UNIVERSITY OF LIVERPOOL

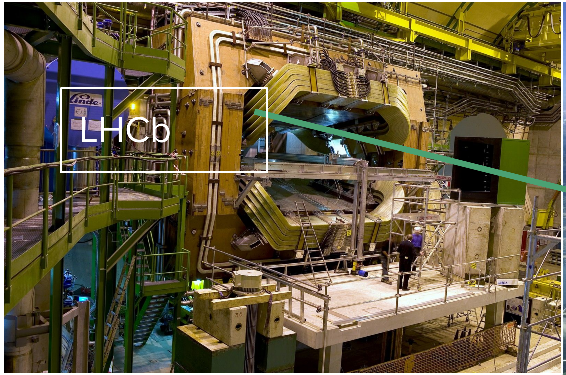
HL-LHC experiments

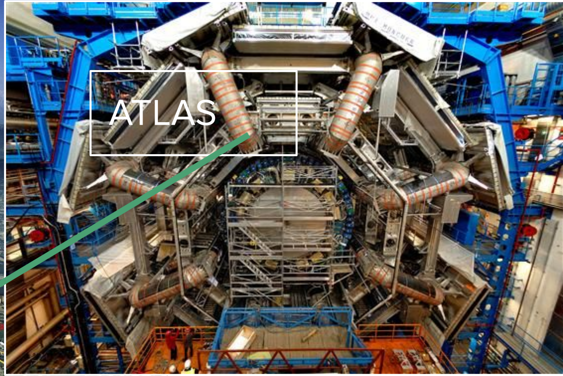
Helen Hayward

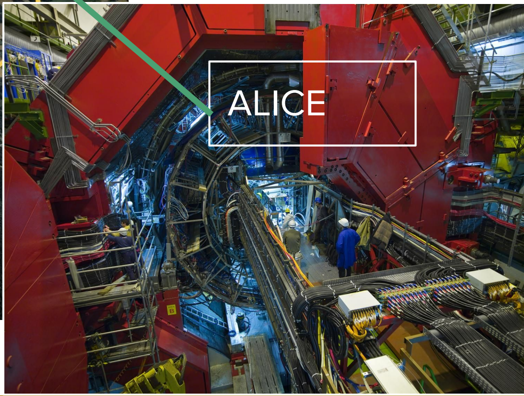
ATLAS EXPERIMENT

= UK involvement

The 4 experiments of the HL-LHC







What/Why the HL-LHC?

To look into detail into new physics, we need more data !

The HL-LHC aims to increase the rate of proton collisions by a factor of 10 from 2028

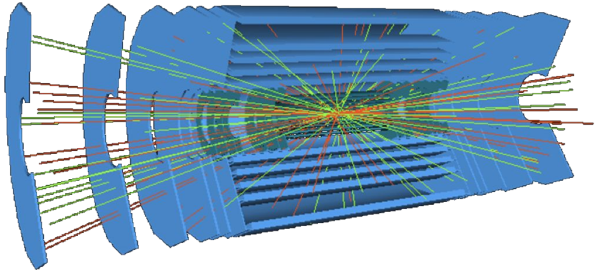
- (see next talk for details)

So easy ?   Lets sit back and enjoy ..?

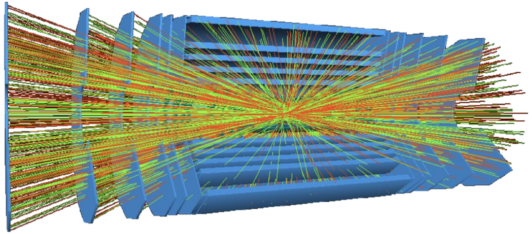
Done by increasing the number of collisions “on top of each other”

- Other wise known as pile-up

LHC



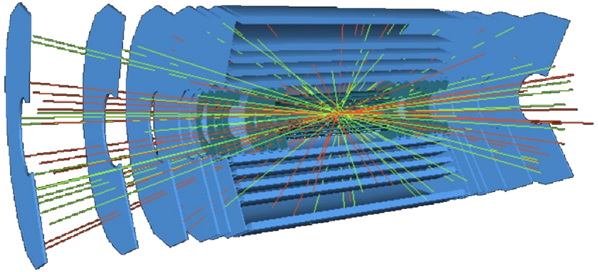
HL-LHC



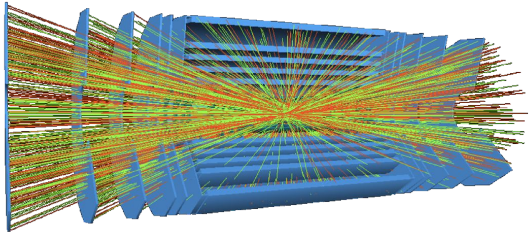
Why upgrade experiments?

- will not survive the integrated luminosities of HL-LHC
- Detectors are designed for LHC conditions
  - More pile-up:
    - Need to separate tracks from different interactions
- With increased luminosity, we need to read data out faster
- Upgrades to triggers
  - More data to analyse
  - which events to keep

LHC:
19-55 pile up in ATLAS



HL-LHC:
140-200 pile up in ATLAS

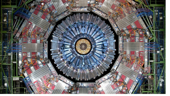


What sort of upgrades?

The upgrades are designed to perform at least well as the current detectors, in the harsher environment of the HL-LHC

Upgrades include:

- Increased radiation hardness (sensor, chip, cables, mechanics...etc)
- Higher data rate capabilities
- Improved acceptance
- Improved resolutions:
    - Where particles are in space:
    - Where particles are in time



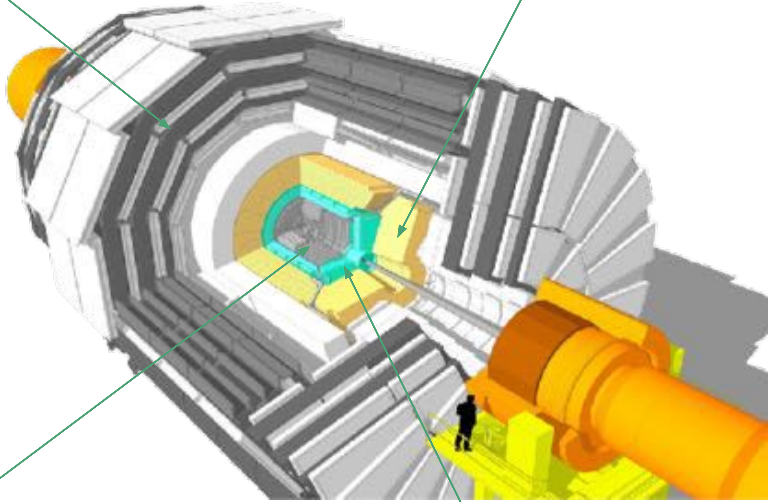
CMS

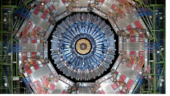
High Radiation environment requires replacement:

- Tracker
- Endcap Calorimeter
- Electronics upgrade to Barrel Calorimeters and Muons detectors

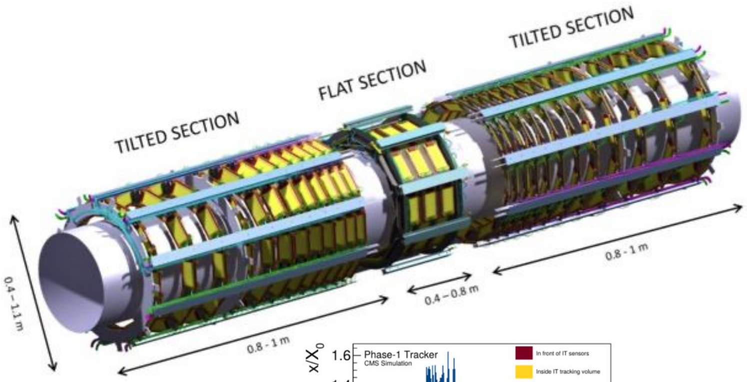
High Pile up requires:

- Improved granularity
- Using timing measurements to mitigate pile-up
    - Precision timing detectors

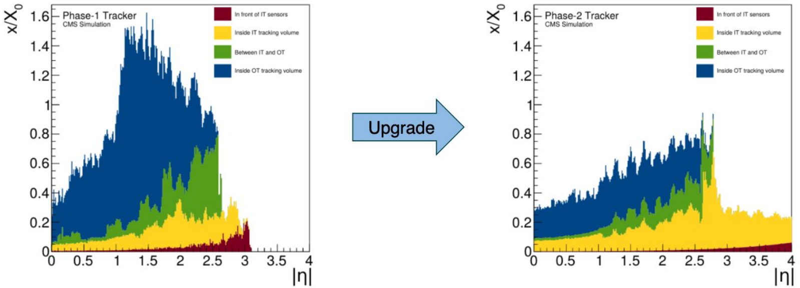


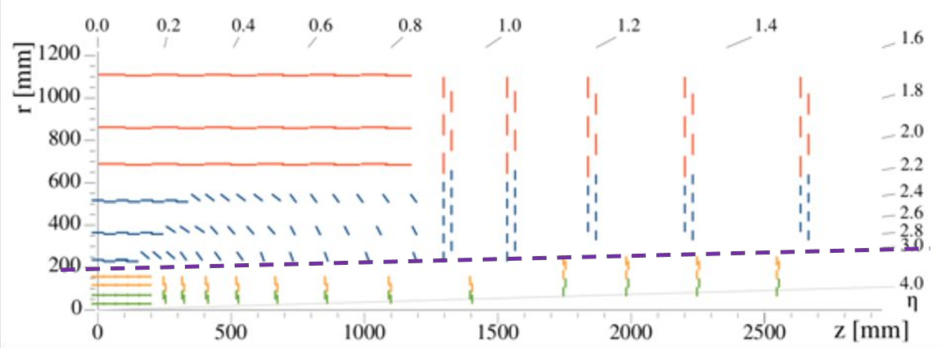


CMS Tracker



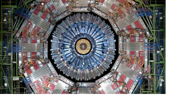
- Increased granularity
- Less material
- Extended coverage
- Tracks being included in initial trigger decision for first time
  - Decision on which events to keep





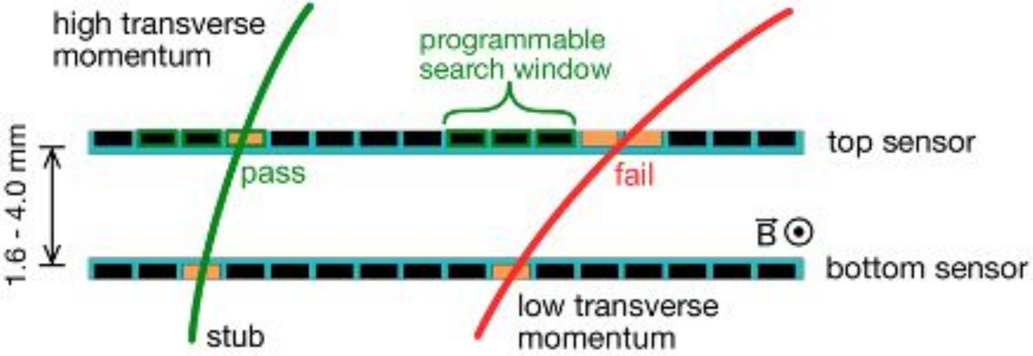
Outer Tracker:

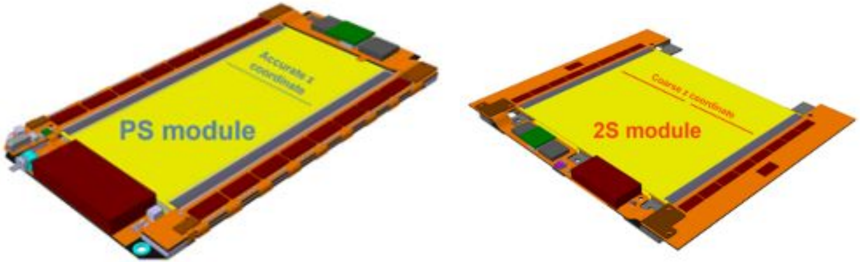
- 200m^2 of silicon
- Light-weight mechanics and modules



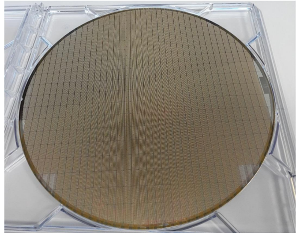
CMS HL-LHC Track Trigger

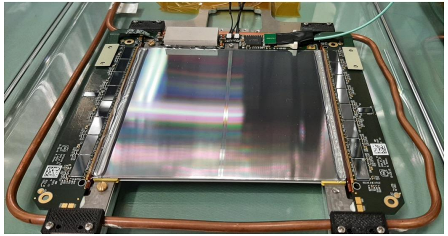
- Tracks curve due to CMS magnetic field
  - More energetic tracks are straighter
- Correlate hits from 2 closely spaced sensors to form stubs
- Allows decision energetic tracks to be identified quickly



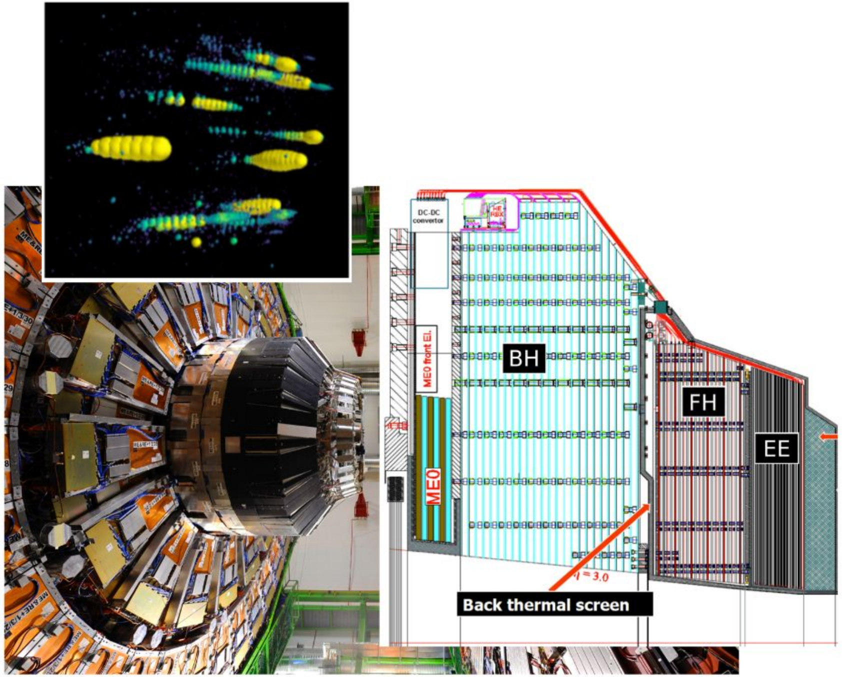


★ New module and electronics required:





CMS Calorimeters

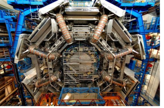


★

New High Granularity Calorimeter

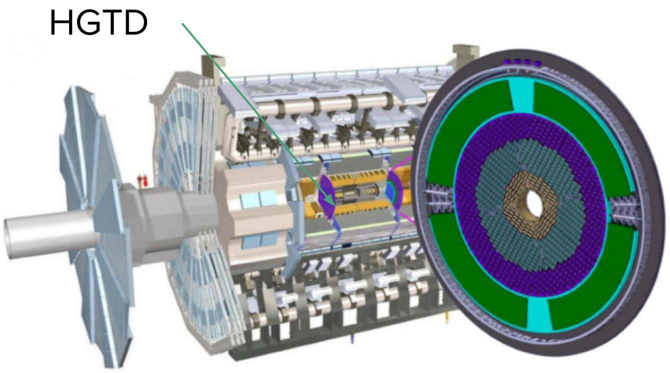
4D reconstruction of Shower Development

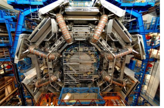
- Sampling calorimeter with silicon sensors
- optimized for a high pileup environment
    - (1cm and timing of < 50ps)



ATLAS - Phase II upgrade

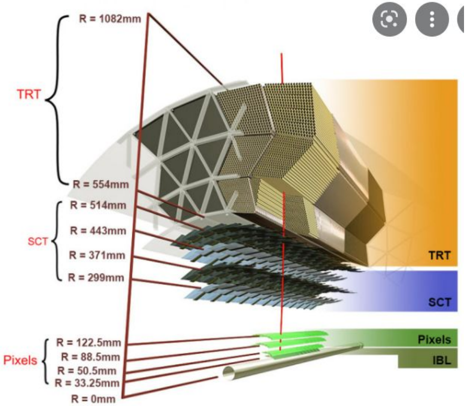
- A new tracking detector (ITK):
  - Almost 100% occupancy in TRT at HL-LHC
  - Replace with all silicon tracker
- New High Granularity Tracking Detector (HGTD)
  - To distinguish tracks in collisions occurring very close in space but well-separated in time.
- Electronics upgrade:
  - Replacing most readout electronics
  - improve to allow full detector information in the trigger for calorimetry and muon systems

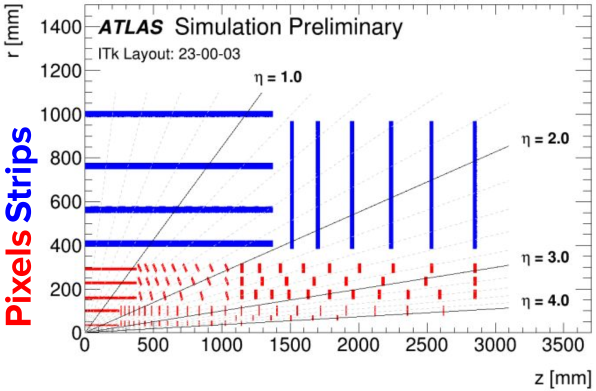


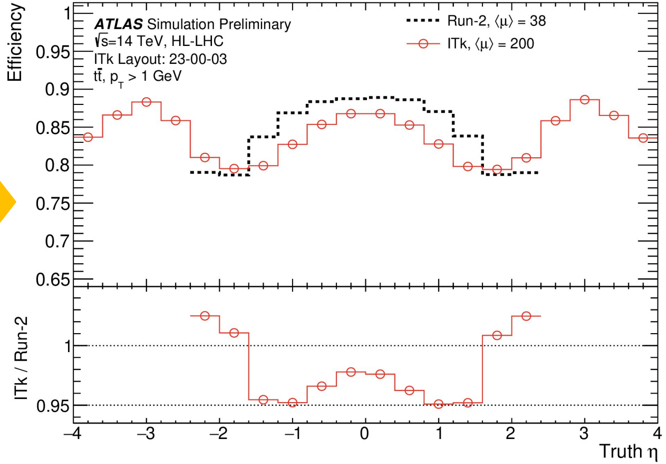


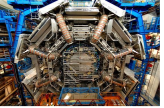
ITk - New Tracking Detector

The Inner Detector will be replaced by all-silicon tracker

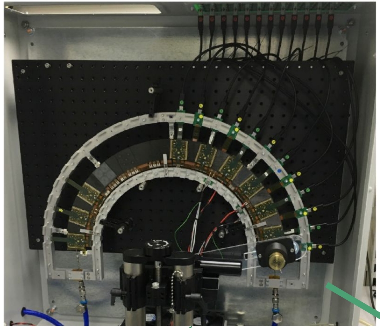








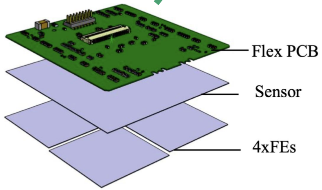
ITk Pixels

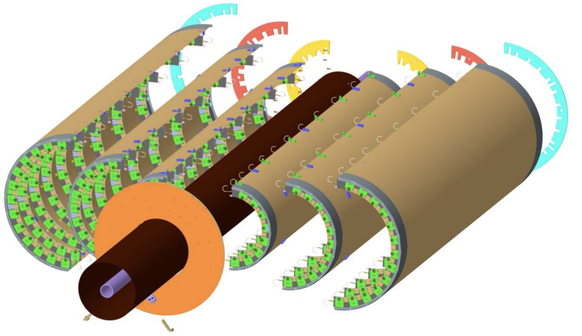


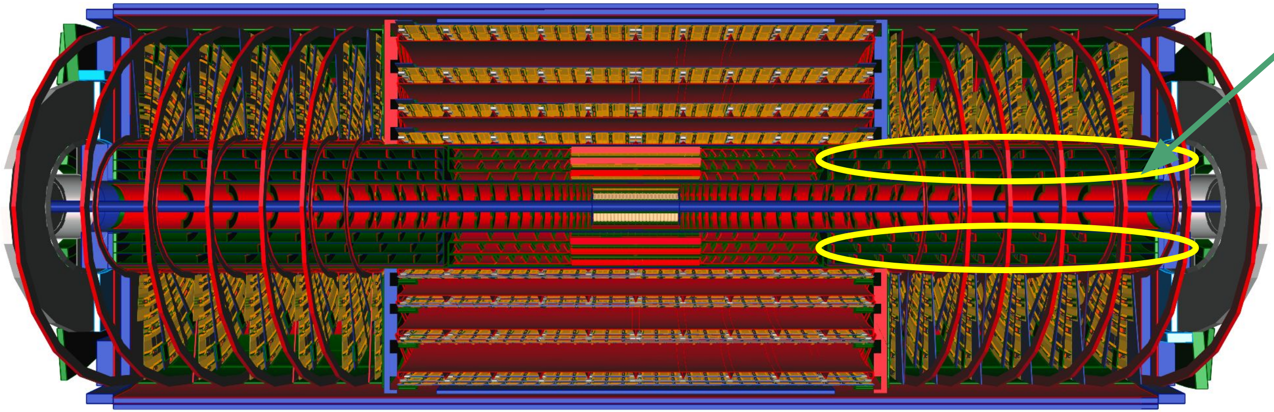
5 layers of pixel sensors

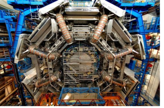
- Inner two layers designed to replaceable

UK are building one complete outer endcap







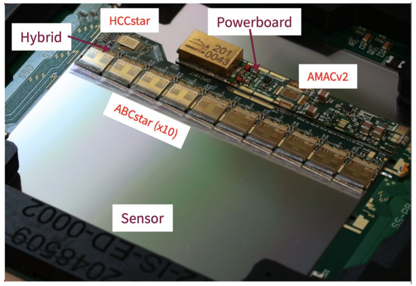


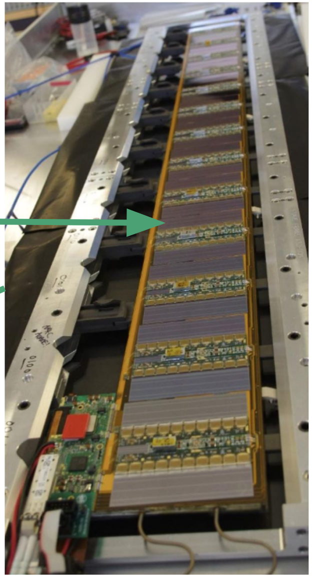
ITk - Strips

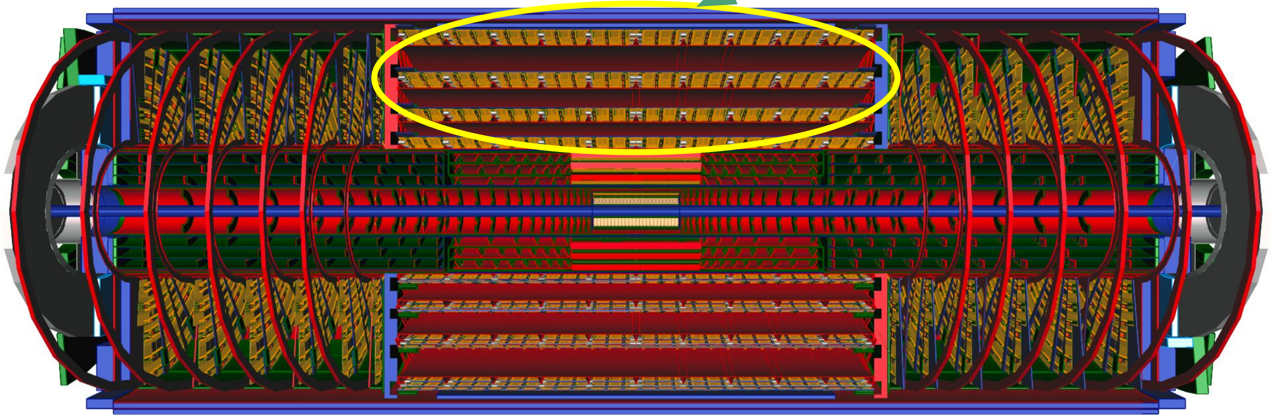
Strip Detector:

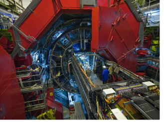
- 4 barrel layers, 12 endcap discs
- 17888 modules
- 320µm thick silicon
- 75.5 µm strip pitch

UK is building half the strip barrel detector

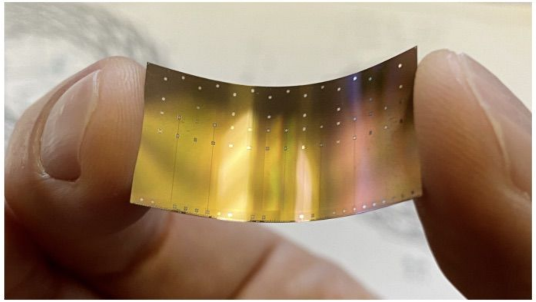


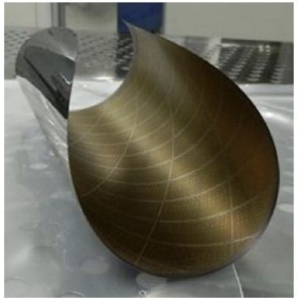




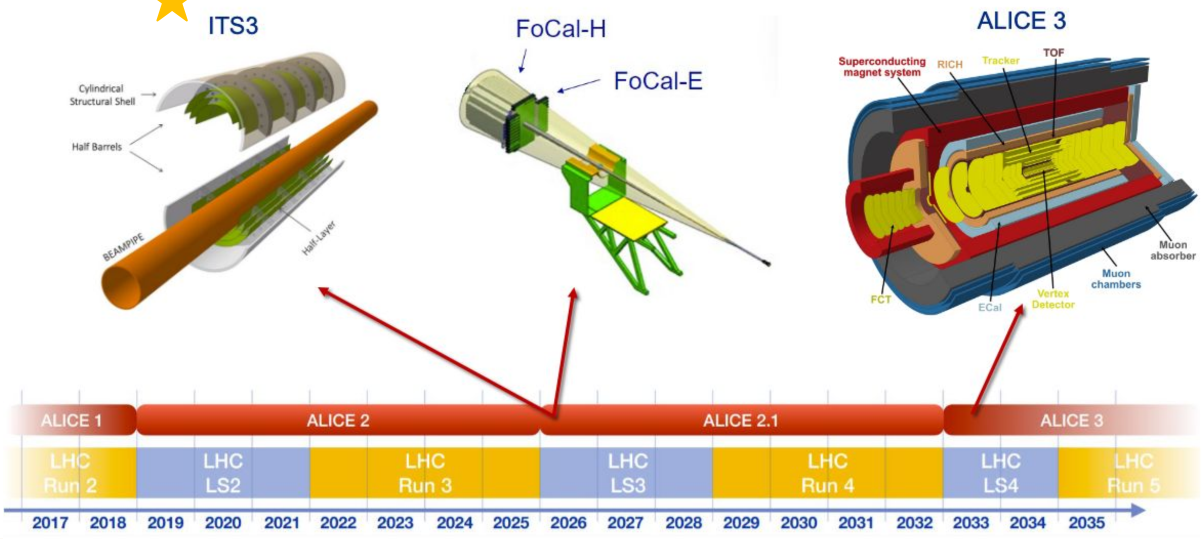


ALICE

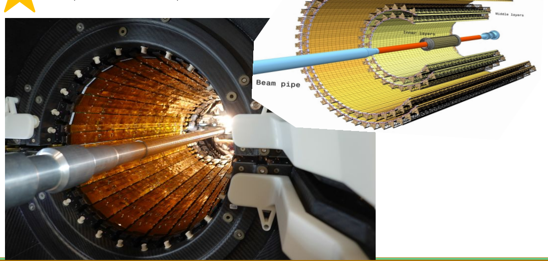


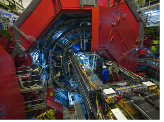


- Upgrade ITS with replacement of inner layers with new curved inner layers
  - ultra-thin silicon sensors
  - innermost layer 18 mm from the interaction point.
- install Forward Calorimeters



ITS2: First large Silicon tracker entirely composed of CMOS Monolithic Active Pixel Sensors (MAPS)



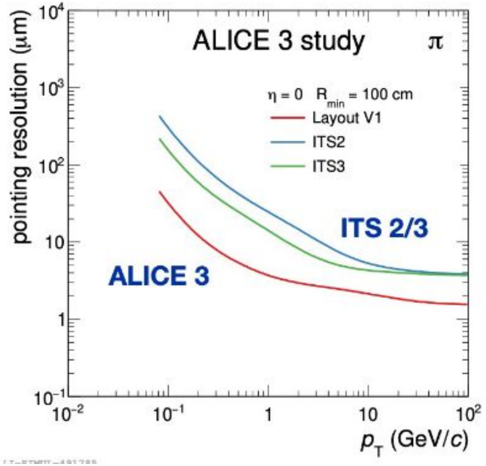


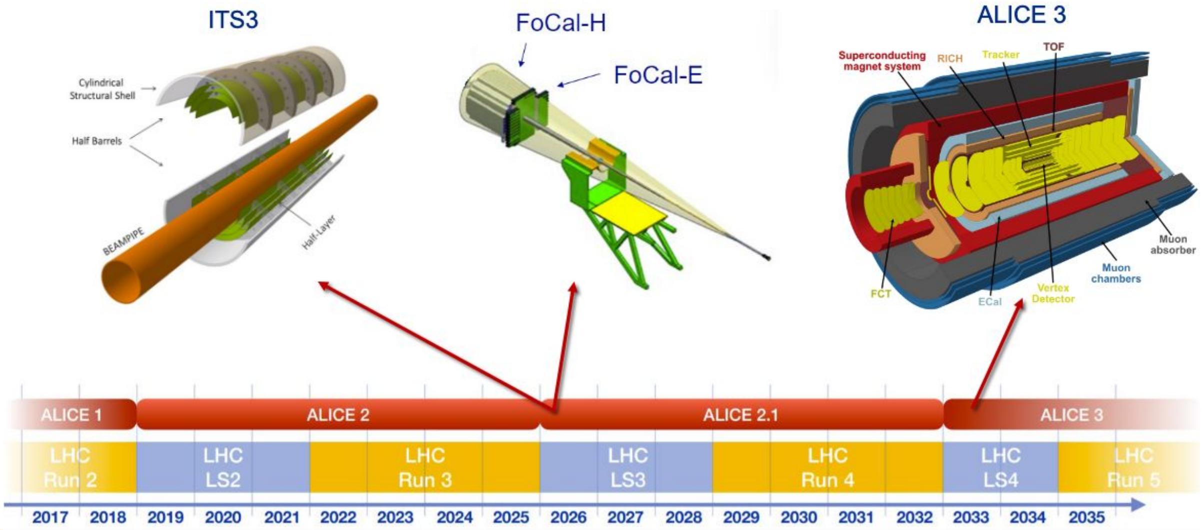
ALICE3

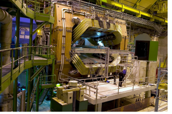
- ALICE3 for installation in 2034.
- Goal is collisions at luminosities 20-50 higher than before

Complete overhaul of detector:

- Compact all-silicon tracker with high resolution vertex detector
- Superconducting magnet system
- Particle ID over large acceptance
- Fast data readout and online processing







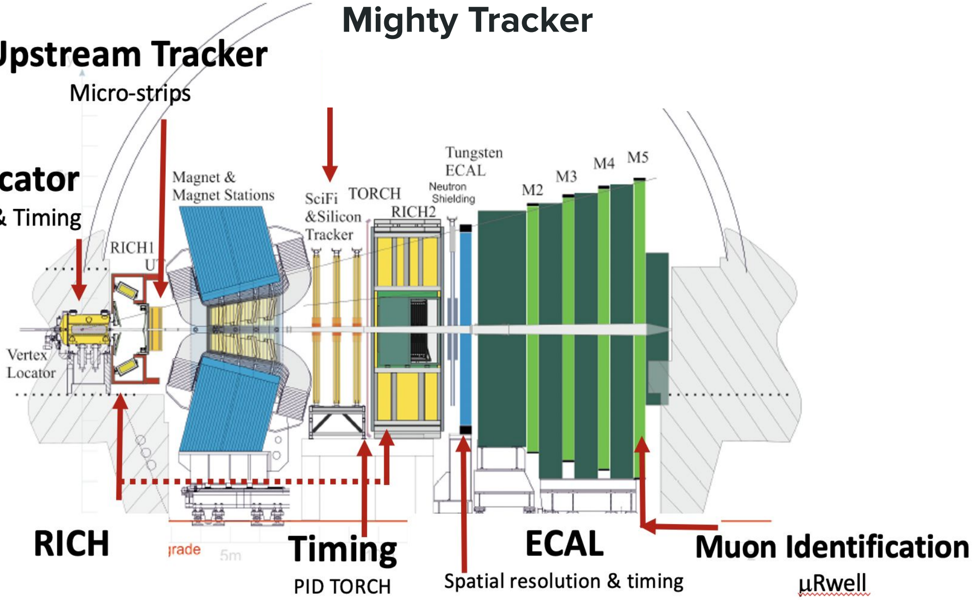
LHCb

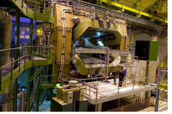
In order to take full advantage of the HL-LHC, LHCb aims to perform at a pile up of 50

In order to do this:

Replace all existing spectrometer components to :

- increase granularity
- reduce material budget
- **Add timing capability to separate particles from different collisions**



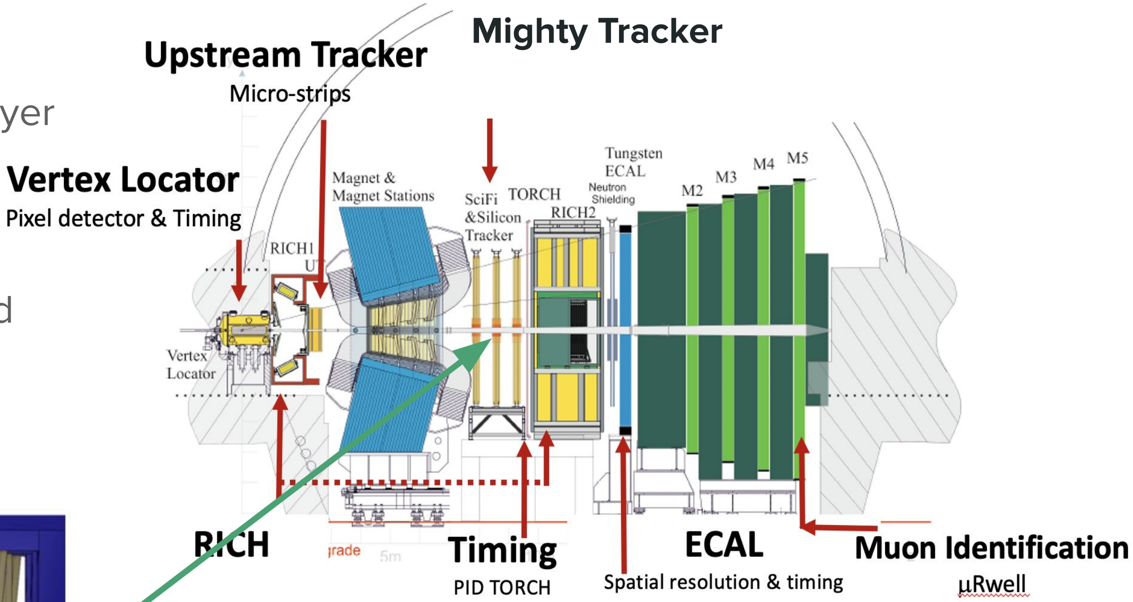


LHCb

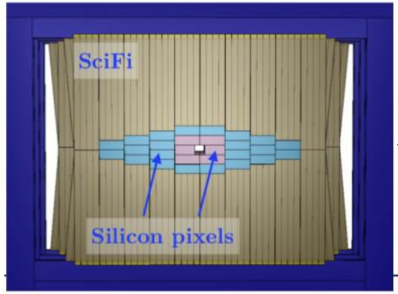
★Mighty Tracker

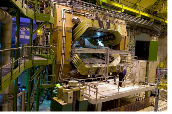
Replace 30m^2 scintillating fibres per layer

- Scintillating Fibre Tracker AND silicon tracker (HV-CMOS)
- Designed to cope with increased occupancy and larger radiation doses.



Replace

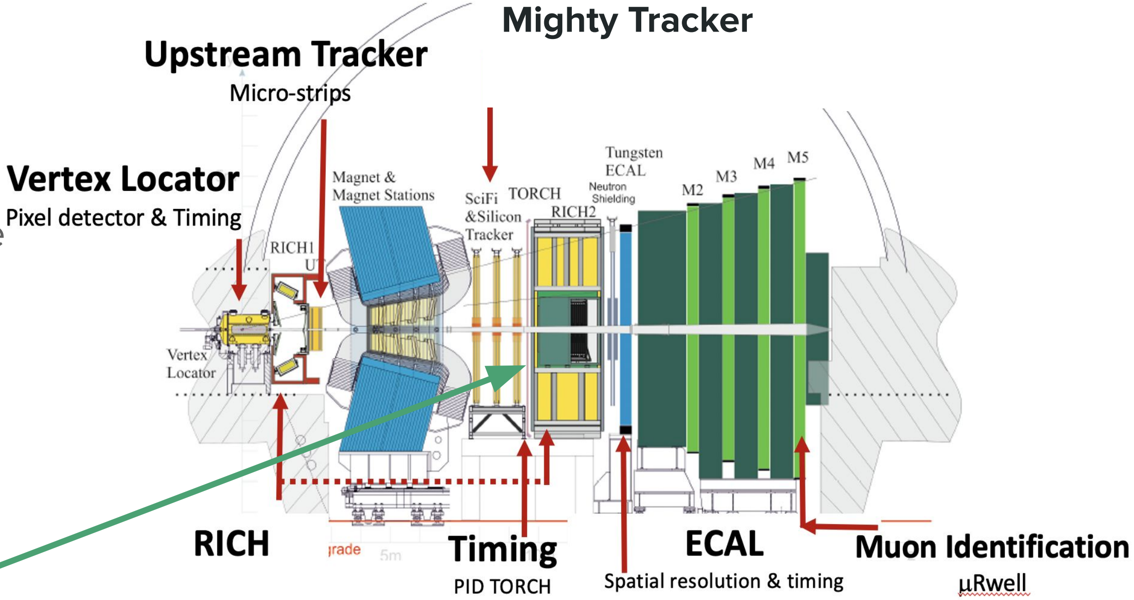


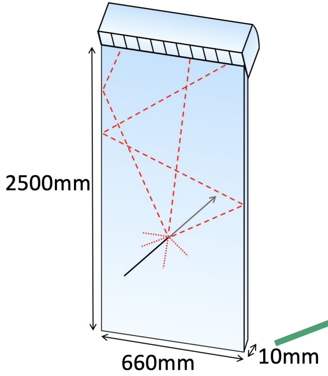


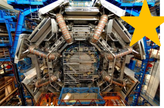
LHCb

★**TORCH:**

- Time of internally Reflected CHerenkov light
- At low momentum, discriminate between kaons and pions








Too much Data?

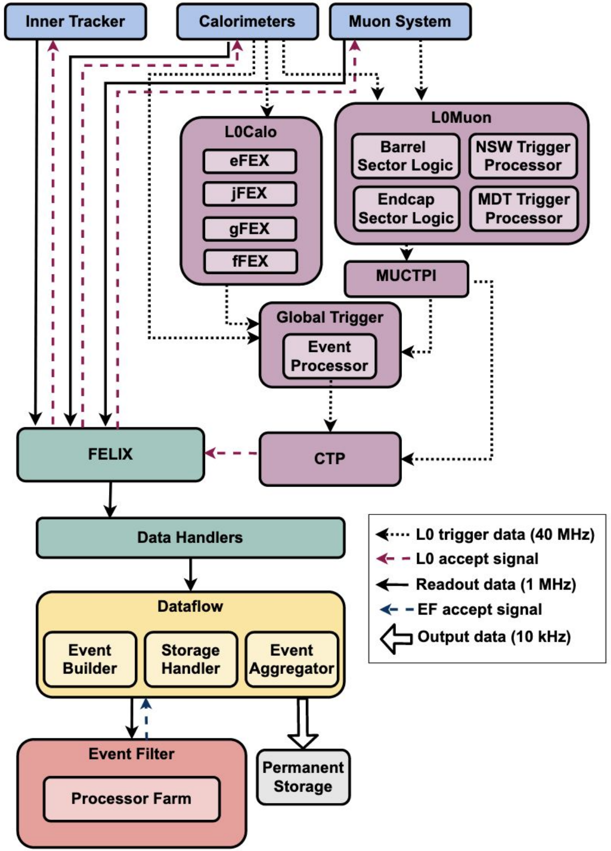
High granularity of detectors great at separating particles

But a lot of data to read out !

Need to reduce 40MHz-> 1MHz ->10kHz to record for analysis

A huge amount of effort is needed in logic needed to make decisions fast

- 40MHz->1MHz : fast object/single-detector based decisions
- 1MHz-> 10kHz : slower "full event decisions"



Summary

We are using the latest technologies to upgrade the 4 detectors to take full advantage of the HL-LHC

Doing things better in a more challenging environment.

- UK is providing core roles in the R&D, and production of these custom made detectors
- UK is providing core roles in the essential data flow

I don’t even have time to mention the upgrades on triggers, electronics, computing, data processing ....