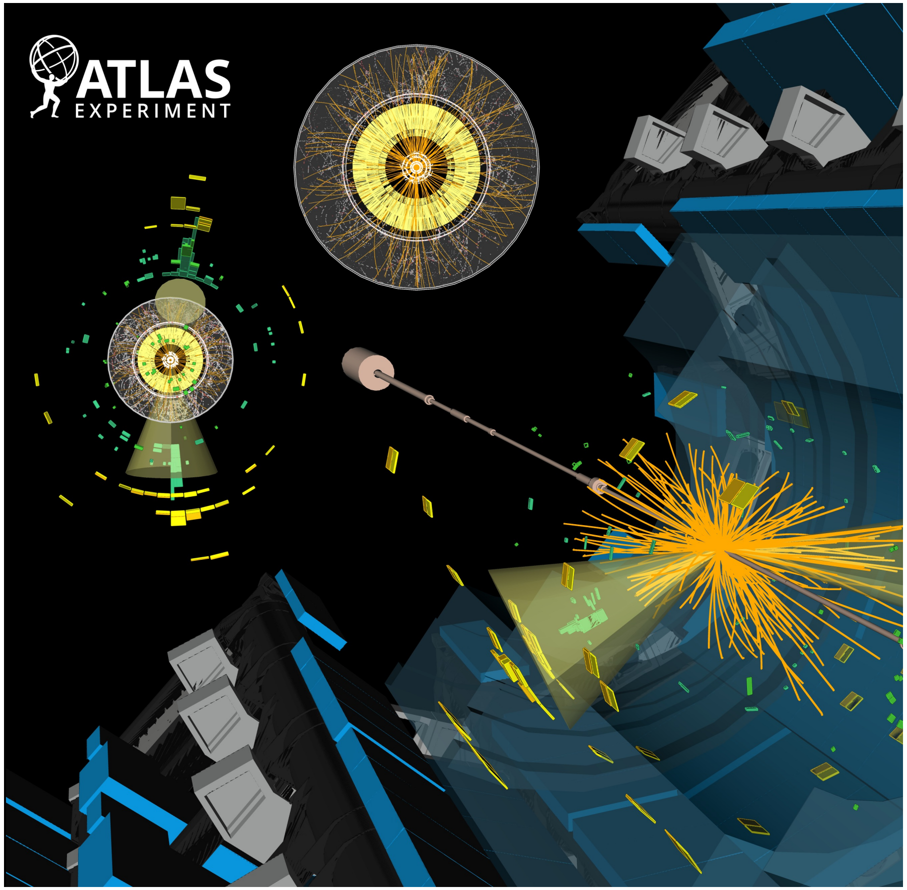
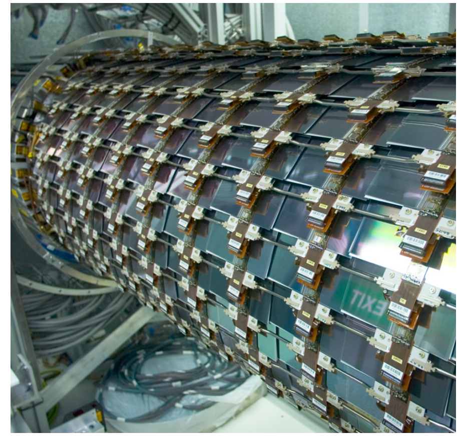
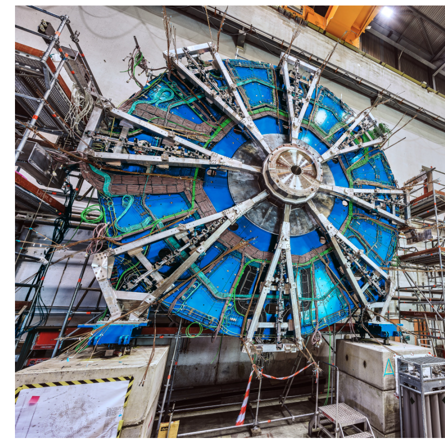






ATLAS Experiment:

Physics Analysis, Operations and Maintenance

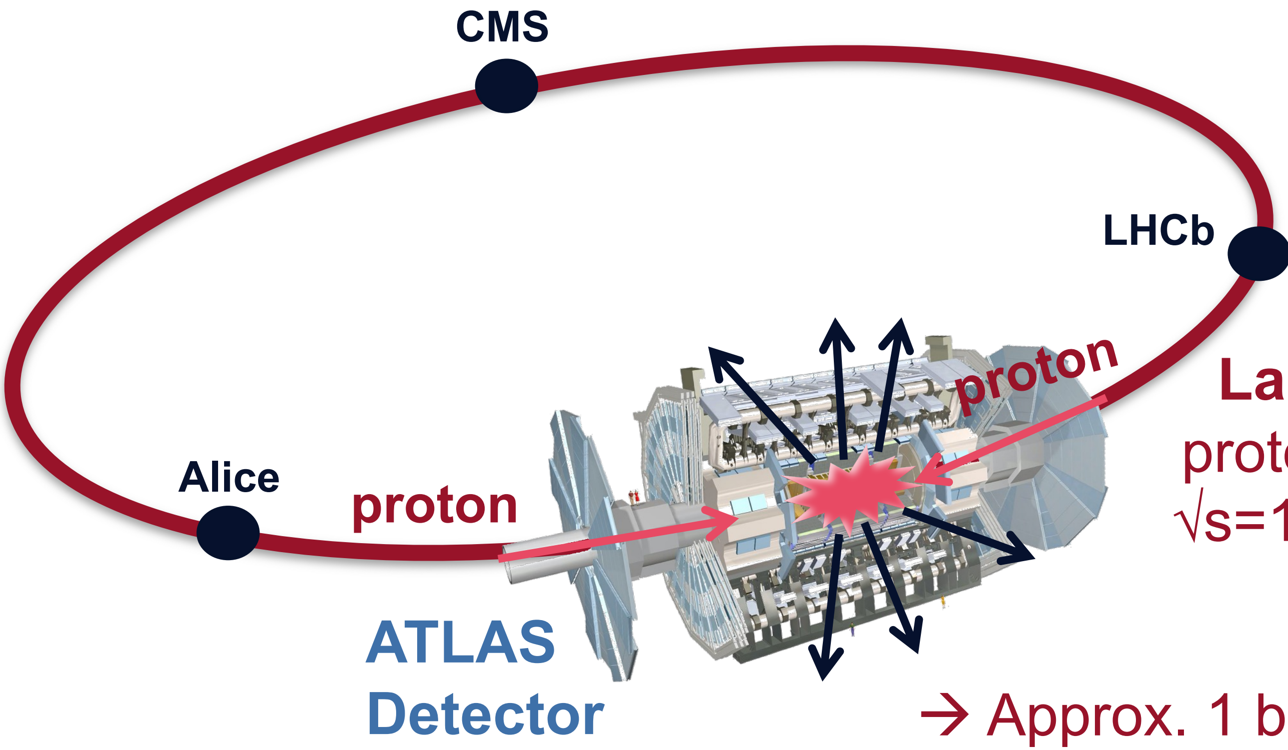
Elisabeth Schopf on behalf of the ATLAS UK community

UNIVERSITY OF OXFORD

ATLAS EXPERIMENT

PPAP Community Meeting, Manchester 2022

+ATLAS & the LHC



Large Hadron Collider:
proton-proton collisions at
√s=13.6 TeV (since 07/22)

→ Approx. 1 billion collisions/second

ATLAS: multi-purpose experiment recording collisions since 2010

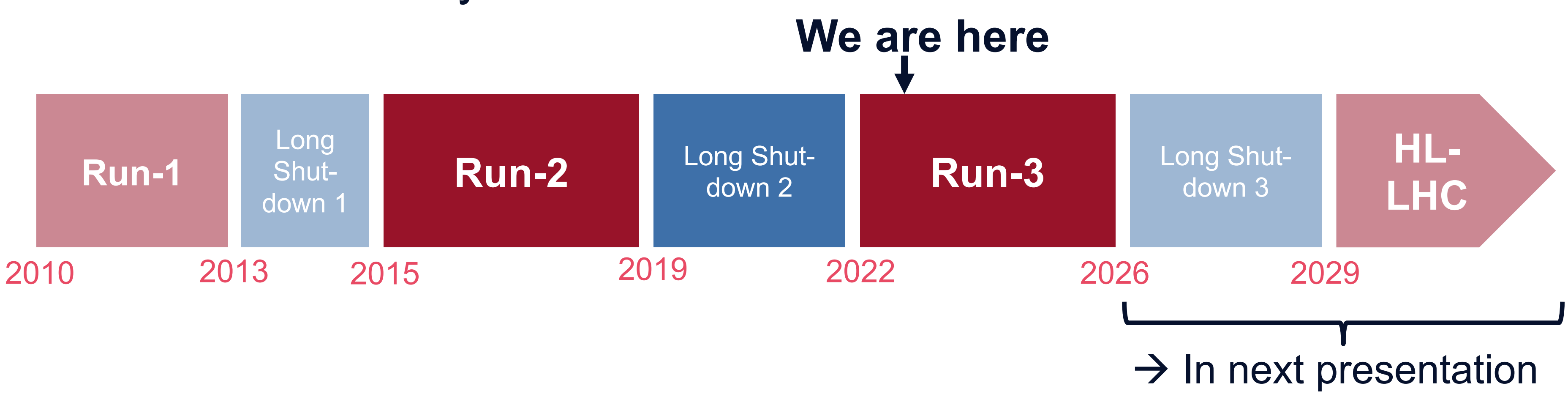
On average 1000 collisions/second saved for physics analysis
→ **Increasingly large data sets: transition to precision measurements and searches for ultra-rare processes**

ATLAS & LHC Roadmap

- Data set of Run-2 available for analysis (13 TeV, 140 fb^{-1})

→ Many results published (1000 papers by the ATLAS collaboration in 06/21!) and **more analyses ongoing**

- **Run-3 data taking started in 07/22** after intense preparations and upgrades (13.6 TeV, projected ~250 fb^{-1})
  - 10 fb^{-1} already recorded



ATLAS UK Community

14 universities + RAL

~400 active ATLAS members

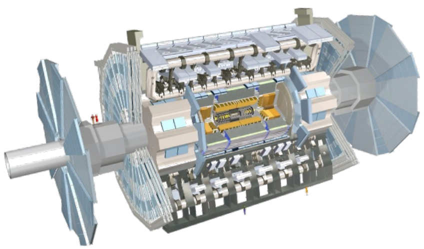
~160 students

Activities: Physics research, data reconstruction, computing, experiment operation & maintenance, detector upgrade

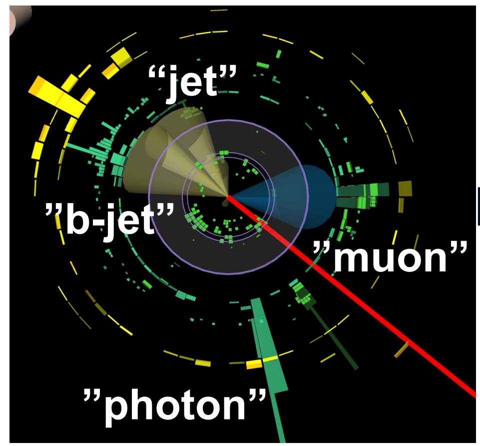
THE UNIVERSITY of EDINBURGH
University of Glasgow
Lancaster University
UNIVERSITY OF LIVERPOOL
MANCHESTER 1824 The University of Manchester
The University Of Sheffield.
WARWICK THE UNIVERSITY OF WARWICK
UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF CAMBRIDGE
Queen Mary University of London
UNIVERSITY OF OXFORD
UCL
Science & Technology Facilities Council Rutherford Appleton Laboratory
US UNIVERSITY OF SUSSEX
ROYAL HOLLOWAY UNIVERSITY OF LONDON

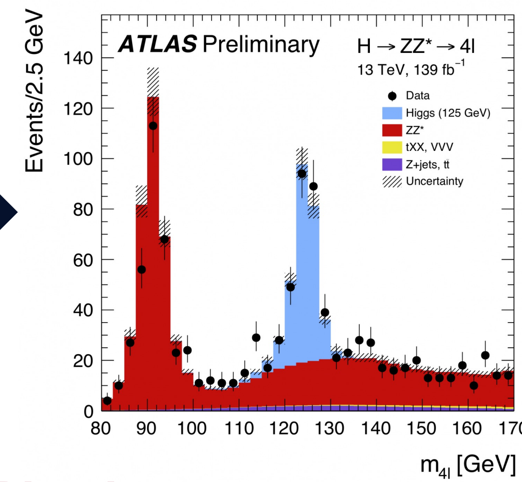
+ ATLAS UK Activities

Computing & simulations



Trigger



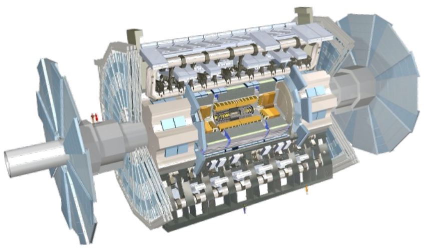


Detector & Trigger | **Object reconstruction** | **Physics measurements**

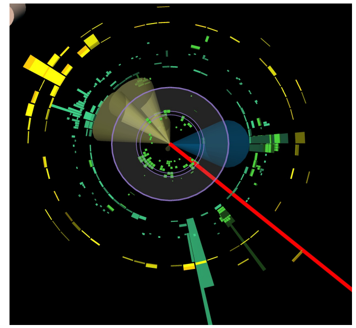
Strong and continued involvement and leadership from the UK ATLAS community across key areas of experiment operation and physics measurements

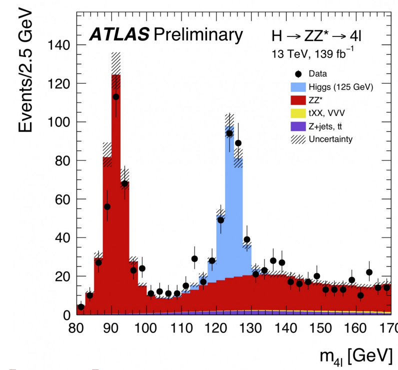
+ ATLAS UK Activities

Computing & simulations



Trigger





Detector & Trigger **Object reconstruction** **Physics measurements**

- Semiconductor tracker (**SCT**) and trigger (**L1Calo, HLT**) operation, maintenance and upgrade
- Object reconstruction (**tracking, muons, jets, b-jet and tau ID**)
- Measurements (**Standard Model incl. Higgs boson, searches for new physics**)

+ providing **computing** resources and (improved) **simulated data**

Run-2 Physics Highlights

Immense amount of results, including key milestones and first observations, with **major UK involvement and leadership** (sub-group convenerships, analysis coordination)

Areas span:

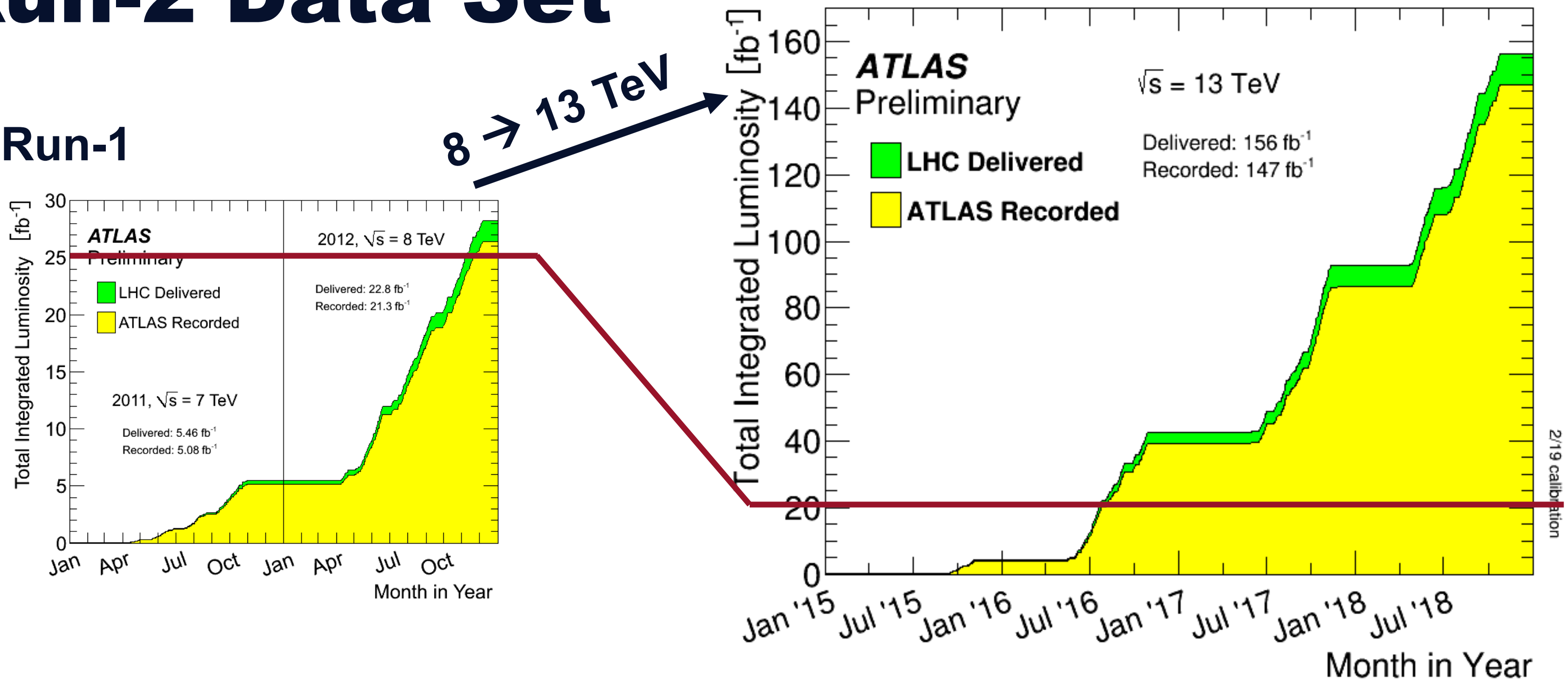
- Higgs boson, W, Z, top and B-hadron measurements, incl. precision measurements and searches for rare processes
- Searches for new particles, extended Higgs sector, invisible particles, Supersymmetry (SUSY)

Run-2 Data Set

Run-1

8 → 13 TeV

Run-2

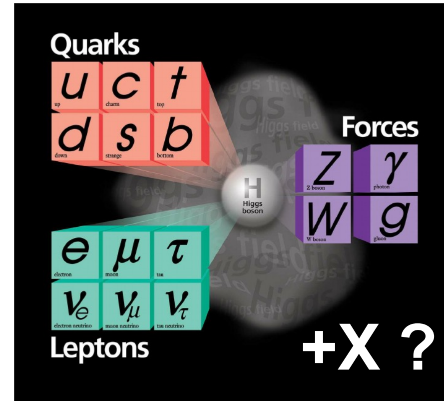


Run-2: massively successful and resulted in immense data set

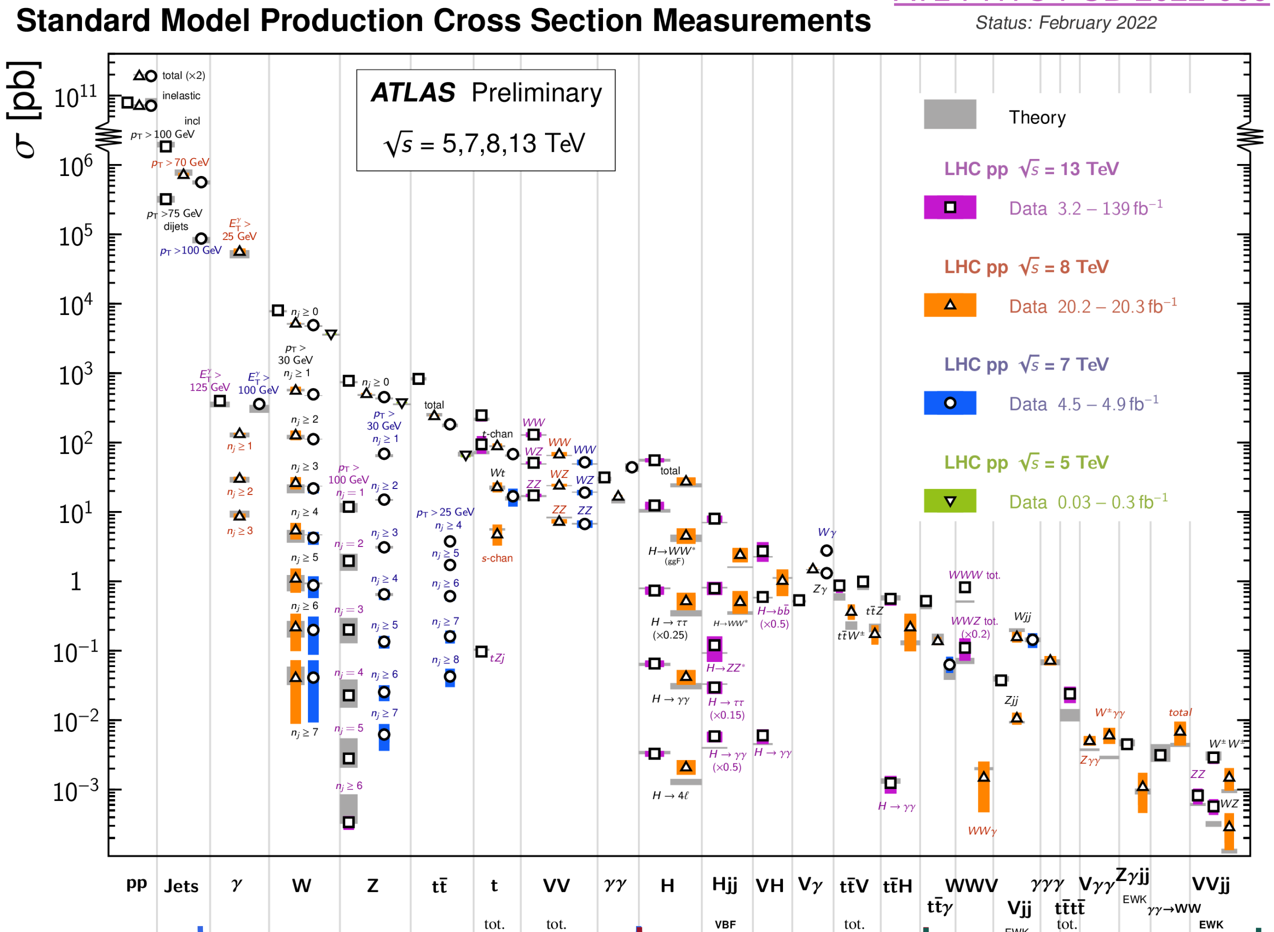
Thanks to dedicated LHC and experiment operations teams

W bosons	~26 billion
Z bosons	~8 billion
Top quarks	~275 million
Higgs bosons	~8 million
Higgs pairs	~4000
Zγjj events	~650

Run-2 Physics



ATL-PHYS-PUB-2022-009



W, Z, top quark and photon (precision)

Higgs boson

Ultra-rare SM processes

Run-2: many first observations (e.g. H→bb, $\gamma\gamma$→WW) and unprecedented precision

→ Most extensive knowledge about SM

More data will allow to **unravel fundamental processes in more detail** and probe extreme phase space regions where **new physics might be hidden**

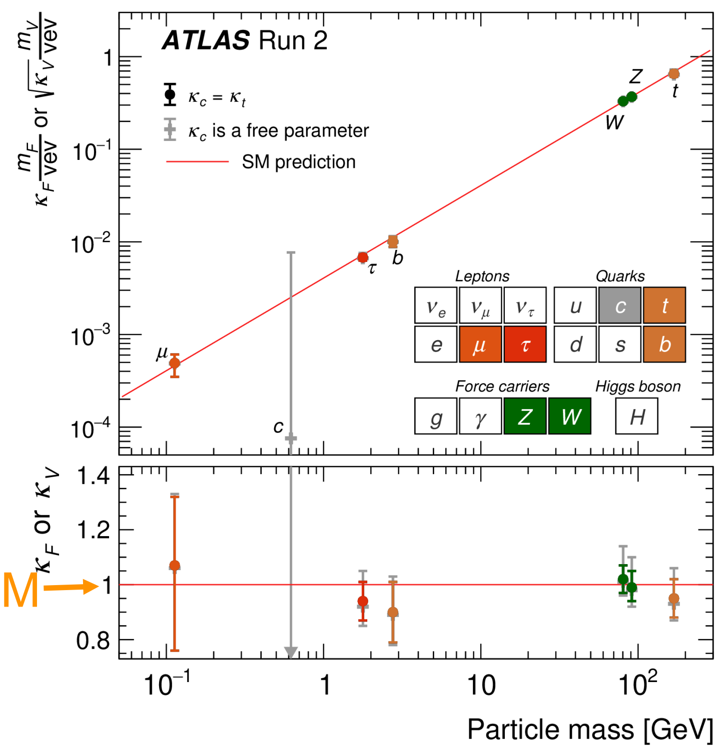
Nature 607, 52–59 (2022)

The Higgs Boson

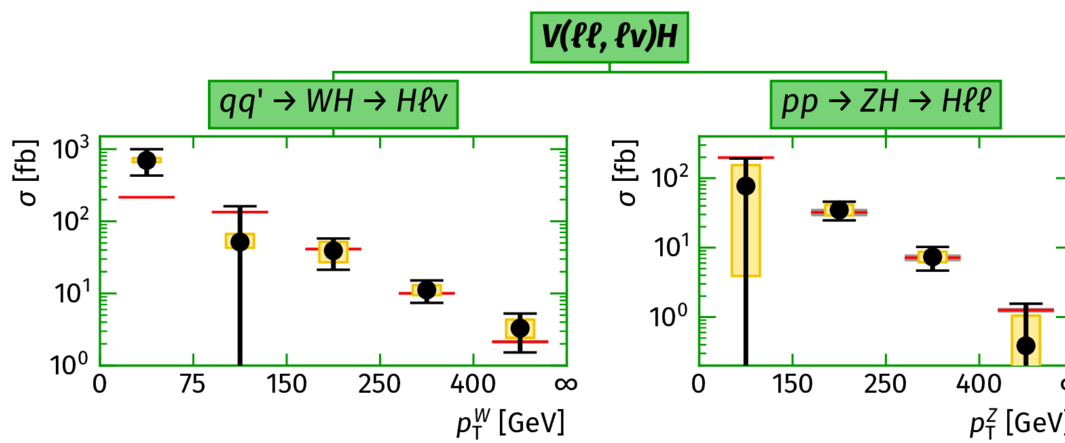
Combining all measurements → most comprehensive map of Higgs boson interactions

All major production modes – ggF, VBF, WH, ZH, ttH – observed!

Coupling strength to SM particles



x-section as function of momentum

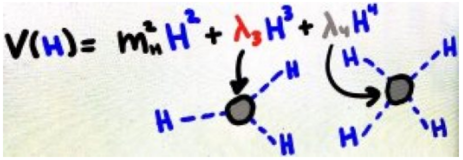


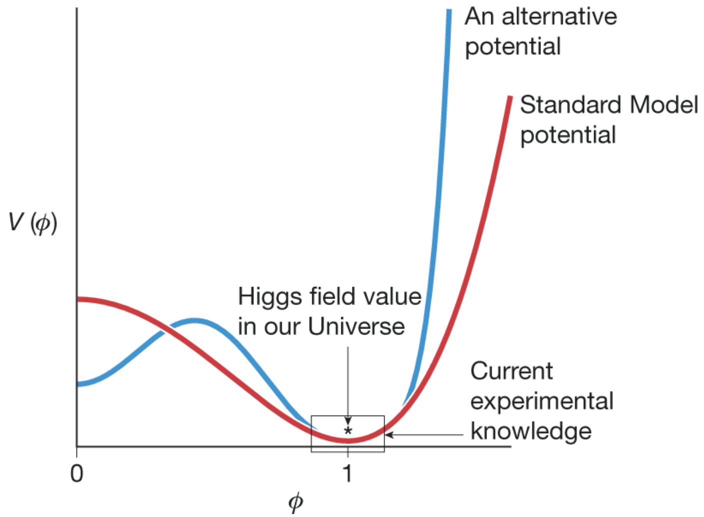
Probing higher and high pT with increasing precision

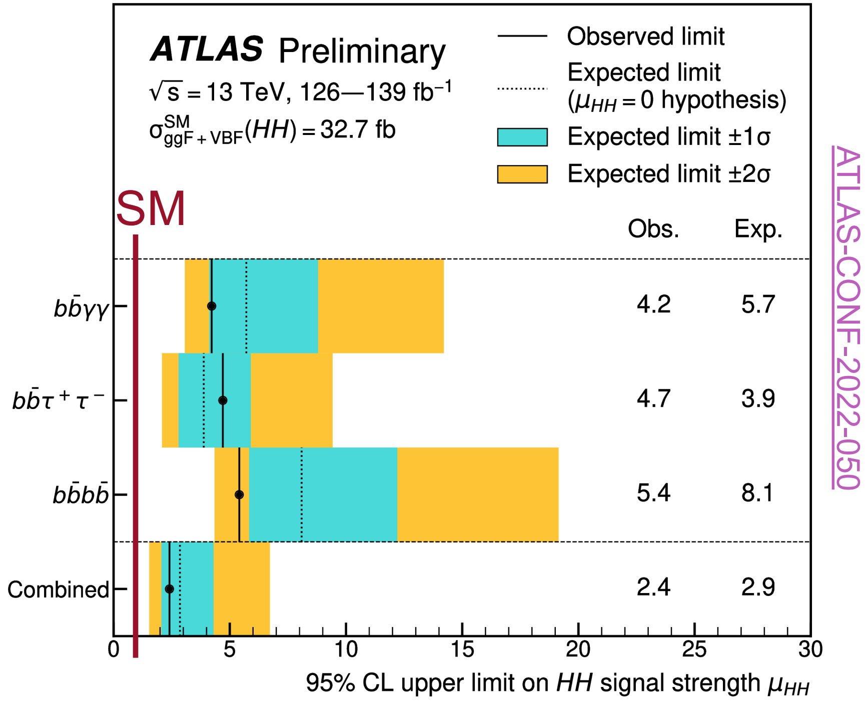
plot thickens: Higgs boson connected to mass generation of all (?) SM particles

+ What about two Higgs Bosons?

Higgs boson self-interaction connected to shape of Higgs field potential → Insights into electro-weak symmetry breaking during universe's early stages and long-term stability







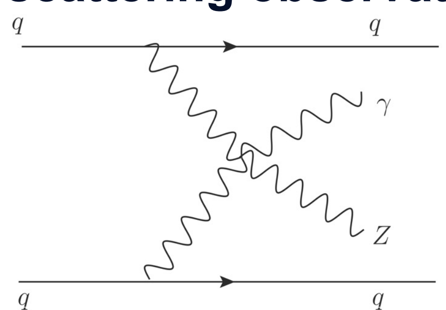
x-section*branching ratio < 2.4*SM expectation
→ reaching SM sensitivity (& beating earlier projections)!

+ W, Z and Top Quark Precision Measurements

- Ultra-rare (never observed before) SM processes are especially susceptible to new physics
- Their measurement further probes validity of SM
  - Electro-weak processes, e.g. vector-boson scattering, also connected to electro-weak symmetry breaking

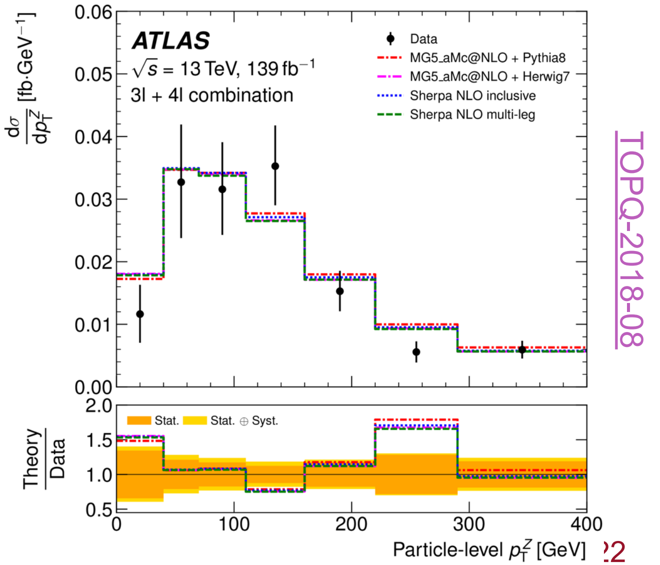
ATLAS-CONF-2021-038

Zγ scattering observation



$$\sigma_{EW} = 4.49 \pm 0.40\ (\text{stat.}) \pm 0.42\ (\text{syst.})\ \text{fb}$$

ttZ x-section measurement



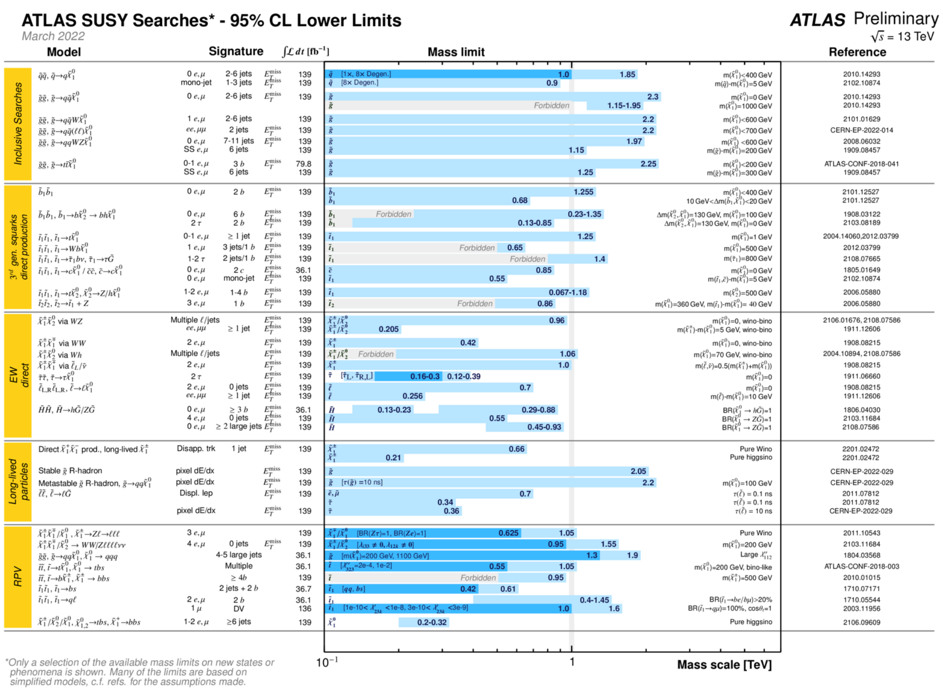
TOPQ-2018-08

→ **(so far) everything in agreement with SM**

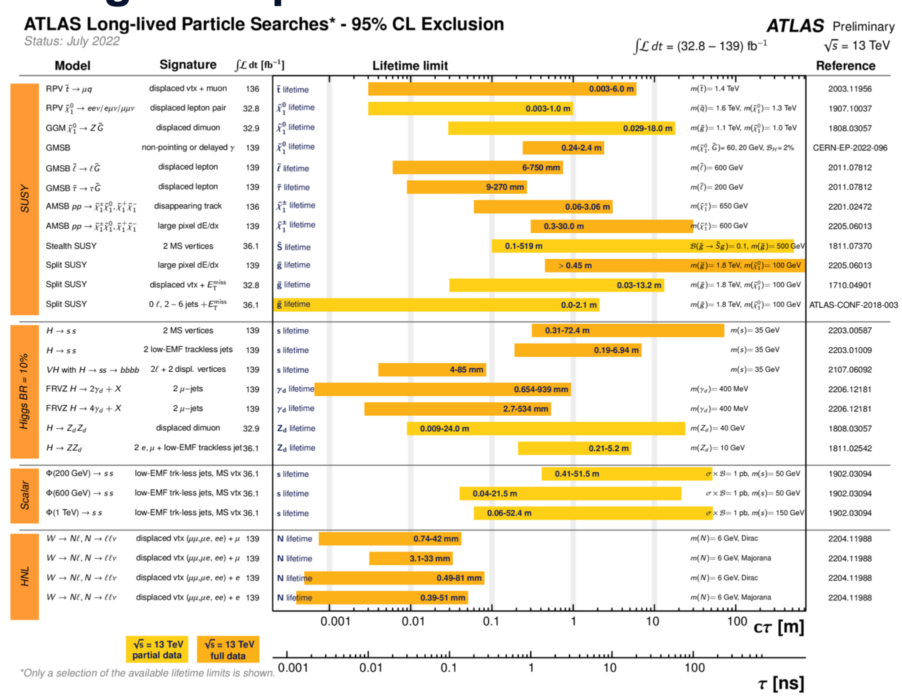
Search for New Physics

Many searches for e.g. light/heavy new bosons (→ extended Higgs sector), supersymmetry including lightest SUSY particle (→ dark matter, …), exotic signatures (→ axions, majorana neutrinos, …)

SUSY [ATL-PHYS-PUB-2022-013]



Long-lived particles [ATL-PHYS-PUB-2022-034]

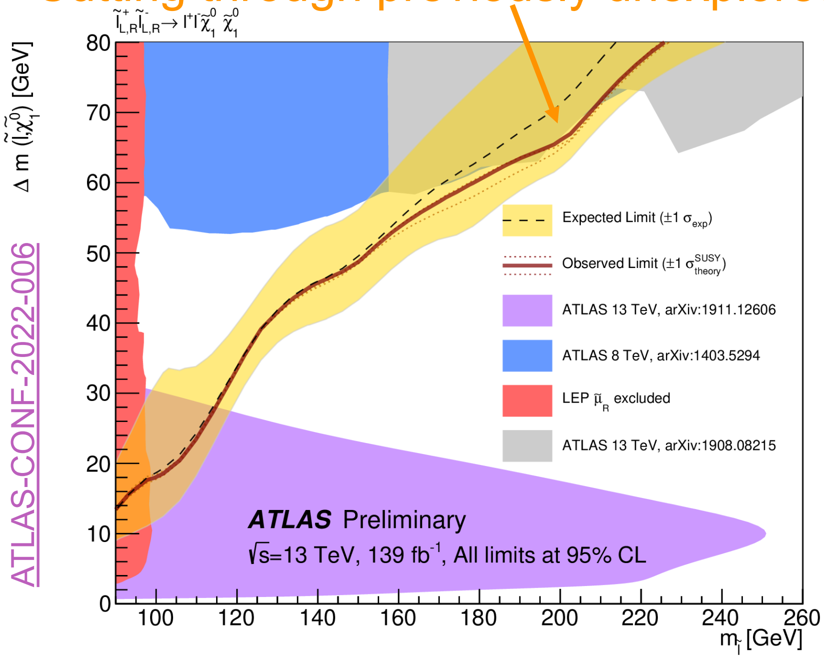


Large range of signatures covered spanning large mass ranges and lifetimes

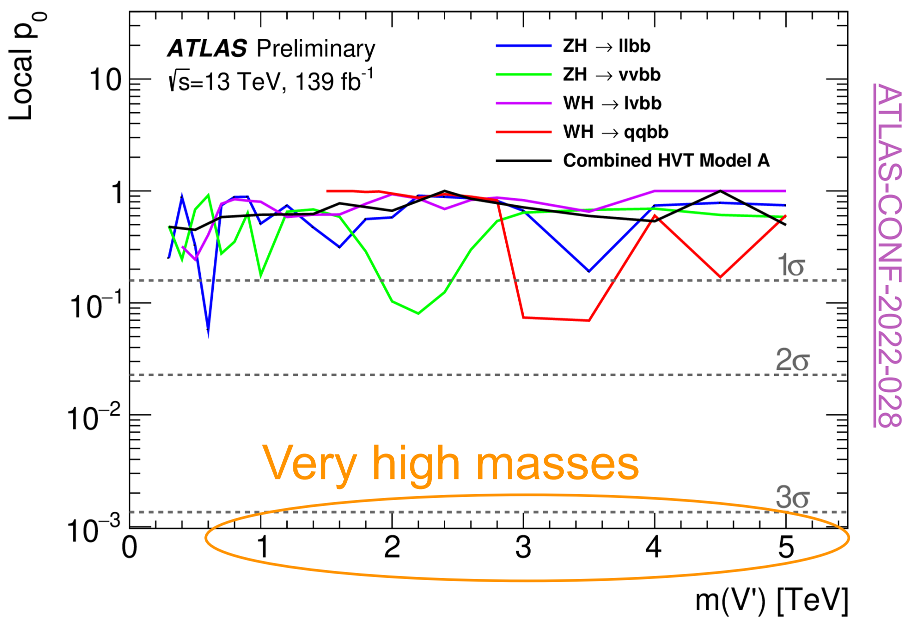
Searches for New Particles

Combining many Run-2 measurements to reach improved sensitivity esp. at ultra-high masses and unexplored phase spaces

Cutting through previously unexplored space



Neutralino and slepton exclusion limits (SUSY)



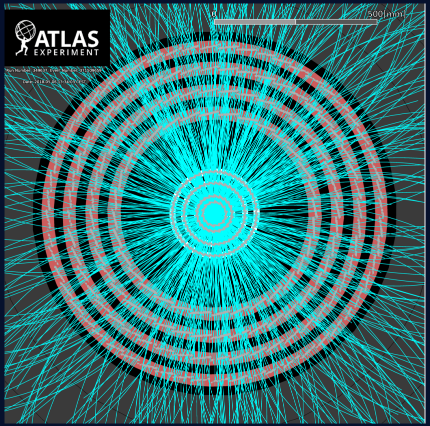
Heavy new particle exclusion limits

Systematically mapping out new phase spaces
→ (so far) no sign of new physics

ATLAS Experiment Operations and Maintenance

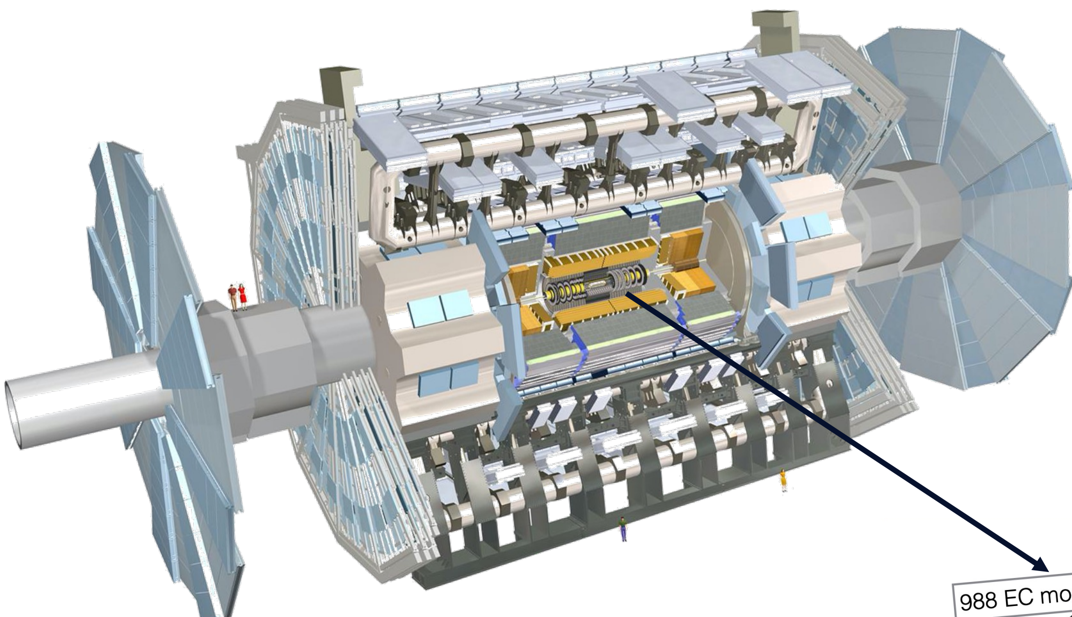
In the following focussed on the systems with major UK involvement

Major to-do items transitioning from Run-2 to Run-3:
- maintaining aging systems
- handling ultra high and dense data rates due to large amount of parasitic collisions (pile-up)
- upgrade and fine tune where possible



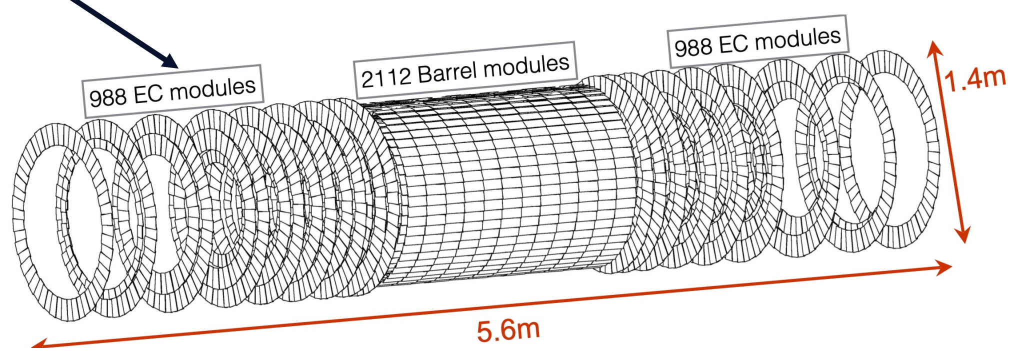
+ Semiconductor Tracker (SCT)

Detector providing tracking information one of the systems closest to the interaction point (immense radiation doses)



Built with major UK involvement

Taking data since 2010

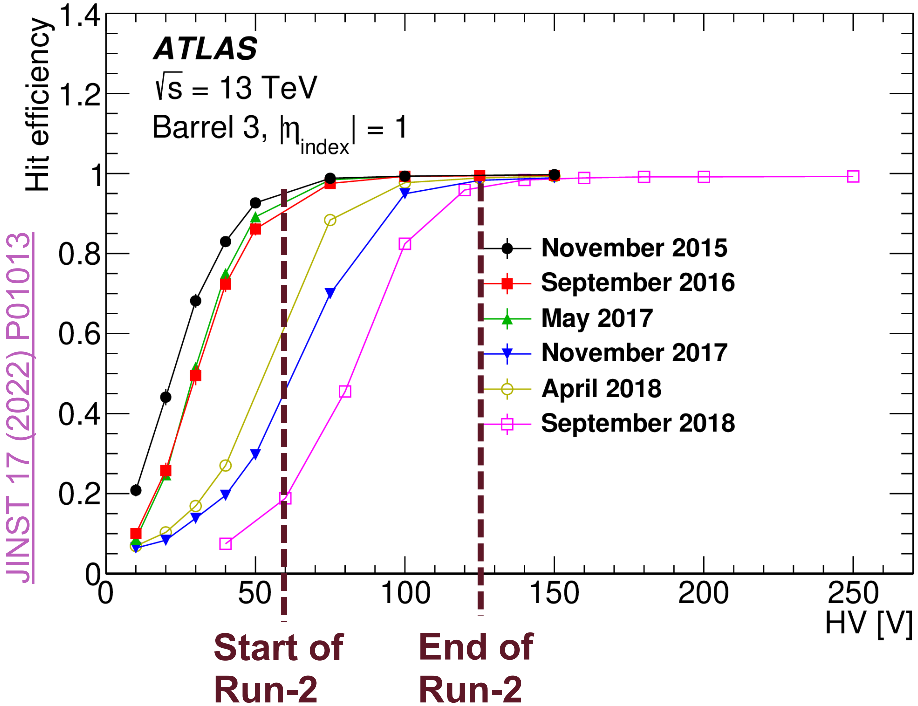


SCT: from Run-2 to Run-3

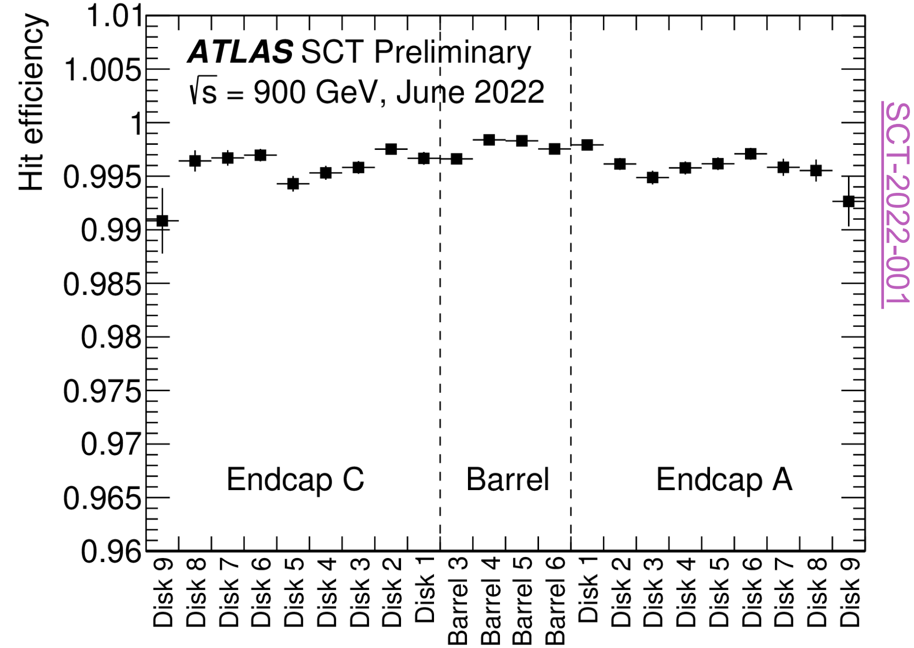
Detector providing tracking information one of the systems closest to the interaction point (immense radiation doses)

Detailed study of Run-2 performance

to prepare for Run-3 operations



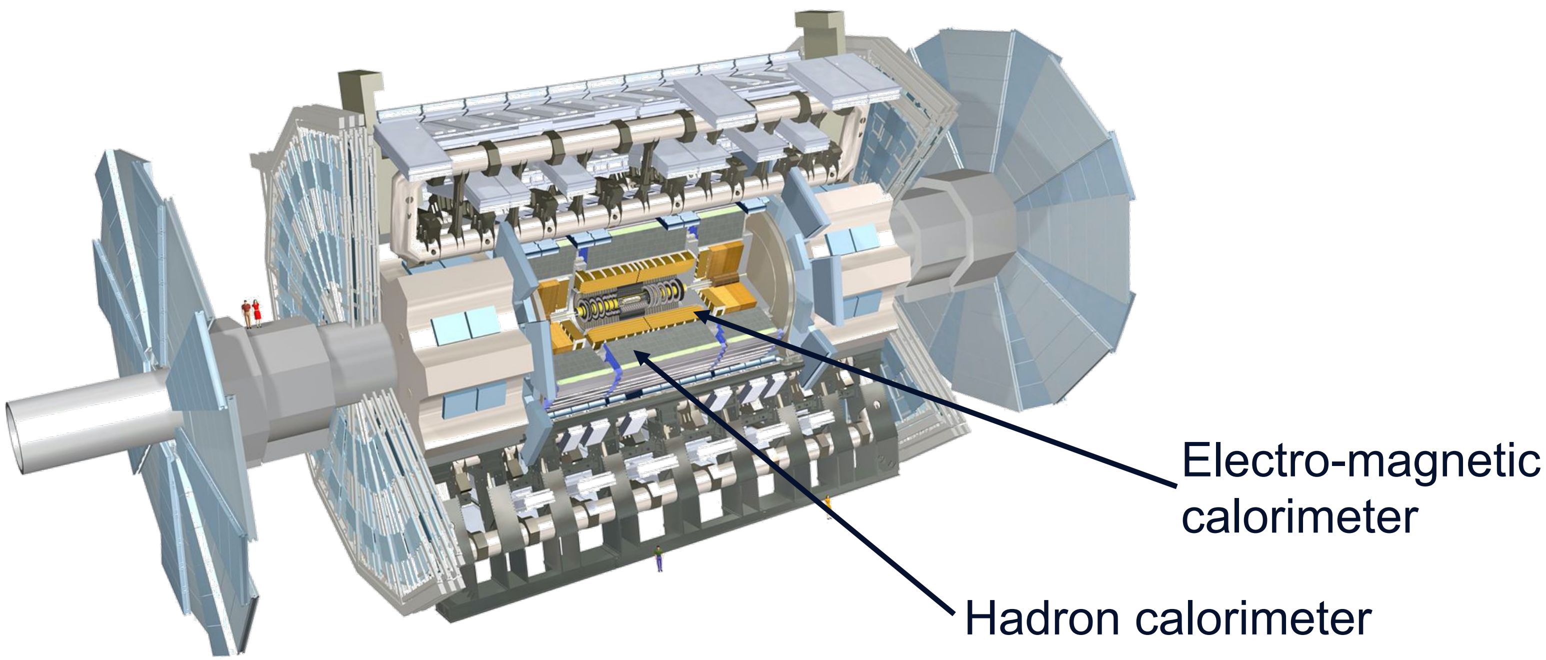
→ High voltage needs to be adjusted



Run-3 commissioning after tweaking operational settings

+ L1Calo Trigger

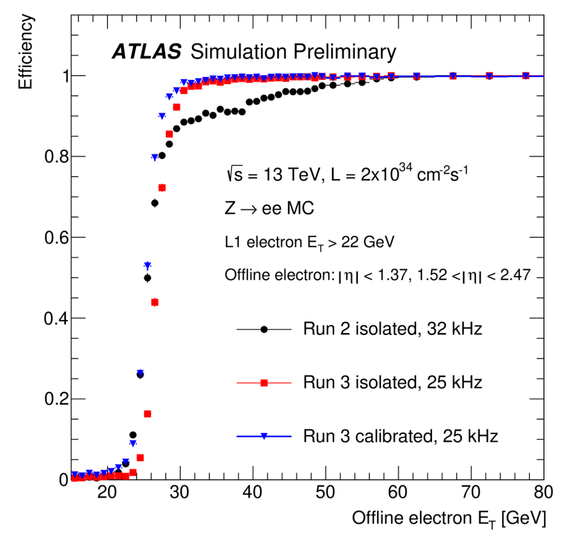
- Hardware trigger delivering decisions with rate of 40,000,000/second keeping 100,000 events/second
- Combines information about dense activity in the calorimeters (→jets, electrons, hadronically decaying tau-leptons) or imbalance of activity (→ missing energy)



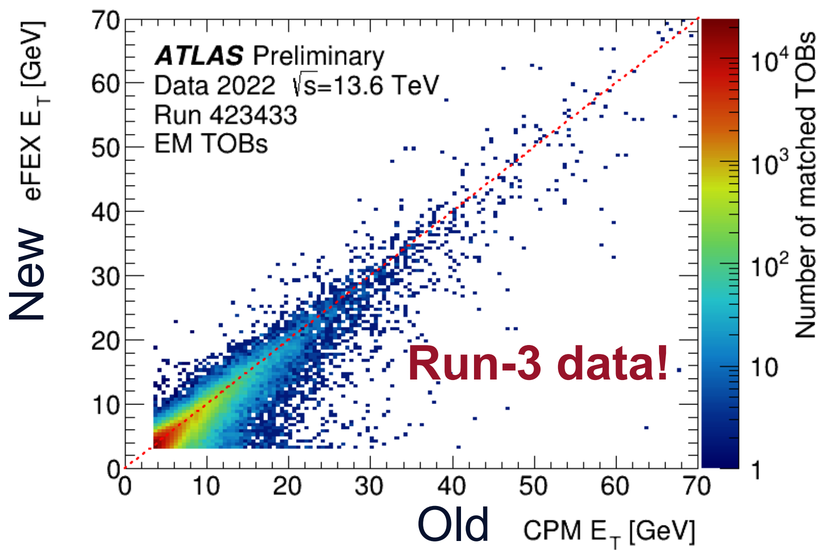
+ L1Calo Trigger Upgrade

- Currently being upgraded (for usage during Run-3) with **UK institutes dominating leadership → improvements in electron and tau trigger + better performance vs. pile-up**

- **Status:**
  - Installation and integration into ATLAS completed (as of last week!)
  - Next year: finalise operation/monitoring software and fine-tuning



Expected improvement in electron trigger performance



Correspondence between old and upgraded systems

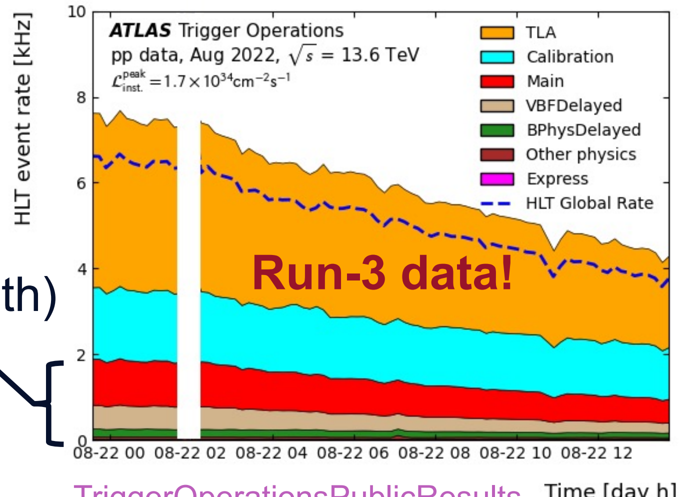
+ High-Level Trigger

- Software based trigger receiving ~100,000 events/second to reduce to ~1000 events/second kept for physics

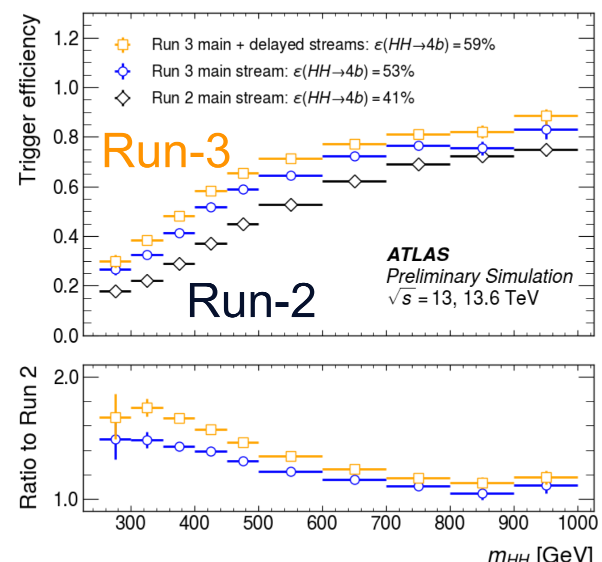
- Software optimisation and upgraded computing facilities towards Run-3 → more frequent and more complex operations (e.g. track reconstruction) possible

→ **Expanded and improved triggering for Run-3!** (dedicated long-lived particles trigger, b-jets, ...`

Default triggers (>90% bandwidth)



TriggerOperationsPublicResults



Better HH→bbbb acceptance

BJetTriggerPublicResults

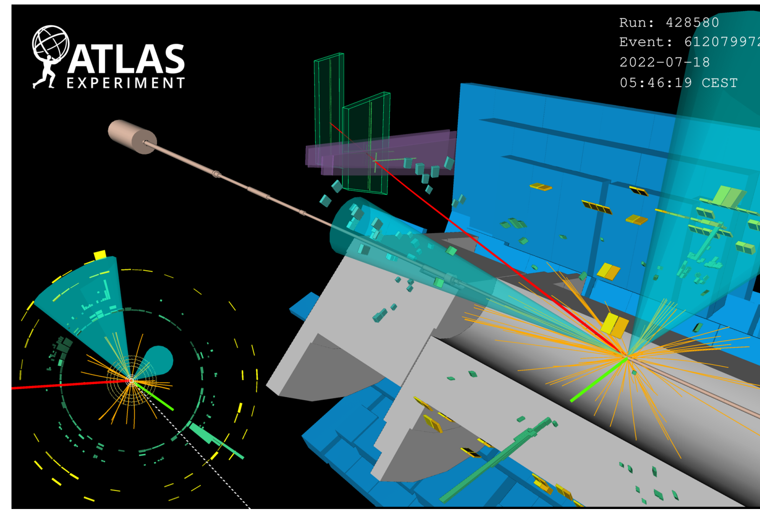
Run-3 Outlook

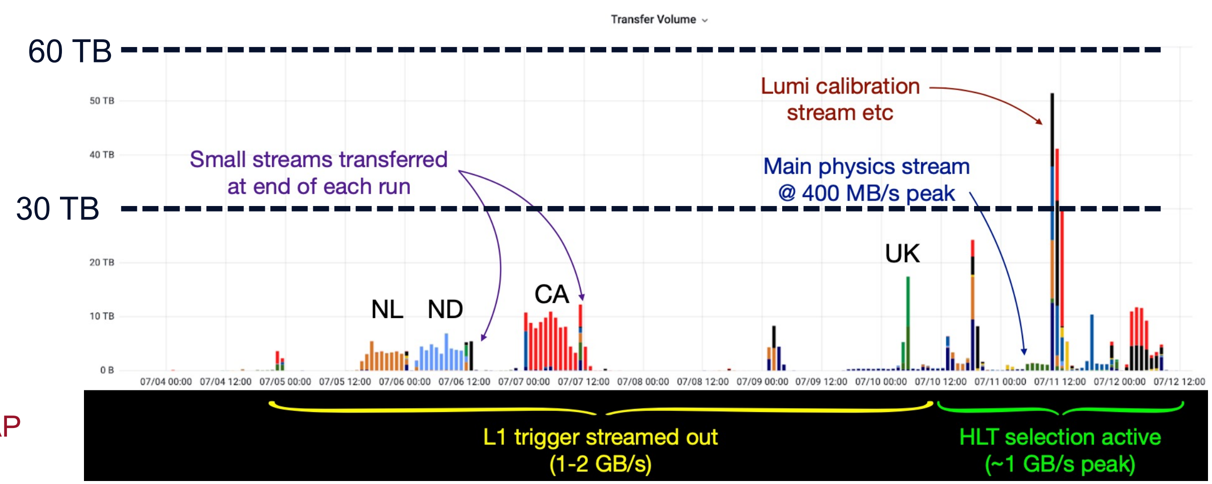
First Collisions

ATLAS Run-3 data taking at collision energy of 13.6 TeV officially started on 05/07/22

ATLAS Control Room: first 13.6 TeV collision

Early Run-3 top quark pair (17/07/22)





Data transfer vs. time (04/07/22 – 12/07/22)

+ Run-3: New Opportunities

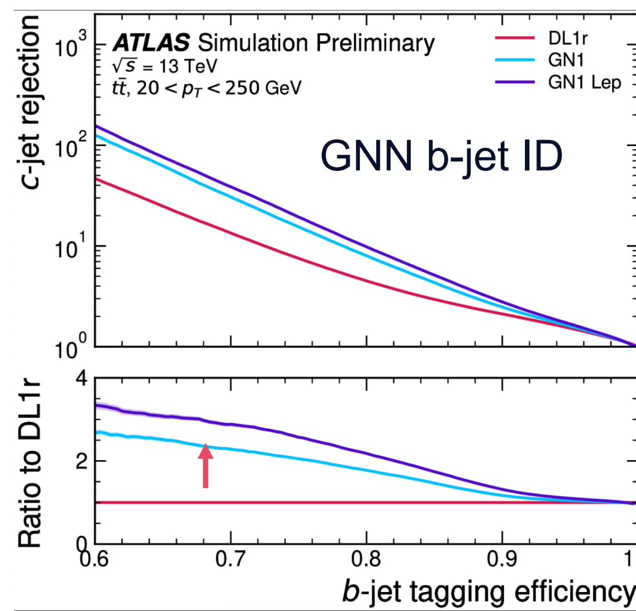
- **Larger dataset expected and increased x-sections** due to higher collision energy (HH +11%, Z' with 6 TeV mass +70%)

- **Upgraded & new detector systems**, e.g. "New Small Wheel" for improved muon trigger and muon reconstruction in forward region

- **Improved triggers and new trigger signatures** for increased acceptance of SM and new beyond SM signatures

- Continued work on **improving reconstruction algorithms**, esp. using advanced machine learning
  - Tracking in ultra-dense environments
  - Graph neural networks for b-jet identification
  - …

ATL-PHYS-PUB-2022-027

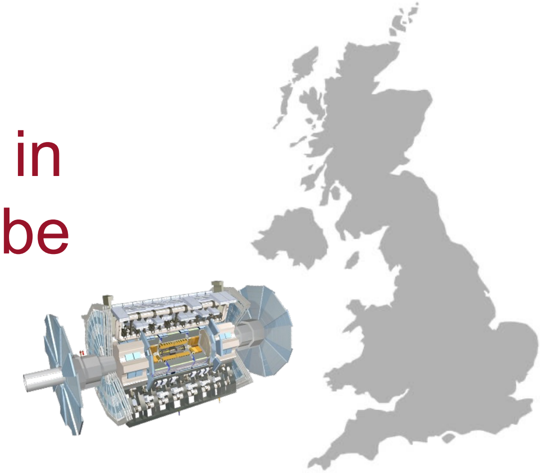


Improved rejection of non-b-jets

+ Summary

- Run-2 was a hugely successful data taking period with many major physics milestones reached
- Run-3 data taking is ongoing, which will collect at least ~2 times the data of Run-2
- Upgrading ATLAS experiment’s systems (where possible) and improving data collection/reconstruction continues
- Many exciting physics results still awaiting as we enter high-precision era!

Large involvement from UK community in key areas and leadership: continues to be integral part of the collaboration



Backup

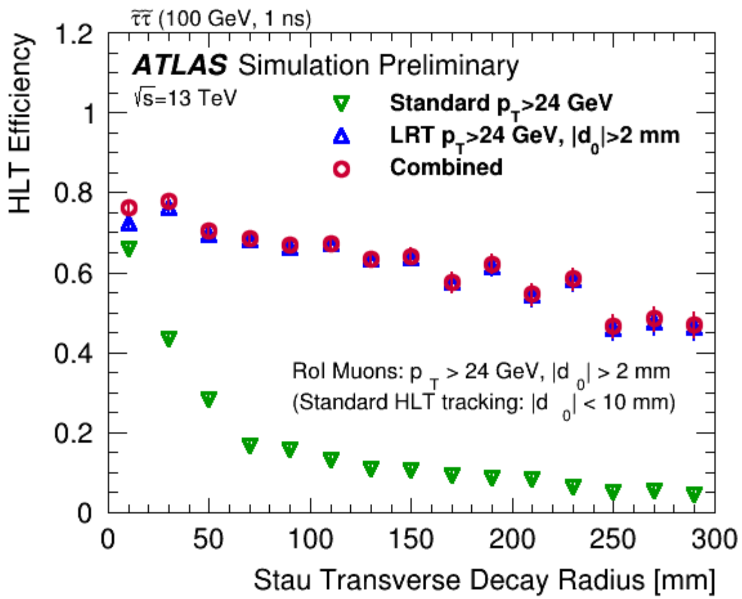
L1Calo Phase-1: UK major tasks

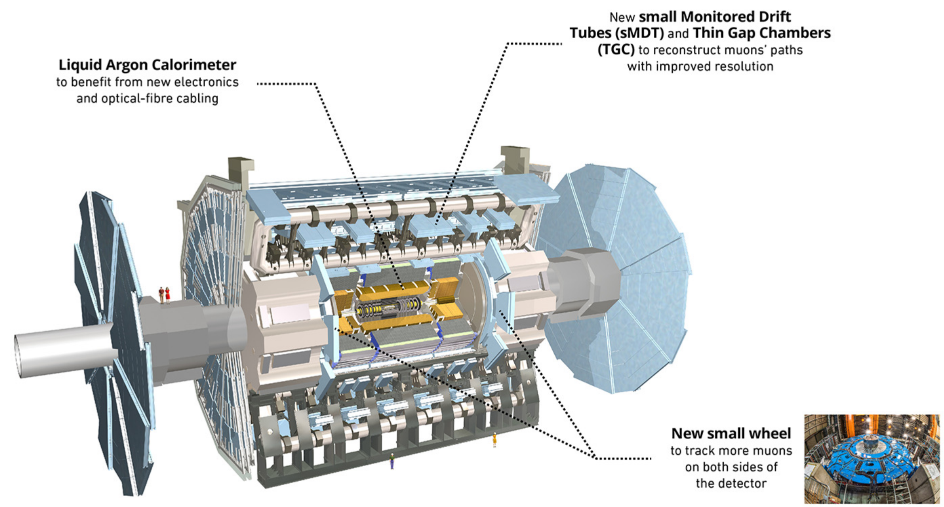
- eFEX module
  - Main processor for identifying electron/tau objects
  - Firmware well established and fairly stable
  - Long history of module production problems, but now installed
- ROD sub-module
  - Readout for eFEX and jFEX modules
  - Used for some time in Point-1, 100 kHz readout established
- Online and offline software
  - Used to configure and validate hardware
  - Reaching maturity for UK modules
  - Will require more features for full operational monitoring
- Commissioning, Run Coordination and Management
  - UK has significant CERN presence and responsibility in all areas
  - Also supported remotely and regular visits from UK experts

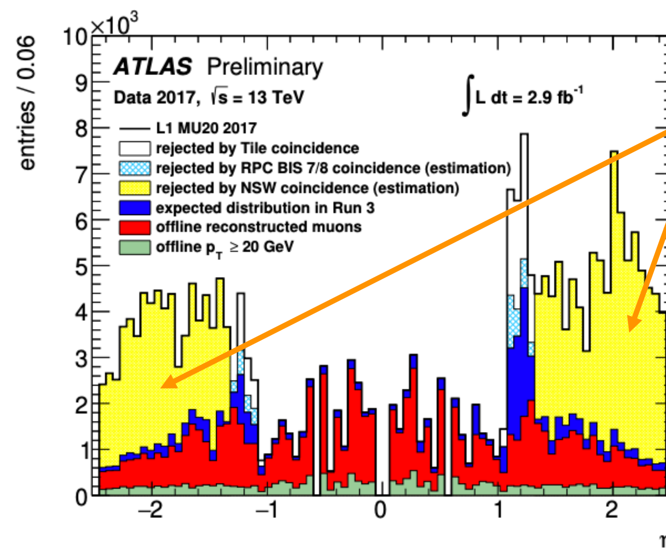
- Last year
  - Installation
  - Low-level debugging (mapping, link stability)
  - Integration with ATLAS (LArg and TDAQ)
- Next year
  - Establish stable operation
  - Calibrate and fine-tune triggers
  - Expect to switch on new triggers in 2023
  - Finish production of eFEX spares

Run-3 Opportunities – additional material

Dedicated trigger for long-lived particles







Background rejection with NSW

+ Simulation

- Simulated data used to be able to develop analysis strategies before full data is available and perform “blind analysis” to avoid bias
  - Several hundred billions of events produced
- Full chain of theoretical description of a given process, detector response, object reconstruction has to be simulated
- Strong UK involvement in improving description of simulation (compared to data) and making simulation of detector/reconstruction response faster

→ Better MC and more efficient MC production for Run-3

Computing

- UK pledges large storage and computing resources (between 10-15% share in CPU resources; several tens of PB storage in form of tape and disk)
- As data sets increases more work put in efficient (lowering time and CPU costs) towards Run-3