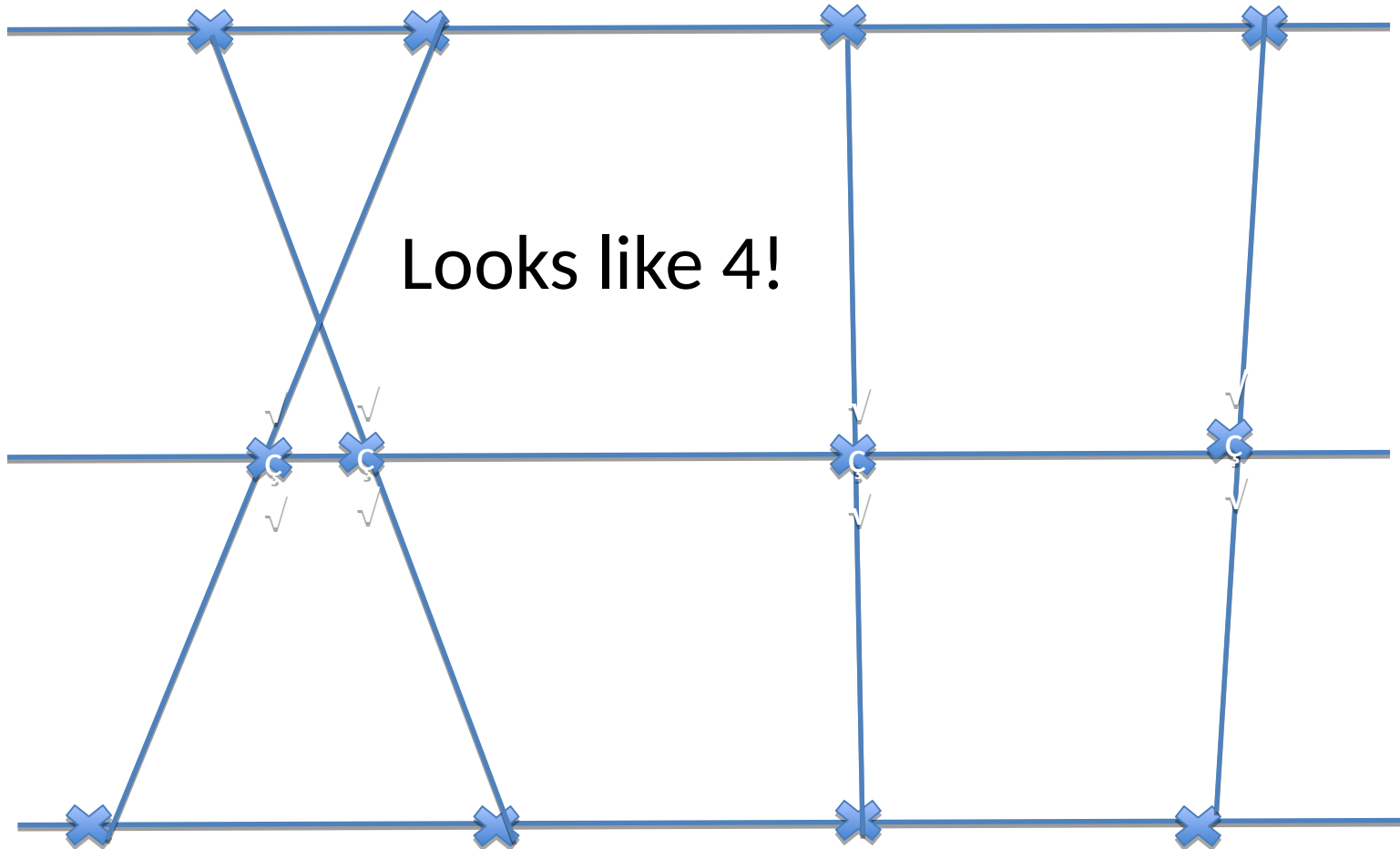  - Having just 2 point can make a pattern recognition nightmare

# How many tracks can you make?

# How many tracks can you make?

Looks like 16!

# How many tracks can you make?

Looks like 4!
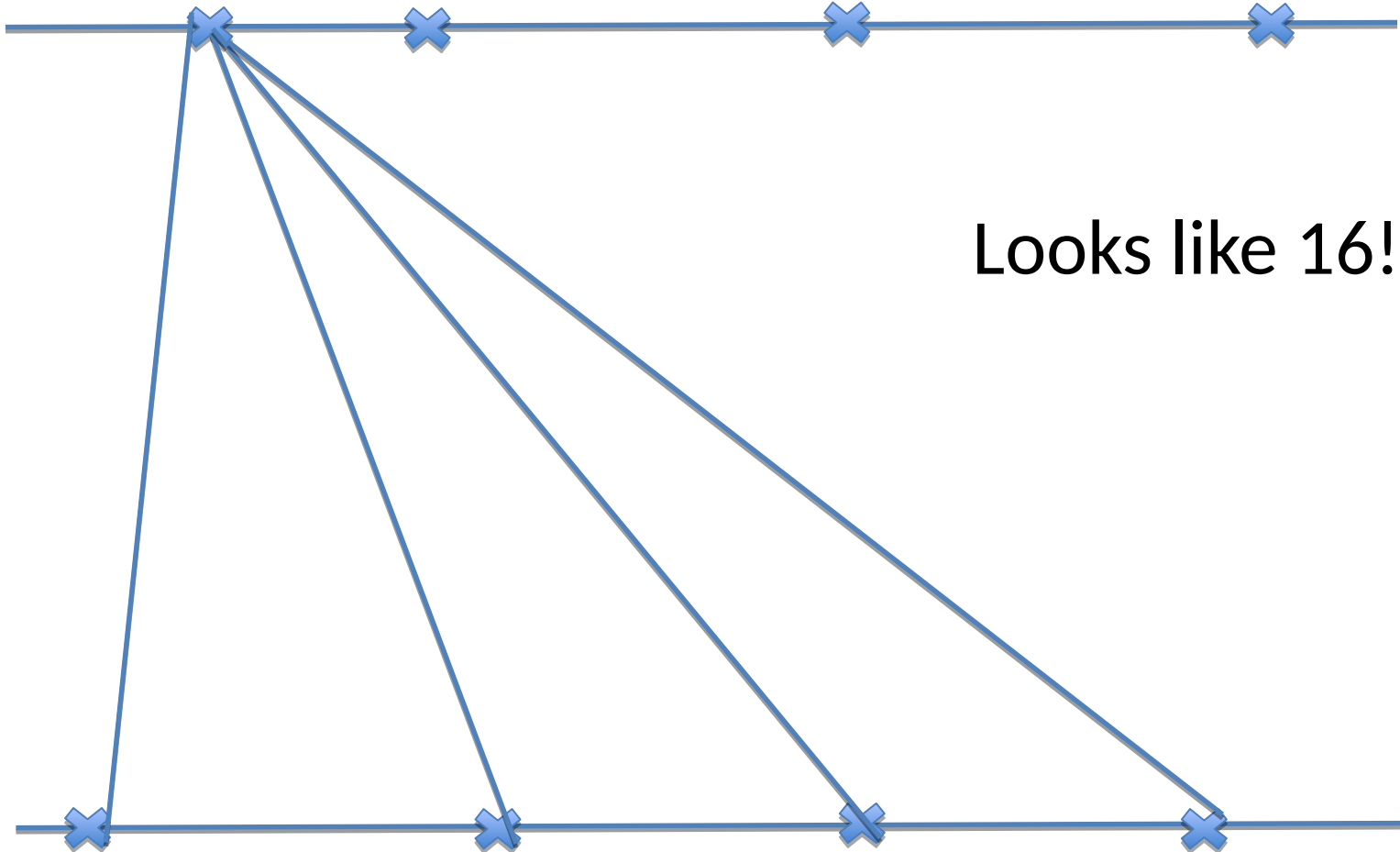
# Redundancy helps several ways.

- You can see the pattern recognition advantage immediately

- 3 points can give a circle, and hence, a momentum measurement

- There are other challenges with lots of tracks coming from a fairly common point, with a mixed system of planes

# Another pattern recognition challenge

This is a mess!
1) Make smaller detector elements
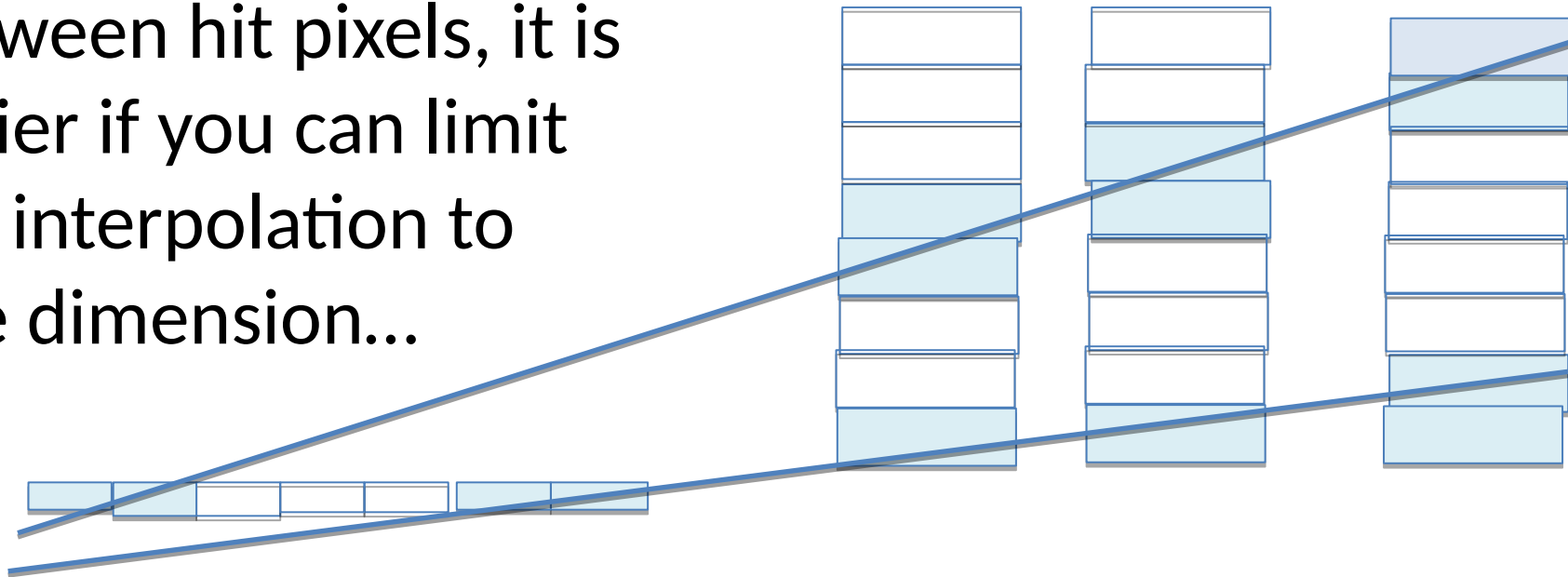2) Move them farther from the point
3) Add another detector plane
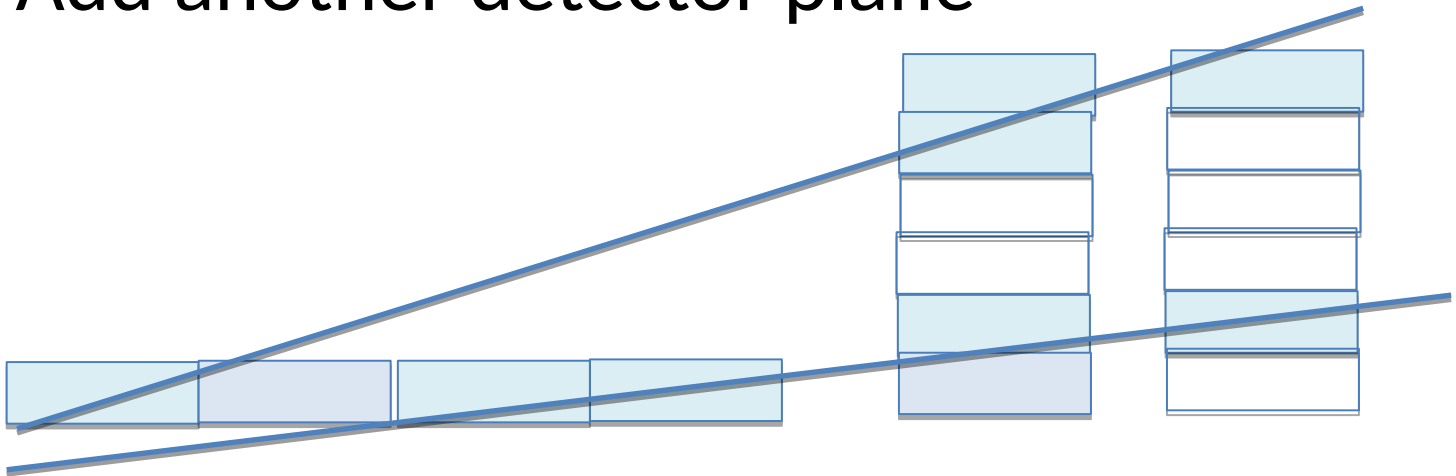
There are lots of different ways to draw lines here!
More tracks makes the situation worse.
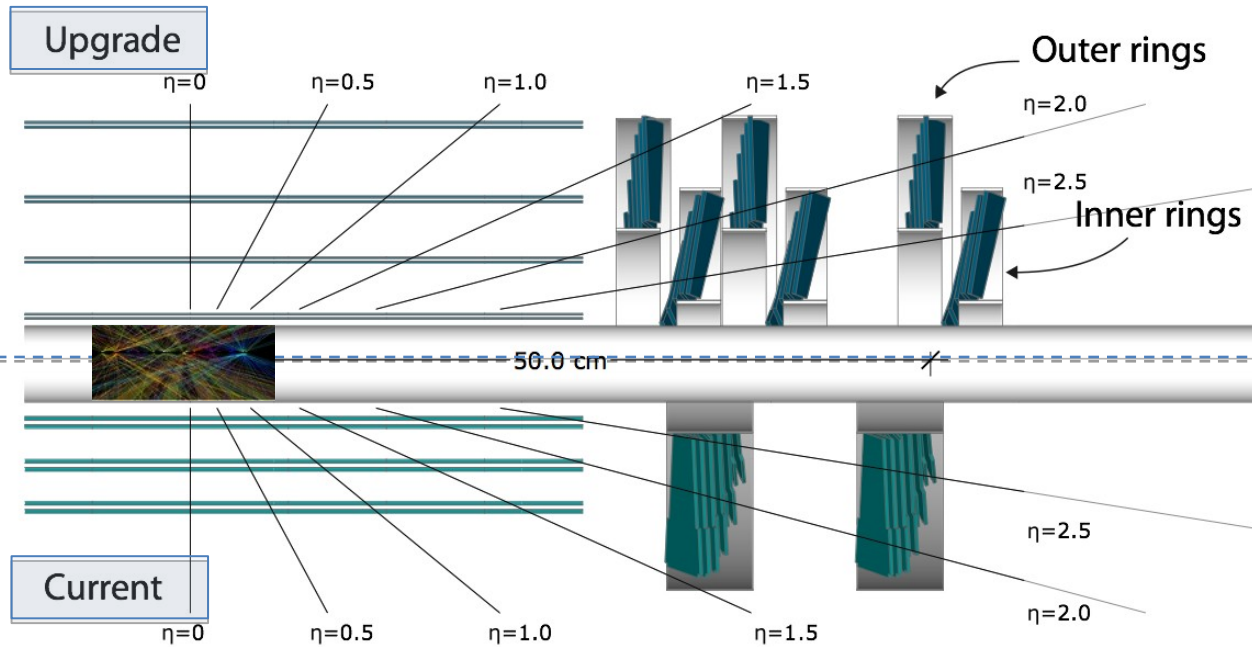
# Another pattern recognition challenge

If one interpolates the amount of charge between hit pixels, it is easier if you can limit the interpolation to one dimension…

This is happening now!

This will happen LS3?
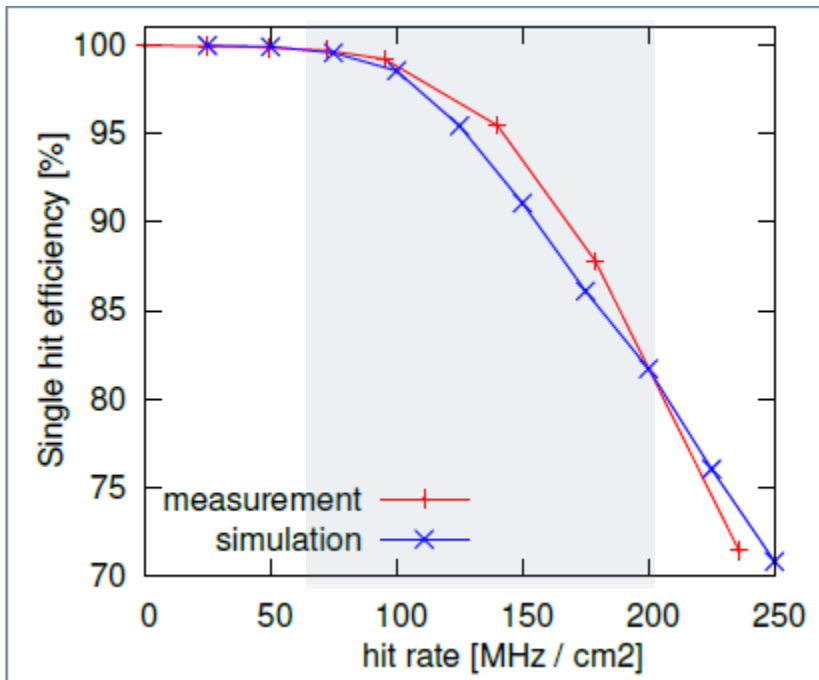
(To be installed in end of 2016 extended technical stop)



Upgrade

η=0    η=0.5    η=1.0    η=1.5    Outer rings
η=2.0
η=2.5    Inner rings

50.0 cm

η=2.5
η=2.0

Current
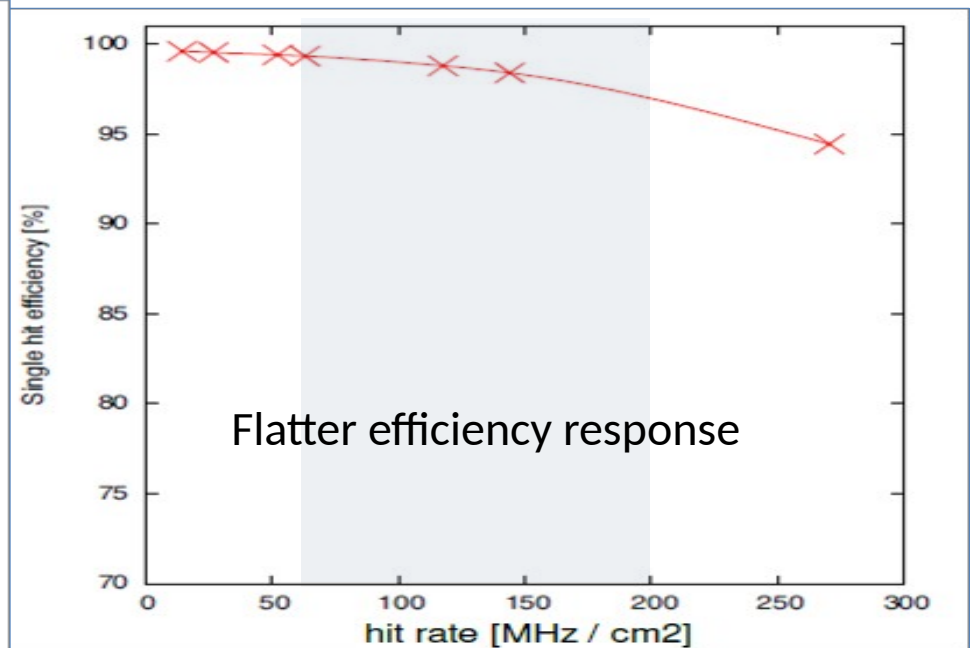
η=0    η=0.5    η=1.0    η=1.5

(The present detector)

# One other reason to upgrade

After LS1, the rate at which collisions occur increases, and the current detector can't cope.

**Current Pixel Detector**



**Upgrade Pixel Detector**



Flatter efficiency response
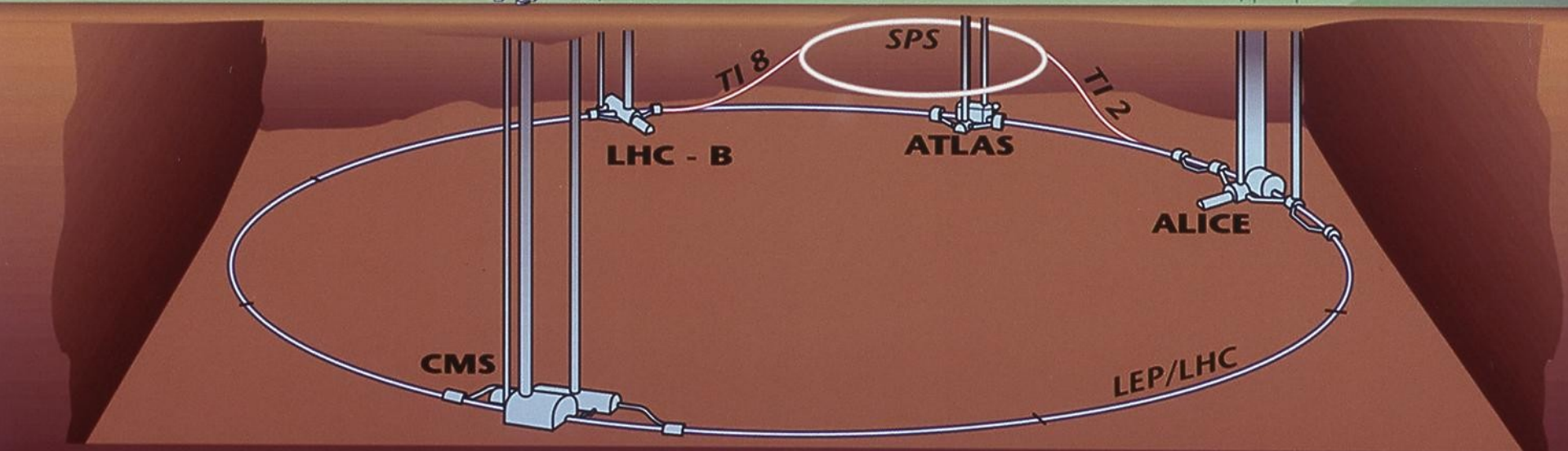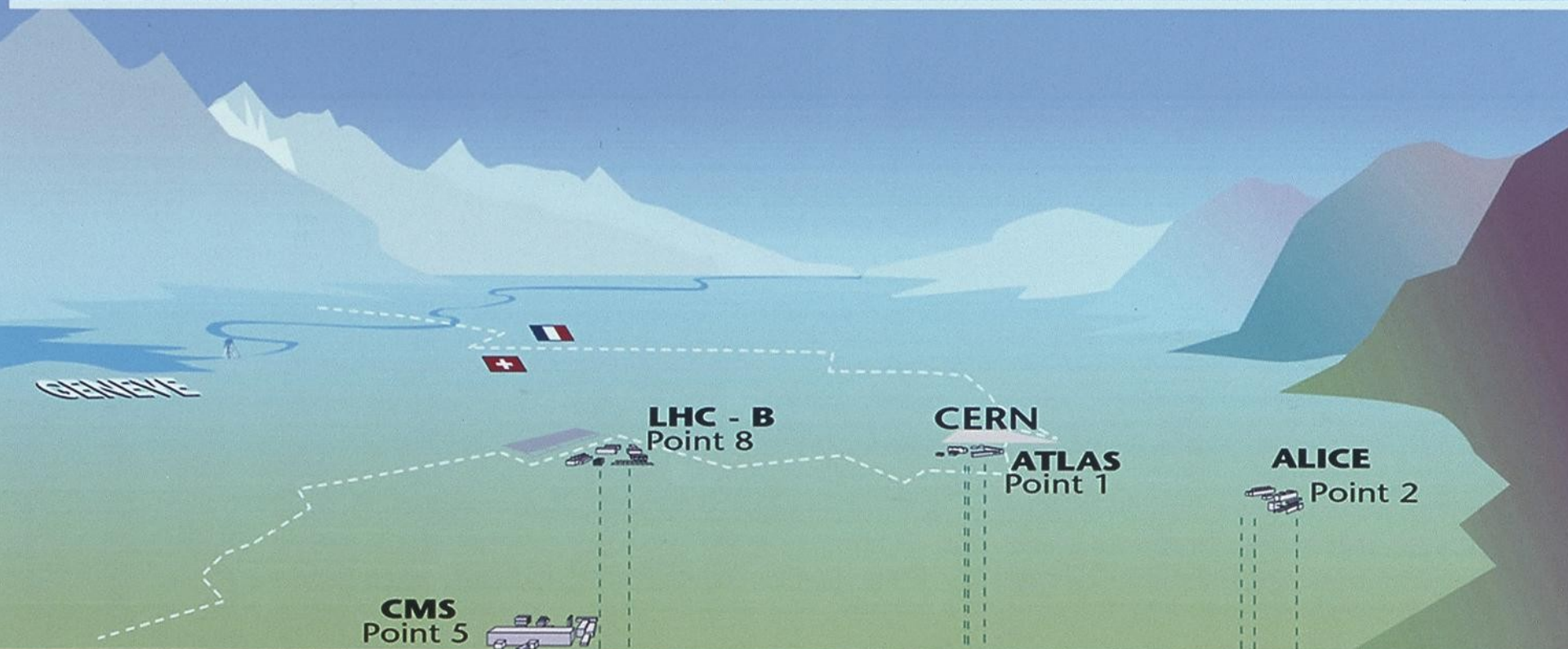
FPiX Expected Fluence after 2017

# Why is this a big deal?

- For 3 planes, the efficiency of a 3 hit track, roughly scales as the efficiency of a detector plane cubed.
  - This is the probability of getting hits in all 3 planes
  - If the planes were 50% efficient: 12.5% tracking eff.
- For 4 planes, it is more complicated:
  - I can never remember this, so I always do a game:
    - Suppose the 4 planes are 50% efficient, it's like a coin toss
      - There are 2*2*2*2 ways to flip 4 coins
      - There is one way to get all heads
      - There are 4 ways to get 3 heads and one tails
      - Tracking efficiency: 5 ways / 16 total ways = 31.25%
- More planes = more Tracking efficiency
- Better detector chip = more tracking efficiency

# Overview

- The next few years will be challenging ones for the pixel detector
  - We will have an increase in luminosity and energy
    - More tracks in the detector
    - Efficiency challenges until...
  - We will install a new detector for the even higher luminosity running in 2017 until LS3(=?)

# Overall view of the LHC experiments.

# Where is CMS?