# ATLAS activities and studentship

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# LHC

- LHC first started serious data taking in 2011
  - Run 1, ran at up to 75% nominal luminosity, culminated in discovery of Higgs boson
- LHC Run 2 finished at end of 2018
  - Reached 2 times nominal luminosity, delivered over 5 times data of Run 1
- Now in Long Shutdown 2 for upgrade for Run 3 (2022-2024)
  - Machine consolidation, Phase-I upgrades to ATLAS
- Further Long Shutdown 3 starting in 2024 for upgrade to HL-LHC
  - Phase-II upgrades to ATLAS for 5 to 7 times nominal luminosity

# ATLAS



Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Transition radiation tracker
Semiconductor tracker
Toroid magnets
Solenoid magnet
Muon chambers

- One of two general purpose detectors at the Large Hadron Collider

- Different subsystems in layers around collision point to record trajectory, momentum and energy of particles
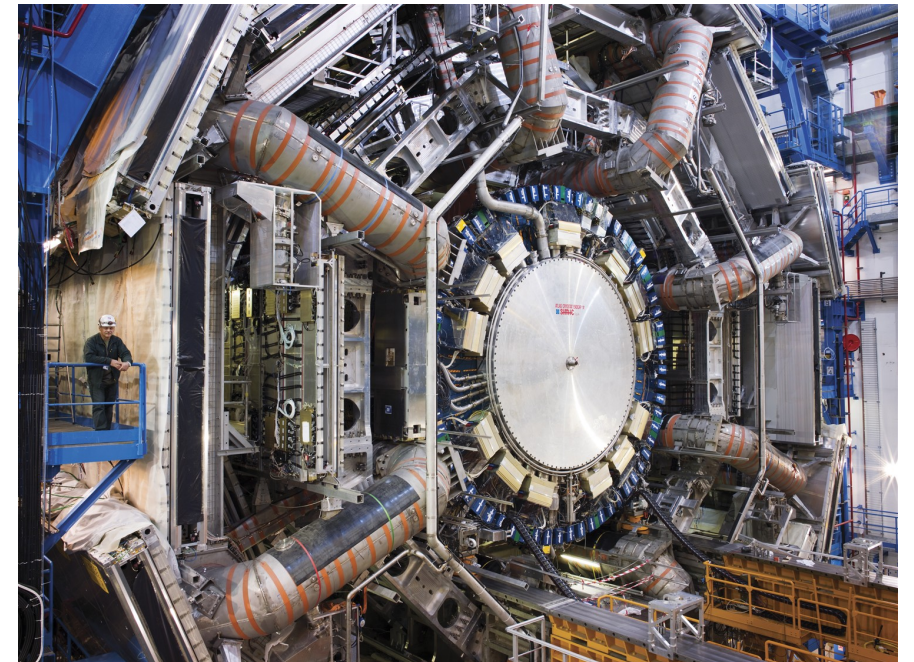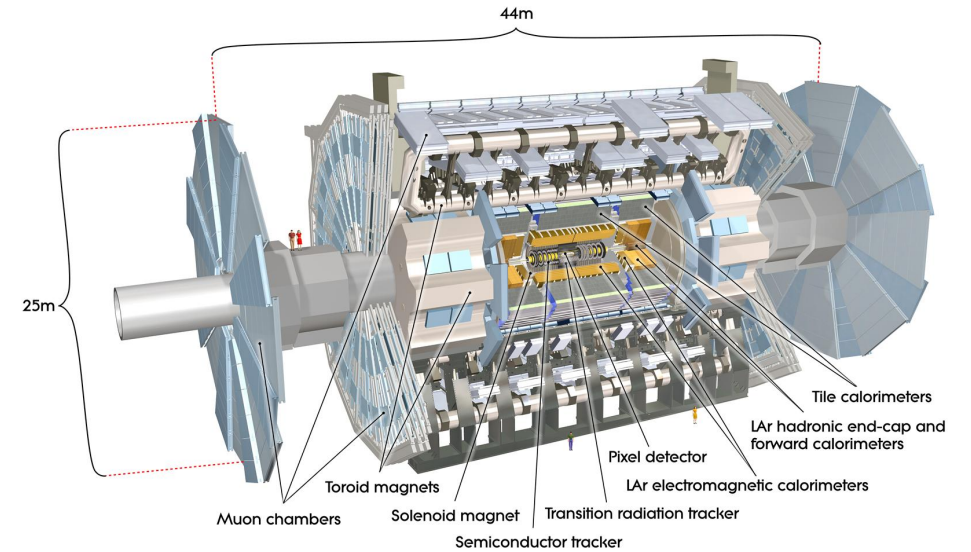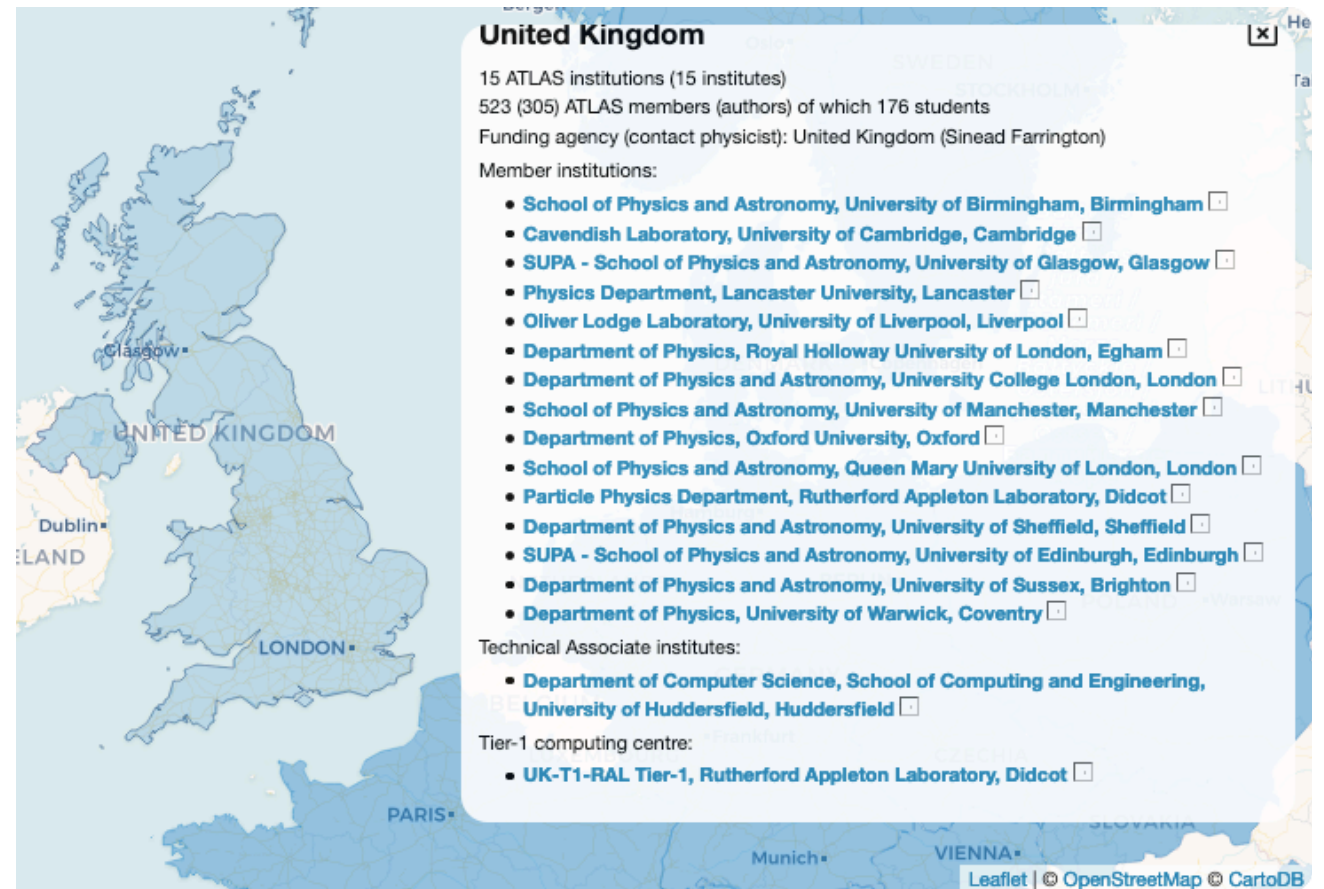
# ATLAS Collaboration

- Worldwide effort

- Beyond the scientific authorship, significant engineering effort: ~1000 people
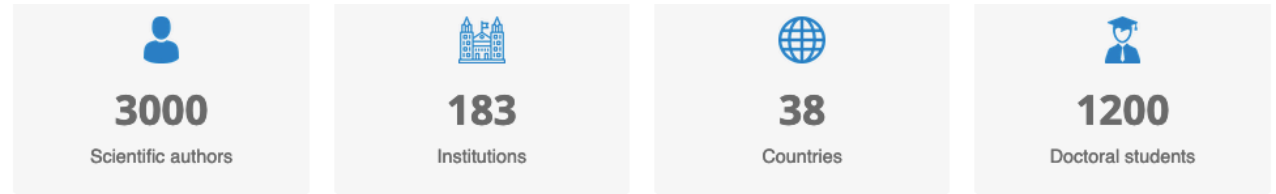
# ATLAS UK

- 14 universities + RAL PPD
  - We have good links with all ATLAS UK universities

- RAL also hosts the UK Tier-1 computing centre
  - Dedicated internet link to CERN
  - Complete copy of LHC raw data





**United Kingdom**

15 ATLAS institutions (15 institutes)
523 (305) ATLAS members (authors) of which 176 students
Funding agency (contact physicist): United Kingdom (Sinead Farrington)

Member institutions:
- School of Physics and Astronomy, University of Birmingham, Birmingham
- Cavendish Laboratory, University of Cambridge, Cambridge
- SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow
- Physics Department, Lancaster University, Lancaster
- Oliver Lodge Laboratory, University of Liverpool, Liverpool
- Department of Physics, Royal Holloway University of London, Egham
- Department of Physics and Astronomy, University College London, London
- School of Physics and Astronomy, University of Manchester, Manchester
- Department of Physics, Oxford University, Oxford
- School of Physics and Astronomy, Queen Mary University of London, London
- Particle Physics Department, Rutherford Appleton Laboratory, Didcot
- Department of Physics and Astronomy, University of Sheffield, Sheffield
- SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh
- Department of Physics and Astronomy, University of Sussex, Brighton
- Department of Physics, University of Warwick, Coventry

Technical Associate institutes:
- Department of Computer Science, School of Computing and Engineering, University of Huddersfield, Huddersfield

Tier-1 computing centre:
- UK-T1-RAL Tier-1, Rutherford Appleton Laboratory, Didcot

Leaflet | © OpenStreetMap © CartoDB

# RAL ATLAS group

- 22 staff (physicists, engineers)
- 2 PhD students (Warwick, Birmingham) (soon to be 3!)
- Photos not comprehensive
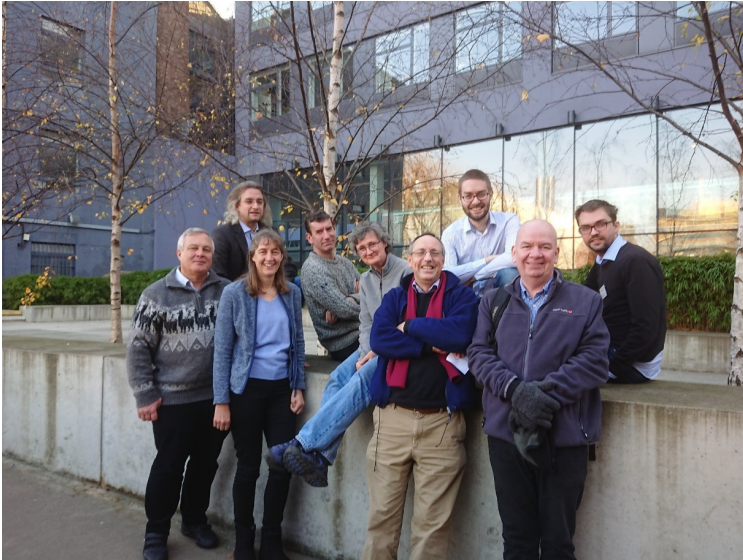
# RAL activities



- Built and operated SemiConductor Tracker and trigger systems in Run 1 and 2

- Phase-I upgrades: installation before Run 3 (2022)
  - Level-1 Calorimeter Trigger and High Level Trigger

- Phase-II upgrades: installation before Run 4 (2026)
  - Level-0 Global Trigger, Event Filter and new Inner Tracker (ITk)

- Diverse physics involvement: Higgs, searches for new heavy bosons, B-physics
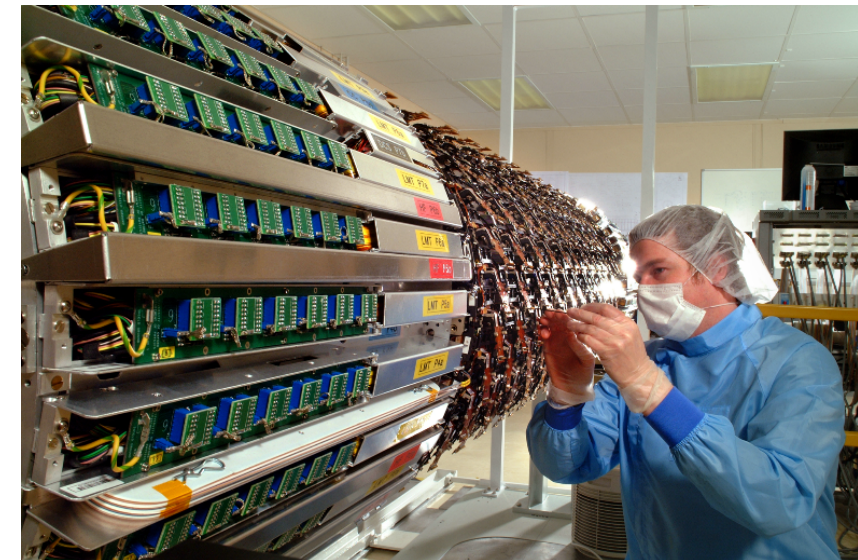
# ITk



- Original Inner Detector reaches its end of life in 2024
  - Will be replaced with new all-silicon detector
- RAL group working on barrel strips and endcap pixels
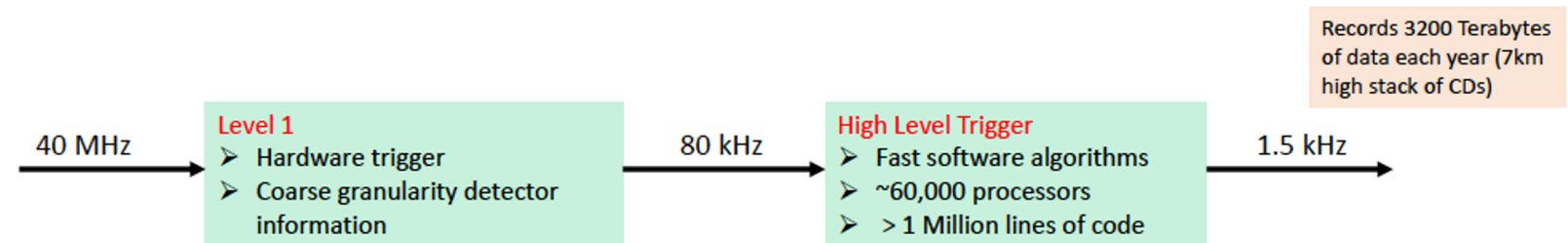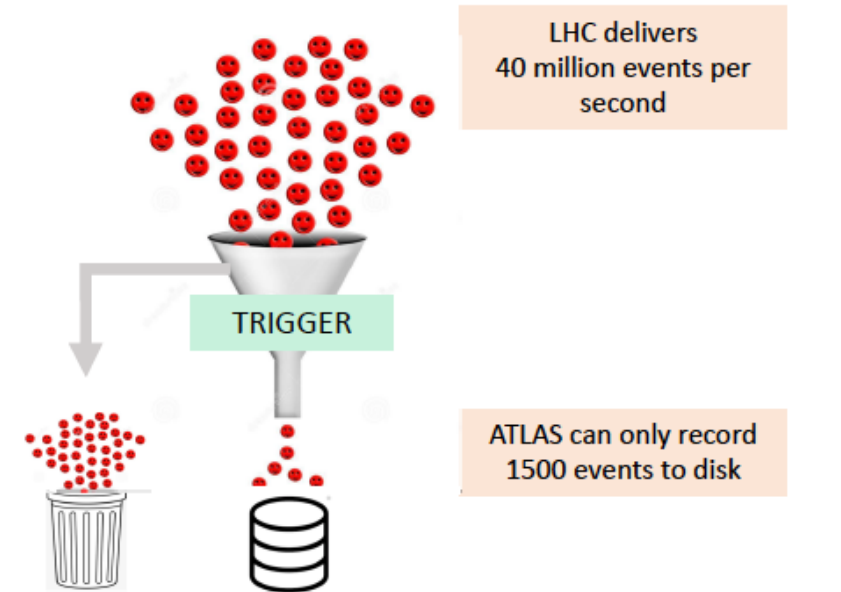  - Design, data acquisition, assembly and eventually operation
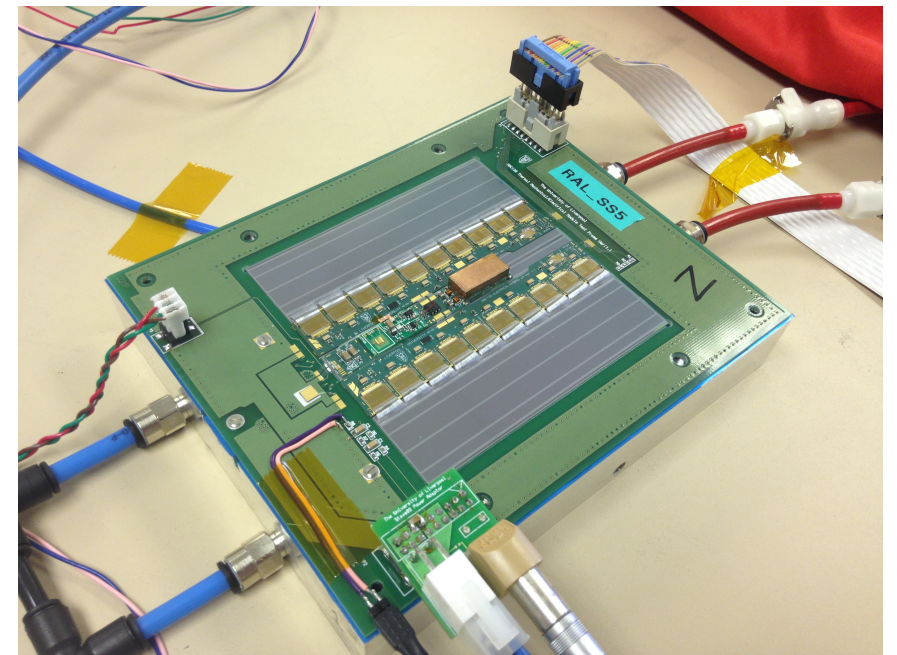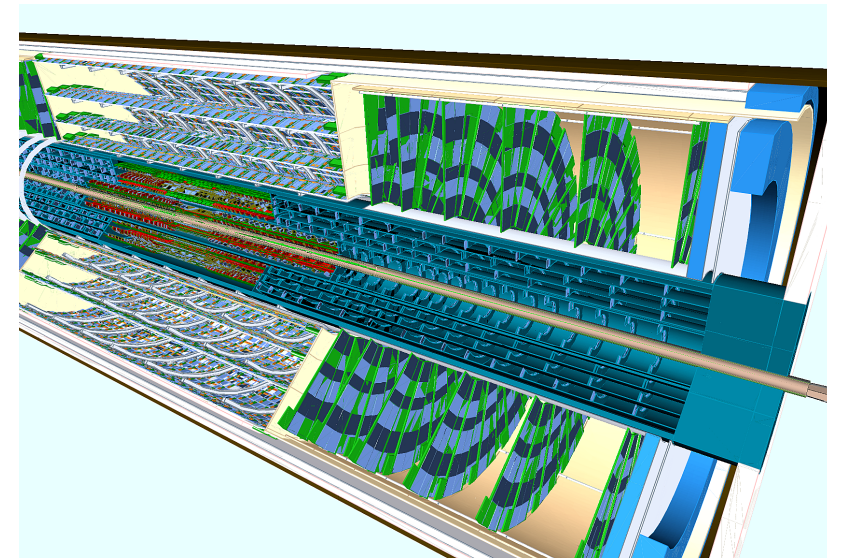
# Triggering at the LHC

- LHC collides bunched beams of protons 40 million times per second
  - Every time the bunches cross, multiple protons collide
  - Real example from 2016 with 85 collisions
    - at end of Run 2 LHC delivering ~1 billion proton-proton collisions per second
- In Run 4, expect an average of 200 collisions each time bunches cross
  - up to 10 billion collisions per second
  - **Interesting** collisions at much much lower rate
    - 1 Higgs boson per 10 billion collisions, some processes only a few collisions per year
- We want just the interesting collisions
  - Sitting in a sea of 'pileup' collisions
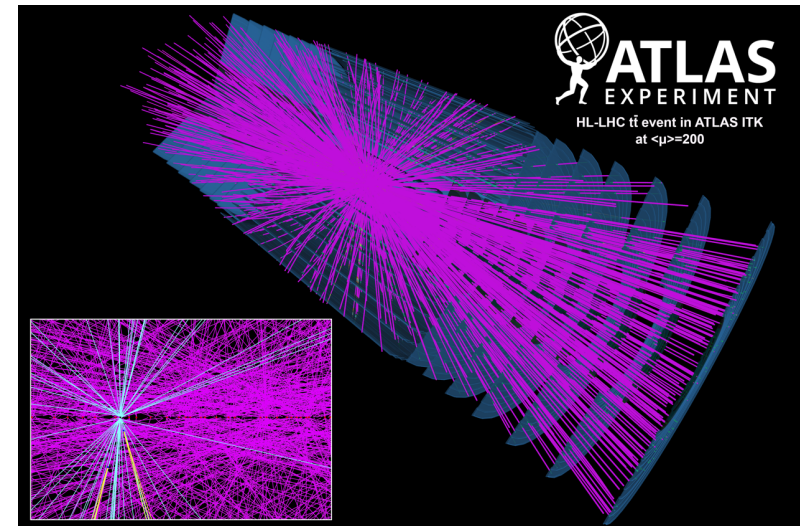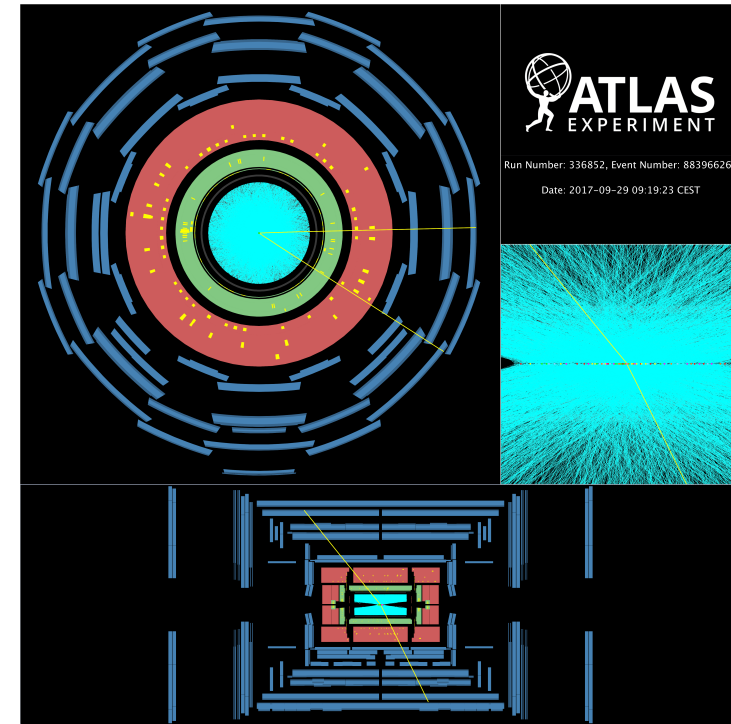
# ATLAS Trigger

- If we stored all the data that ATLAS generates from collisions, we would use every hard drive in the world within weeks

- Store only the interesting collisions (1500/s)
  - Still record the equivalent of full Netflix catalogue every year

- Use dedicated hardware (Level 1 Trigger) and 60,000 CPUs (High Level Trigger)



LHC delivers 40 million events per second

TRIGGER

ATLAS can only record 1500 events to disk

Records 3200 Terabytes of data each year (7km high stack of CDs)

| 40 MHz | Level 1 <br> ➤ Hardware trigger <br> ➤ Coarse granularity detector information | 80 kHz | High Level Trigger <br> ➤ Fast software algorithms <br> ➤ ~60,000 processors <br> ➤ > 1 Million lines of code | 1.5 kHz |

# ATLAS High Level Trigger

- During LS2 rewrote entire trigger code (nearly 1M lines of C++ and Python) to enable multi-threading and improve the selection algorithms



- RAL interests:
  - Tracking – using machine learning techniques to find tracks quickly and efficiently
  - Core trigger software – flow of events/algorithms, control room tools, analysis tools, etc.
  - Validation of trigger software – are we finding the events we want efficiently? Resource usage – memory and CPU time?
  - Beyond CPUs: GPUs and FPGAs for Run 4

# The Glasgow Group

- Group of 10 academics & ~16 research staff + technicians, engineers & PhD students

- Active in many of the world-leading particle physics activities:
    - ATLAS, LHCb & NA62 on the LHC
    - Grid computing (Tier 2 centre here in the building)
    - Neutrinos (T2K & MICE)
    - Linear collider
    - Detector development

- On ATLAS: Higgs, top, SM measurements & BSM searches. Involved in the trigger, computing, simulation & upgrade (tracker & trigger)

# Why the top quark?

- In the SM it's the only quark:
  - With a natural mass:

$$m_{\text{top}} = y_t \frac{v}{\sqrt{2}} \approx 173 \text{ GeV} \rightarrow y_t \approx 1$$

  - <span style="color:red">Top quark interacts strongly with the Higgs sector - special role in EWSB?</span>
  - Decays before hadronizing:
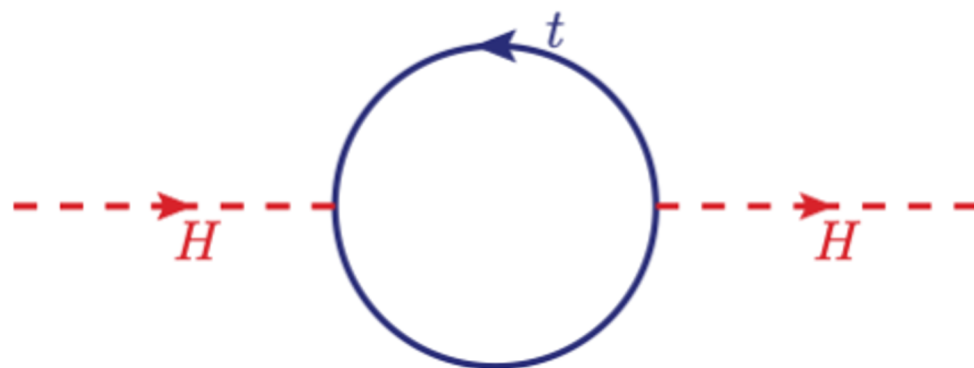
$$\tau_{\text{had}} = 2 \times 10^{-24} s$$
$$\tau_{\text{top}} = 5 \times 10^{-25} s$$

- Copious production rate at the LHC allows for precise tests of QCD involving multiple scales (pT(top), m(top), m(b))

# Why the top quark?



- Corrections to Higgs mass depend on the top quark Yukawa:



- Assume new physics enters at some high scale:

  $$\Delta m_H \approx -\frac{3}{8\pi^2} y_t \Lambda^2$$

  - In effective theory approach:

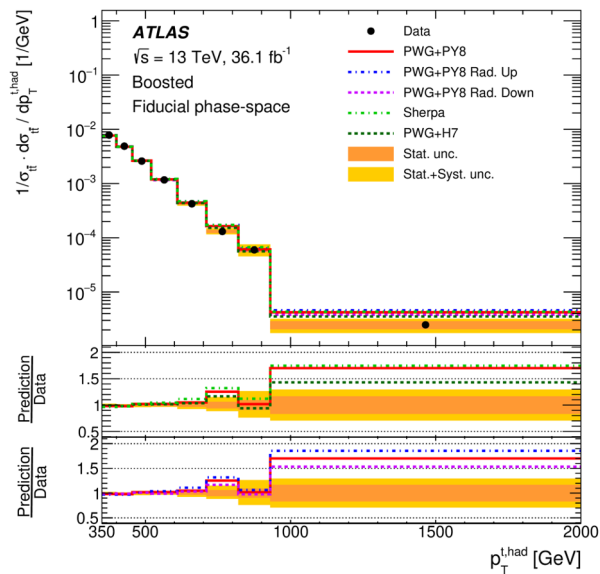    $$\Lambda < 3 \text{ TeV}$$

  - For less than 90% cancellation:

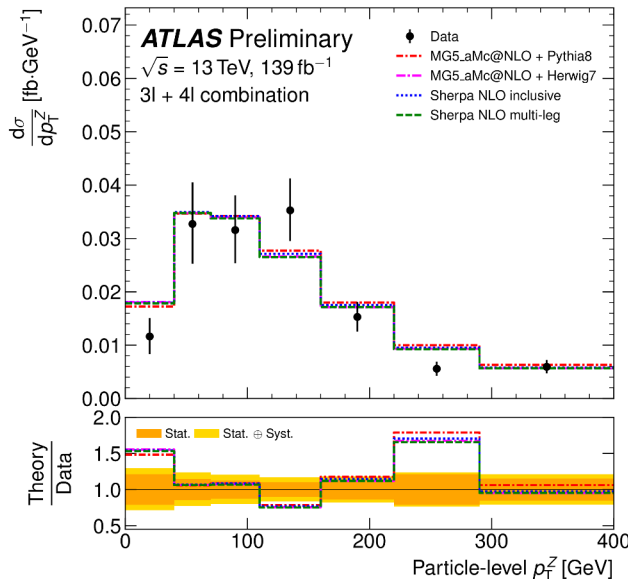- <span style="color:red">Top quark is perhaps the most likely place we will see new physics.</span>

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# Top physics at Glasgow
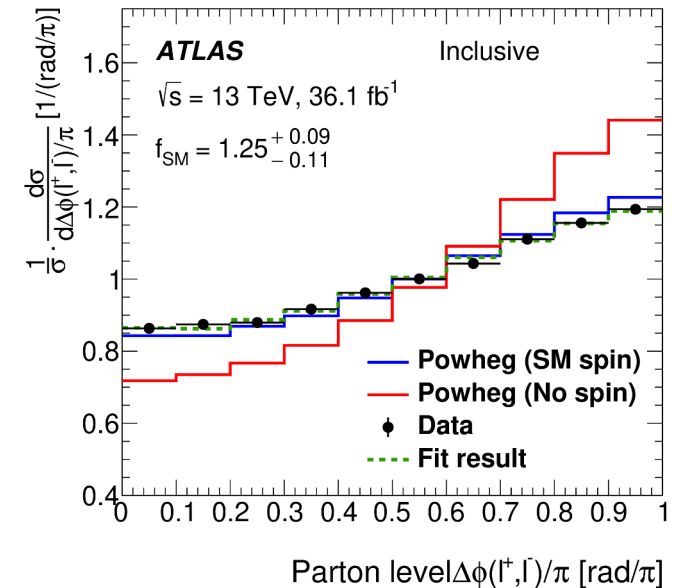
- Nice group of people (3 academics + 2 post-docs + 4 PhD students) on a range of top physics:



Measuring tops with pT > 1 TeV



Measuring rare tt+Z production



Spin correlation in top-quark pairs

- Keep precise PhD analysis project flexible at this point - also allows to see how LHC schedule develops

# Studentship outline

- Start at Glasgow(~6 months)
  - Academic and computing courses
  - Start work on HLT – gain familiarity with project

- Some time at RAL, then 12 - 18 months at CERN
  - Hands-on experience commissioning/operating HLT system during Run 3
    - control room shifts, expert on-call support
  - Join physics analysis group, foundation for physics analysis component of thesis

- Return to RAL
  - Finish physics analysis, write thesis