

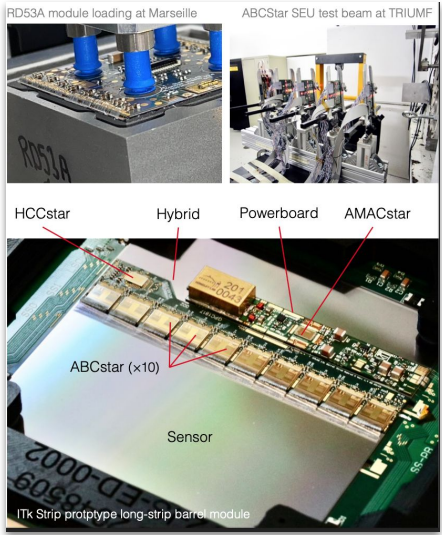


# The ATLAS experiment status

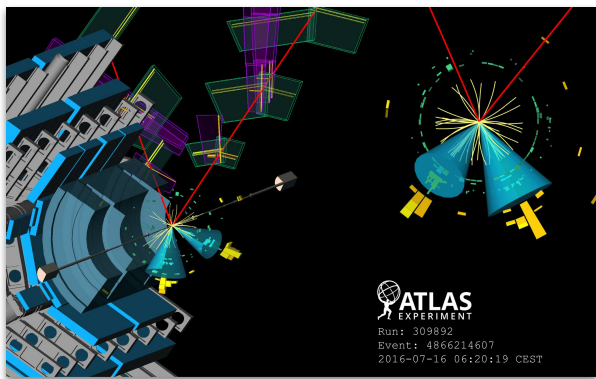
LHCC open session  
9 March 2022

Johannes Elmsheuser (BNL)  
On behalf of the ATLAS collaboration





- Recent physics results from ATLAS
- Getting ready for Run 3
- Phase-II upgrades



### ATLAS Software and Computing HL-LHC Roadmap

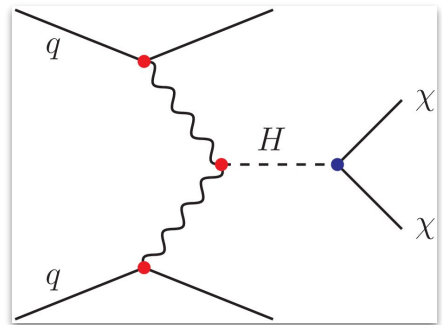
Reference:

Created: 1 October 2021

Last Modified: 28 January 2022

Prepared by: The ATLAS Collaboration

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Total number of submitted papers since last LHCC:

- 21 (17 full Run 2 papers)
- 177 full Run 2 pp results (papers or conference note) in total

New results since last LHCC:

- 12 (9 are full Run 2 pp)

Papers ([link](#)):

- Search for displaced hadronic jets in the calorimeter ([arXiv:2203.01009](#))
- Search for events with MET and vector boson fusion signature ([arXiv:2202.07953](#))
- Bose-Einstein correlations at 13 TeV ([arXiv:2202.02218](#))
- $H(125) \rightarrow \gamma\gamma$  differential cross-section ([arXiv:2202.00487](#))
- $VH; H \rightarrow cc$  ([arXiv:2201.11428](#))
- Single VLQ production in all hadronic final state ([arXiv:2201.07045](#))
- Global PDF fit ([arXiv:2112.11266](#))
- Modelling of V+jet process ([arXiv:2112.09588](#))
- Search for tqg FCNC in single top at 13 TeV ([arXiv:2112.01302](#))

CONF notes:

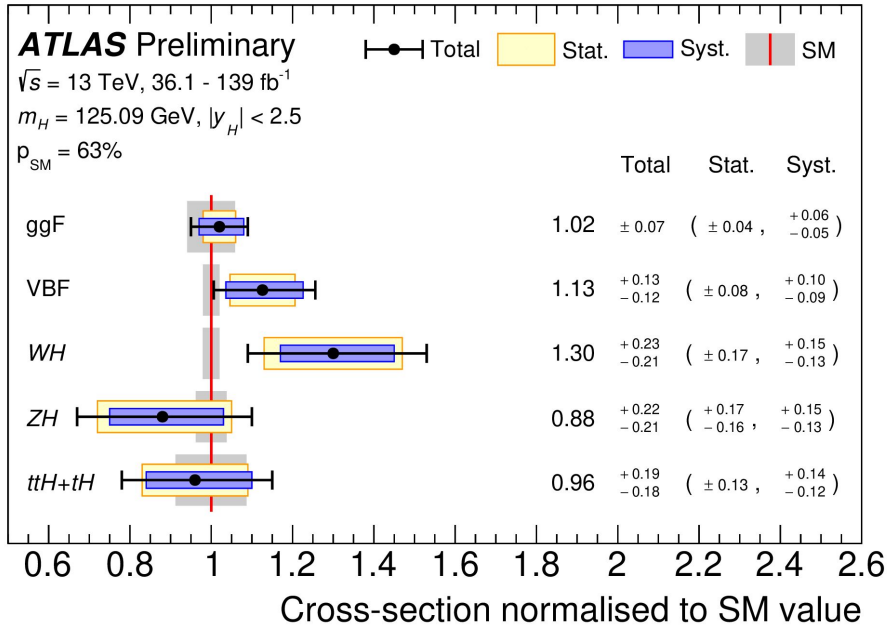
- Search for flavor-changing neutral-current couplings between the top-quark and the photon with the ATLAS detector ([ATLAS-CONF-2022-003](#))
- $H(125)$  combination differential cross-sections  $\gamma\gamma$  and 4l Displaced Lepton Jet Search ([ATLAS-CONF-2022-002](#))
- Displaced Lepton Jet Search ([ATLAS-CONF-2022-001](#))

In addition there are several PUB notes on HL-LHC extrapolation studies

Expect many more results at upcoming conferences:

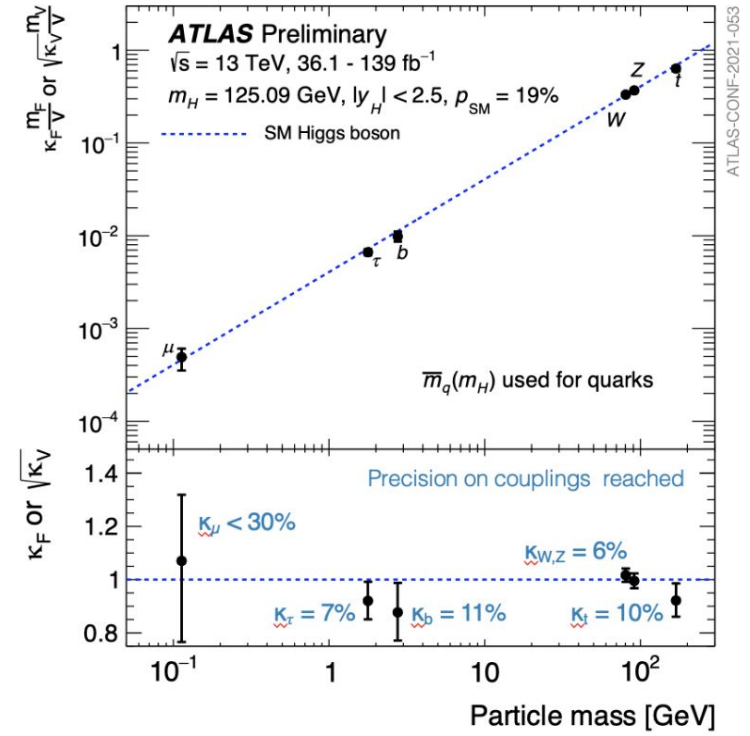


Global fit yields signal strength measurement of  $\mu = 1.06 \pm 0.06$

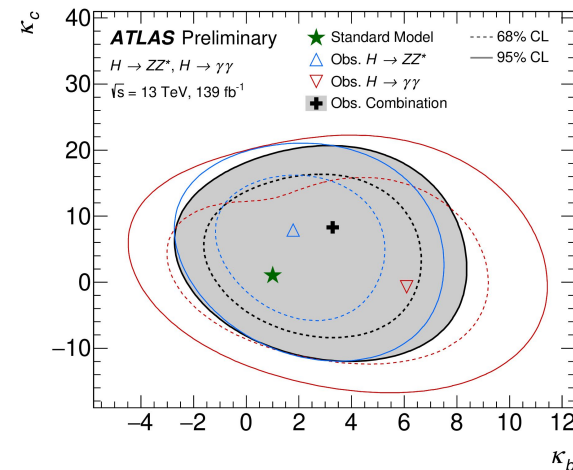
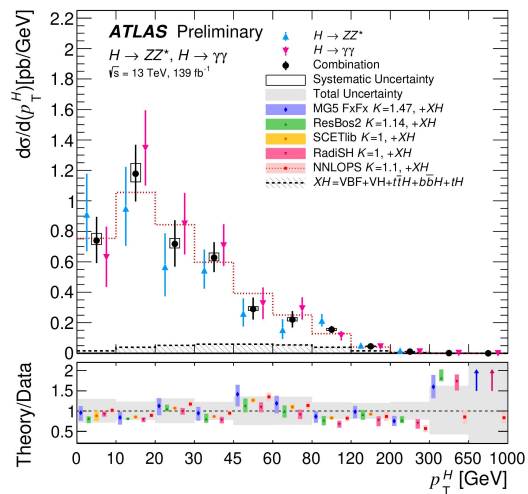
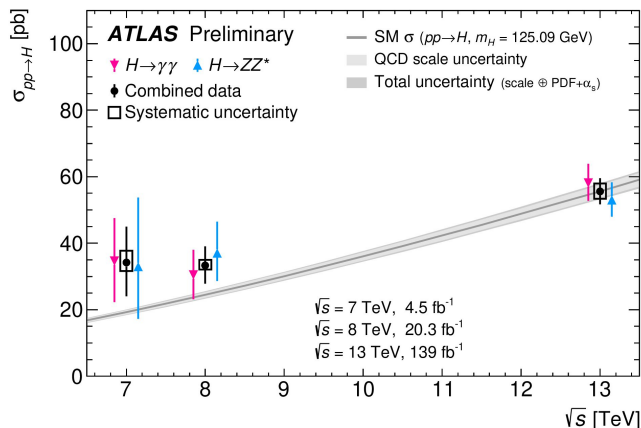


Coupling measurements ( $B_i = B_u = 0$ )

$$\kappa_{\gamma} = 1.04 \pm 0.06, \kappa_{Z} = 0.92^{+0.07}_{-0.06}, \kappa_{Z\gamma} = 1.37^{+0.31}_{-0.37}$$

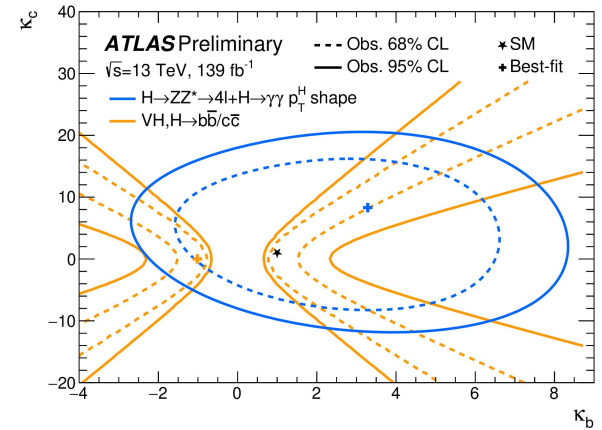
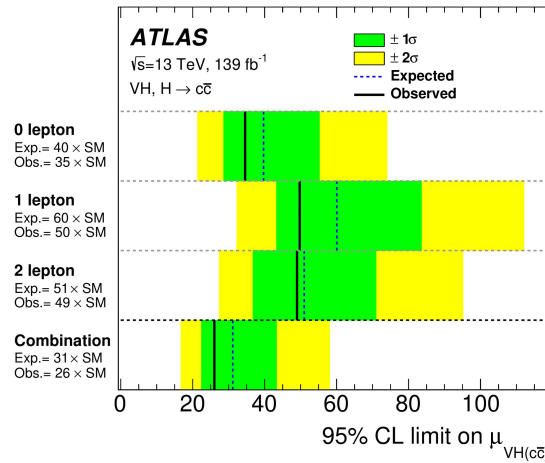
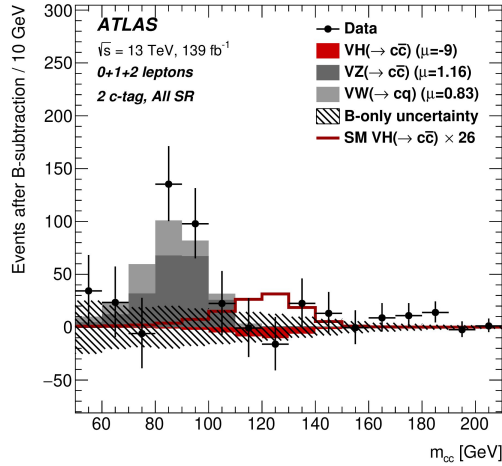


Yet unattained precision on Higgs boson couplings



[ATLAS-CONF-2022-002](#)

- Combination of fiducial  $H \rightarrow 4\ell$  and  $H \rightarrow \gamma\gamma$  cross-sections extrapolated to the full phase space
- Total Higgs boson prod. cross-section:  $55.5^{+4.0}_{-3.8}$  pb with SM prediction of  $55.6 \pm 2.8$  pb
- Measure  $N_{\text{jet}}$ ,  $p_T^H$ ,  $|y^H|$  and  $p_T^{\text{leading jet}}$  differential cross-sections
- Observed limits at 95% CL on Yukawa couplings  $\kappa_b$  and  $\kappa_c$  when only the  $p_T^H$  shape is used to constrain the parameters for the combined and individual decay channels results



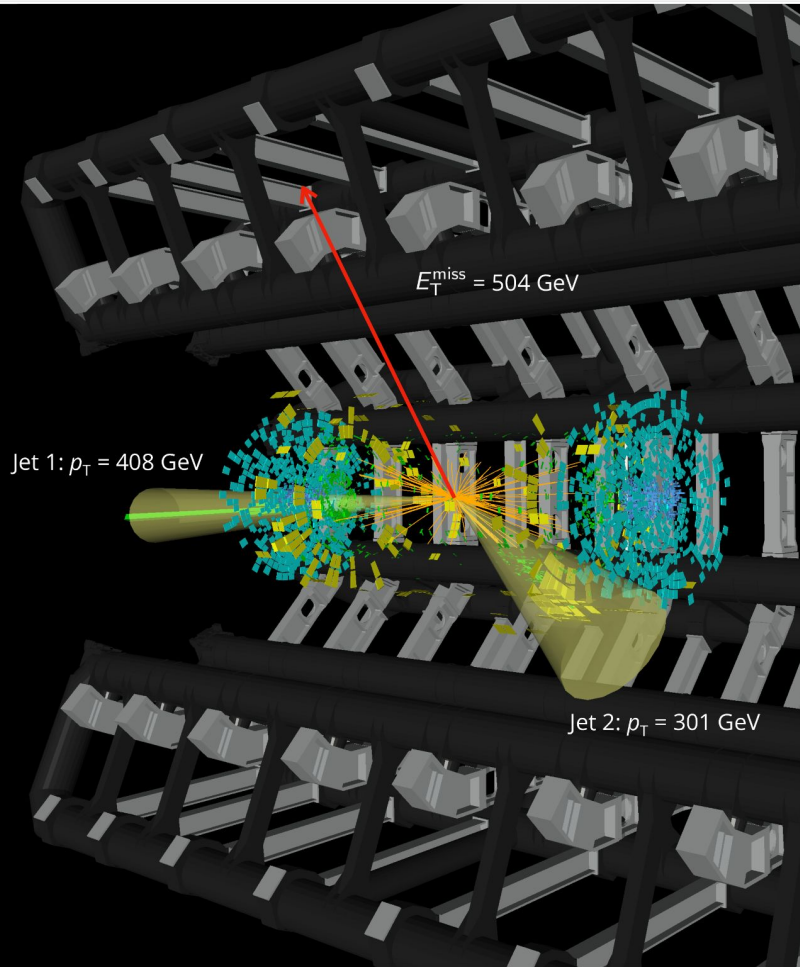
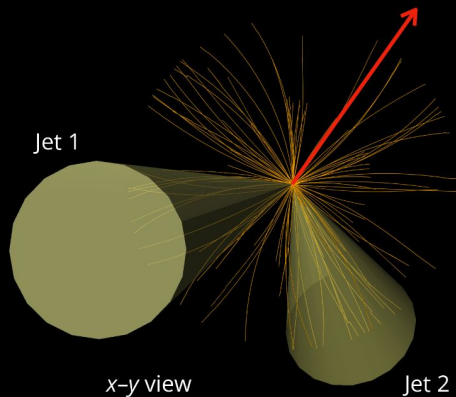
[arXiv:2201.11428](https://arxiv.org/abs/2201.11428), [ATL-PHYS-PUB-2022-002](https://atlas.cern/ATL-PHYS-PUB-2022-002)

- Flavour-tagging algorithms are used to identify jets originating from hadronization of charm quarks
- (W/Z)H( $\rightarrow$ c $\bar{c}$ ) observed (expected) CLs limit on  $\mu$  is 26 (31) times SM at 95% CL
- Combination (W/Z)H,H $\rightarrow$ b $\bar{b}$  analysis, constrain ratio  $\kappa_c/\kappa_b$  without assumptions about width of Higgs boson:  $|\kappa_c/\kappa_b| < 4.5$  at the 95% CL smaller than ratio of b- and c-quark masses  
 → Higgs-charm coupling weaker than Higgs-bottom coupling

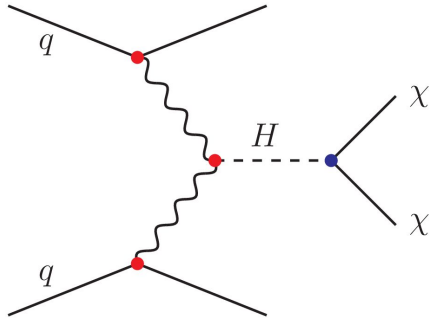


Run: 279984  
Event: 237776402  
2015-09-21 20:21:50 CEST

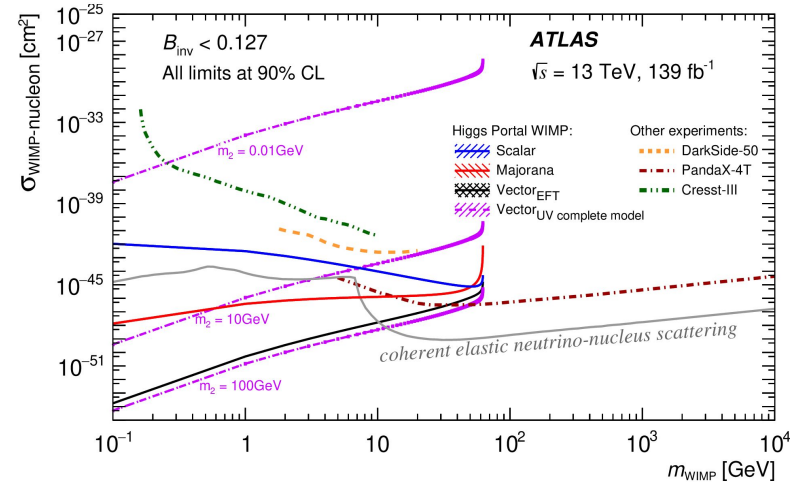
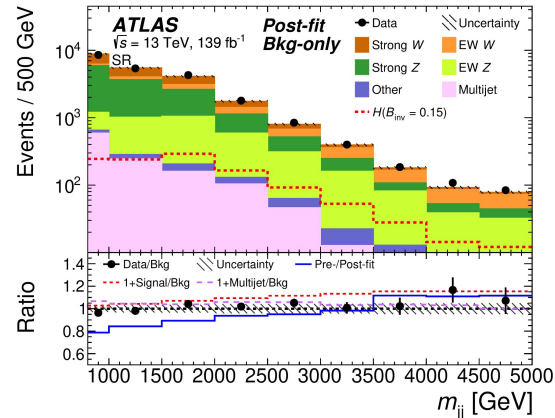
$m_{jj} = 2.5 \text{ TeV}$   
 $\Delta\eta_{jj} = 4.0$   
 $\Delta\phi_{jj} = 1.6$



# Invisible Higgs decays

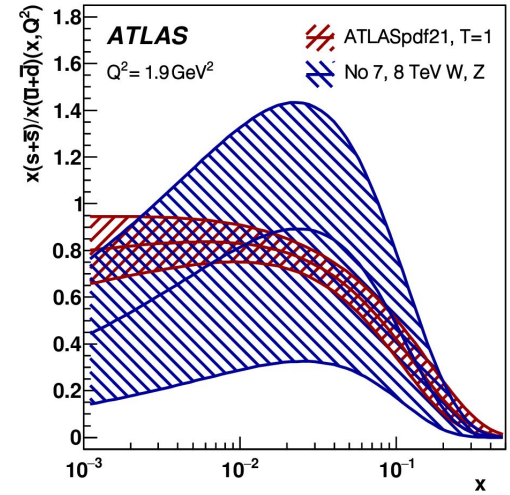
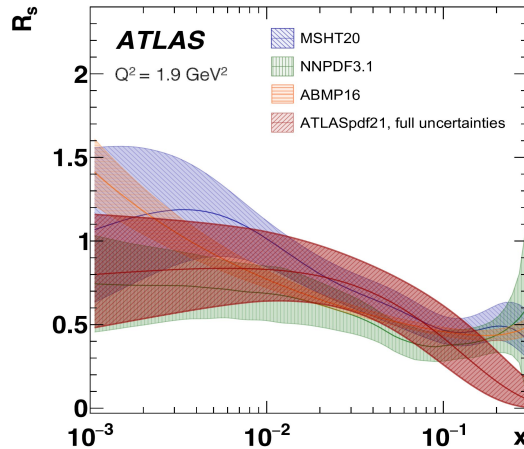
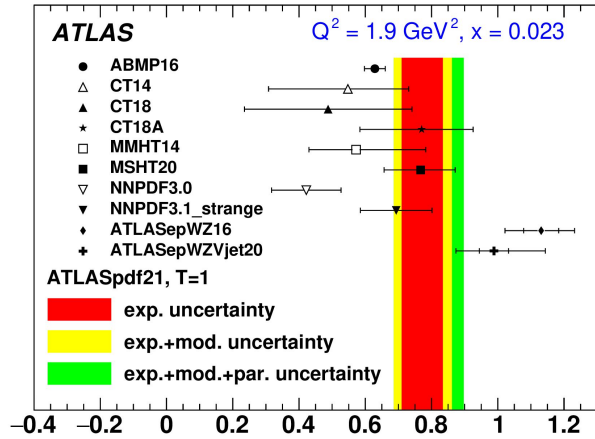


[arXiv:2202.07953](https://arxiv.org/abs/2202.07953)



- Search for Higgs bosons produced via vector-boson fusion and decays into invisible particles
- SM Higgs BR to invisible: observed upper limit 0.145 at 95% CL (expected limit 0.103)
- Dark matter portal limits:  
Invisible decays of additional scalar bosons with masses 50 GeV to 2 TeV, upper limits on  $\sigma$  x BR in range from 1.0 pb ( $m=50 \text{ GeV}$ ) to 0.1 pb ( $m=2 \text{ TeV}$ )



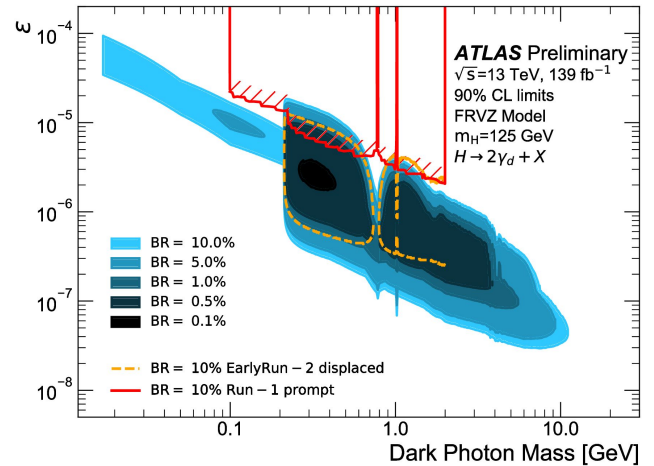
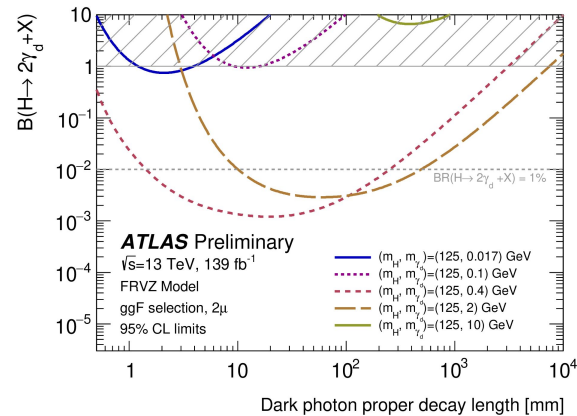
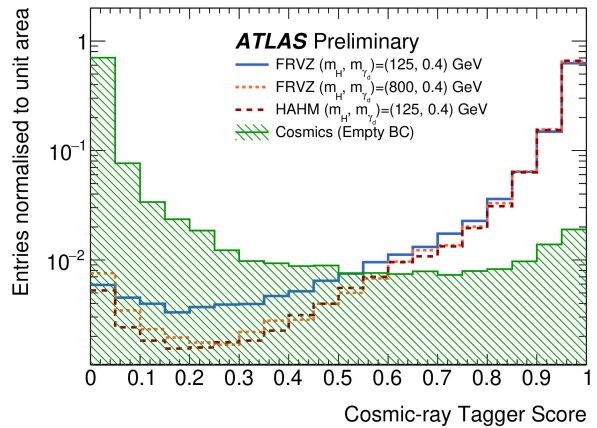


$$\text{PDF ratio } R_s = x(s + \bar{s}) / x(\bar{u} + \bar{d})^{R_s}$$

[arXiv:2112.11266](https://arxiv.org/abs/2112.11266)

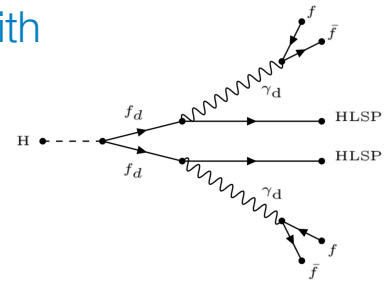
- PDFs are relevant for essentially everything we do at the LHC
- Used here: differential cross-section measurements of production of inclusive  $W^\pm$  and  $Z/\gamma^*$  bosons,  $W^\pm$  and  $Z$  bosons in association with jets,  $t\bar{t}$ , inclusive jets and direct photons - NNLO perturbative QCD
- strange PDF assumed to be 2/3 of down PDF in HERAPDF
- PDF ratio  $R_s$  now with improved constraints depending on  $(x, Q^2)$

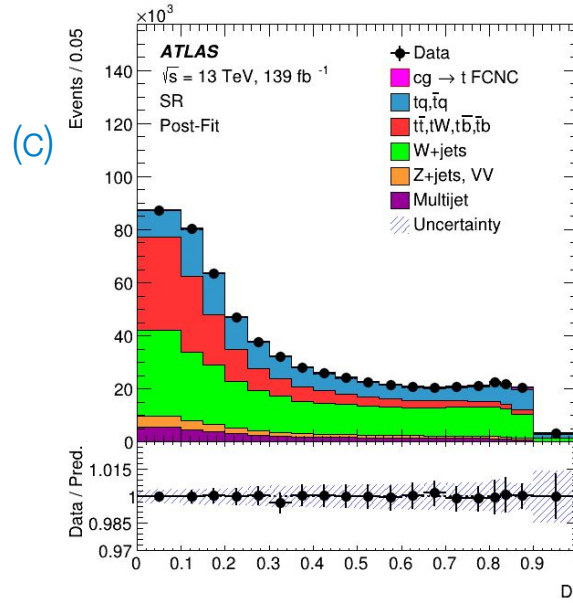
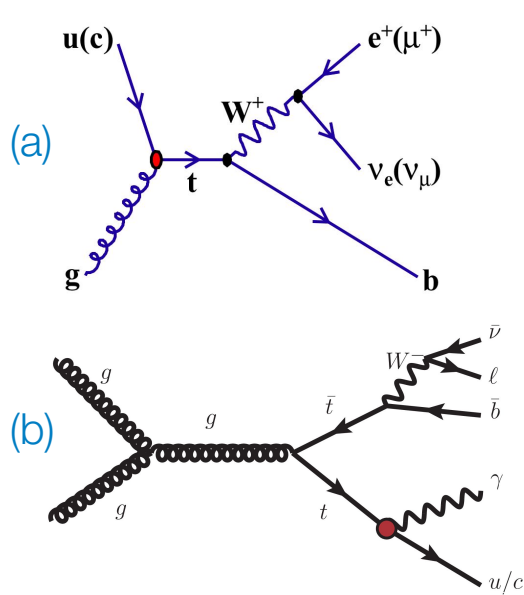
# Displaced lepton jet search



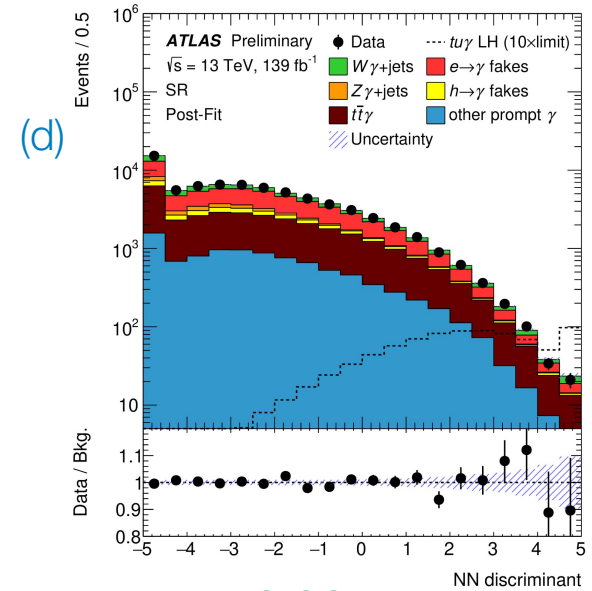
## ATLAS-CONF-2022-001

- Search for light neutral long-lived particles with masses  $O(\text{MeV}-\text{GeV})$
- Production of long-lived dark photons in decay of Higgs boson (ggF, WH) with events of displaced collimated SM fermions reconstructed in calorimeter or muon spectrometer
- Exclude Higgs boson  $BR > 0.1\%$  at 95% CL for Higgs boson decays into 2 dark photons for dark-photon mean lifetimes  $c\tau$  in range 10 mm to 250 mm and dark photons with masses in range 0.4 to 2 GeV





[arXiv:2112.01302](https://arxiv.org/abs/2112.01302)



[ATLAS-CONF-2022-003](https://atlas.conf-2022-003)

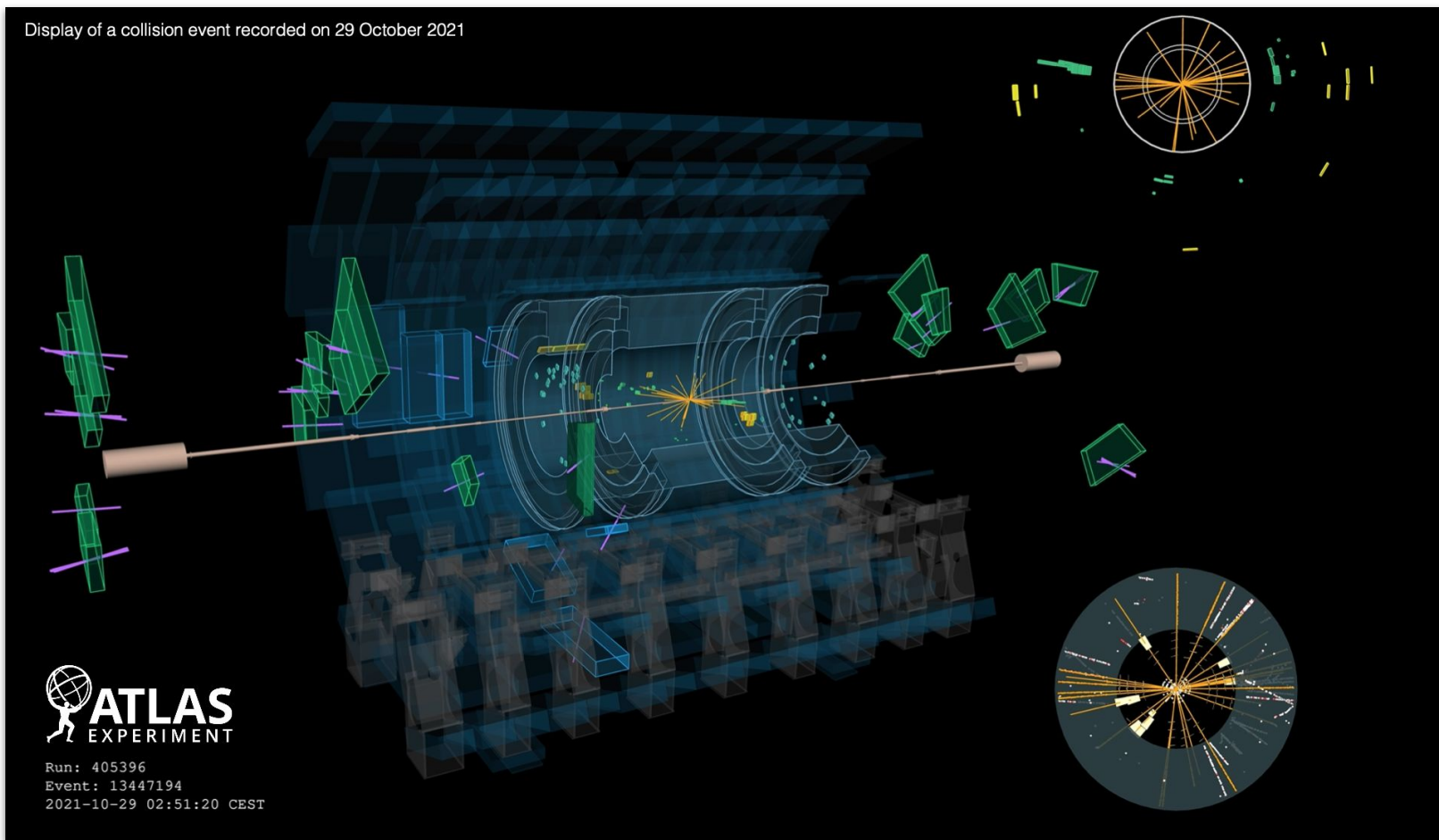
- FCNC suppressed in SM - can occur in production ((a)+(c)) and decay ((b)+(d))
- Use multiclass deep neural network or neural networks to classify events
- Search for  $g+u(c) \rightarrow t \rightarrow Wb$  with limits on  $\sigma \times BR < 3.0$  (4.7) pb at 95% CL.  
 Translates into  $BR(t \rightarrow u(c)+g) < O(10^{-4})$
- Search for  $t \rightarrow u(c) + \gamma$  with limits  $BR(t \rightarrow u(c) \gamma) < O(10^{-5})$  at 95% CL



Side A on 3 Feb 2022

- Detector is closed
- Shown: Big Wheel of muon system with beam pipe and Lucid forward detector

Display of a collision event recorded on 29 October 2021

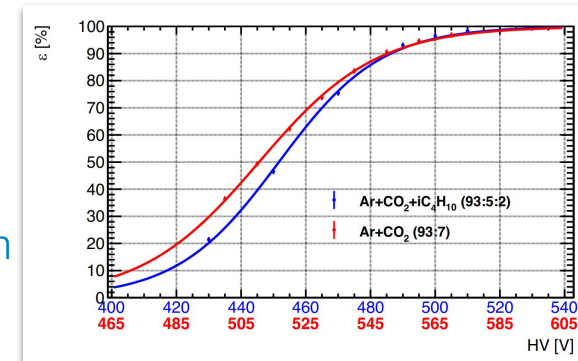
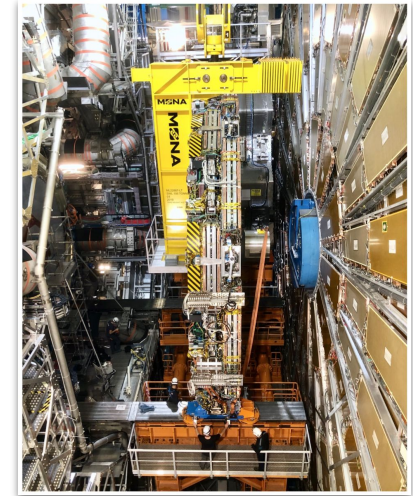


Run: 405396  
Event: 13447194  
2021-10-29 02:51:20 CEST

# Phase-I upgrade projects I

Muon New Small Wheel (NSW) integration and commissioning in ATLAS ongoing:

- Slightly higher noise than during surface commissioning observed locally in few MM layers on side A (not so on Side C)
- Recent “MM isobutane” review. Committee recommends to start Run 3 with 2% of  $iC_4H_{10}$  (higher efficiency and higher gain), but also to implement ageing monitoring and continue ageing studies
- Integration into ATLAS DAQ partition partially achieved
  - sTGC sector participated in overnight cosmic data taking
- Trigger tests between Muon SectorLogic and TriggerProcessor ongoing
- Testing of beam injection system (automatic HV ramping) ongoing
- Operations procedures in preparation after initial experience from milestone weeks

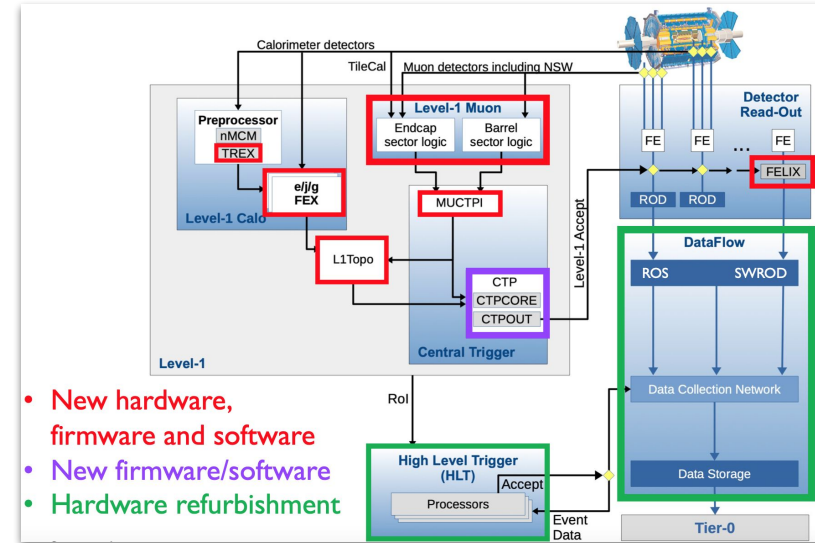


BIS78-A (sMDT+RPC) muon chambers:

- installed & under commissioning

# Phase-I upgrade projects II

- **Liquid-argon calorimeter**
  - LAr integrated and under commissioning with Tile and L1Calo
- **L1 calorimeter trigger**
  - New electronics to benefit from more granular digital L1 calorimeter readout and new endcap triggers
  - All L1Calo boards are being commissioned (TREX, jFEX, gFEX, Hub/ROD, FOX, TopoFOX, L1Topo) or in production (eFEX — delays due to problems with 2nd production half)
  - Commissioning throughout 2022
- **L1 muon trigger**
  - ALTI, CTP, MUCTPI and endcap sector logic being commissioned and Trigger path being validated, NSW connection under validation, BIS78 trigger with standalone commissioning in coming months
- **TDAQ**
  - FELIX and SWROD fully installed and under commissioning
  - Final firmware reviews ongoing, addressing readiness and long-term support



Experiment briefing: Trigger in Run 3  
<https://atlas.cern/updates/briefing/run-3-trigger>

- Inner detector
  - Pixel & SCT kept cold; ready and waiting for beam
  - TRT front-end cooling leaks stable (but slightly increased to 2 l/day), Baseline gas configuration for TRT in 2022 defined
- Tile calorimeter
  - Front-end cooling system refurbishment done, separation valves installation completed, several leaks fixed (lost two modules, barrel and extended barrel (0.8% acc.) after closing), ready for beam
- Liquid Argon calorimeter
  - New hardware fully installed and validated
- Muon spectrometer
  - RPC gas leak repairs continuing, foam (polyurethane) to consolidate inlets and prevent future gas leaks under test at small scale after review; TGC chamber replacements completed
- Forward detectors
  - LUCID-2 A & C-sides with new PMTs installed, LUCID-3 prototypes for HL-LHC on JFC3 shielding
  - ZDC & ALFA: refurbishments completed for ZDC, ALFA installed (physics only in 2023)
  - AFP: Near and far stations installed, new PMTs for TOF counter
- Trigger & Data Acquisition (TDAQ)
  - Network (10 GB/s switches) deployed, HLT servers replaced (55%),
  - Transfer to CERN IT at 8 GB/s



## Before cavern closure in March 2022



8 Jan	Start of detector closing
21 Jan	Both Endcap Toroids on beam line
1 Feb	Endcaps in run position, begin of Central Solenoid test
10-17 Feb	Successful beampipe bake-out
21-25 Feb	Milestone Week 11 and cavern cleaning
10 Mar	Begin of final closing and installation of forward shielding
21 Mar	24/7 operations
15-22 Mar	Cavern will be closed
21 Mar-3 Apr	Milestone Week 12, including long cosmic run for barrel alignment of the muons Toroid magnet test (then Toroid back to 0 A)

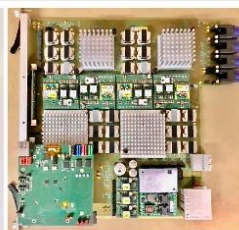
- Major milestone is to complete the **full integration and validation of the new Phase-I L1 systems into the HLT software**:
  - Start with legacy system and phase in new system
  - Phase-I L1 inputs available
  - New multi-threaded HLT framework
- Run 3 trigger menu based on the Phase-I L1 inputs, relevant for the studies in conjunction with the HLT selection performance
- Further **trigger signature optimization, tuning and synchronization with the offline object reconstruction** using the Run 3 geometry and conditions is one of the main focus for the Run 3 startup
- **Trigger fully operational** during the pilot beam, monitoring tools in place and used at Point 1
- Integration, configuration and monitoring has been continuously progressing in Technical Runs and Milestone Weeks



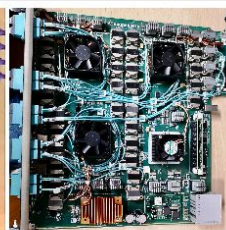
FELIX IO card



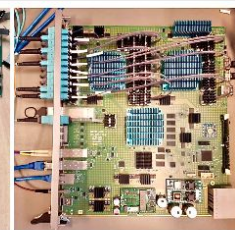
eFEX



jFEX



gFEX



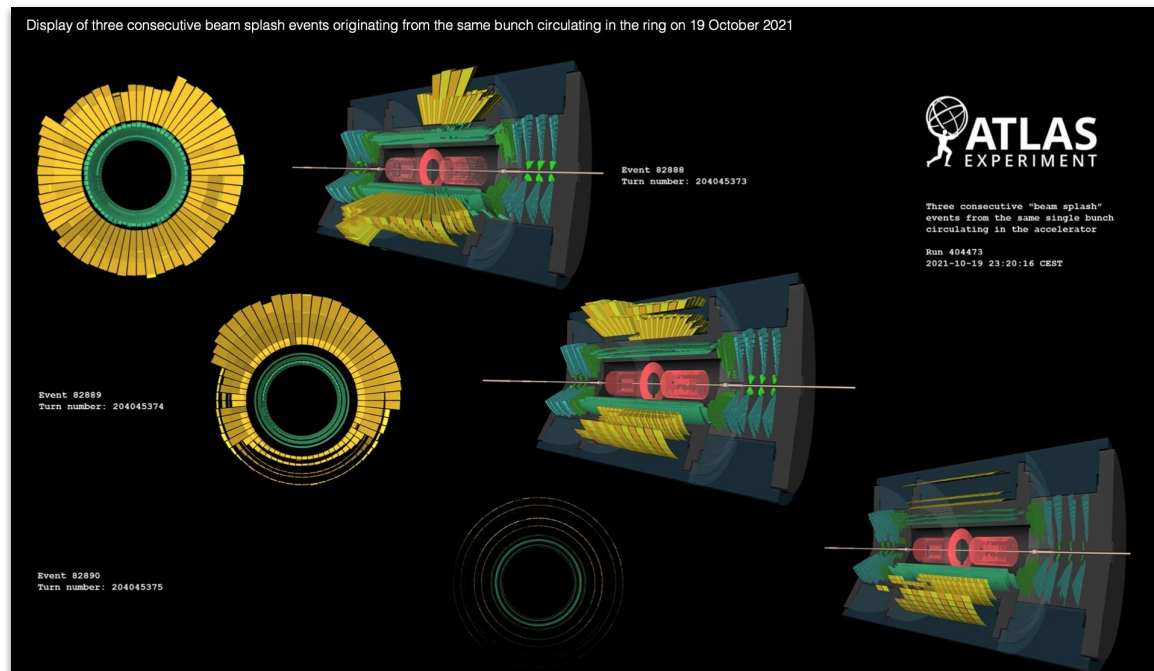
MUCTPI



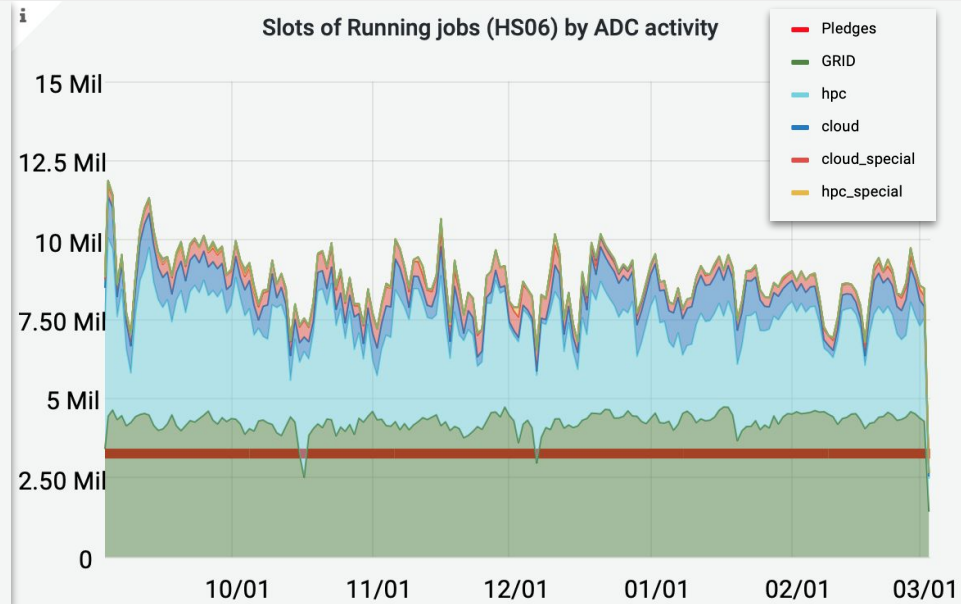
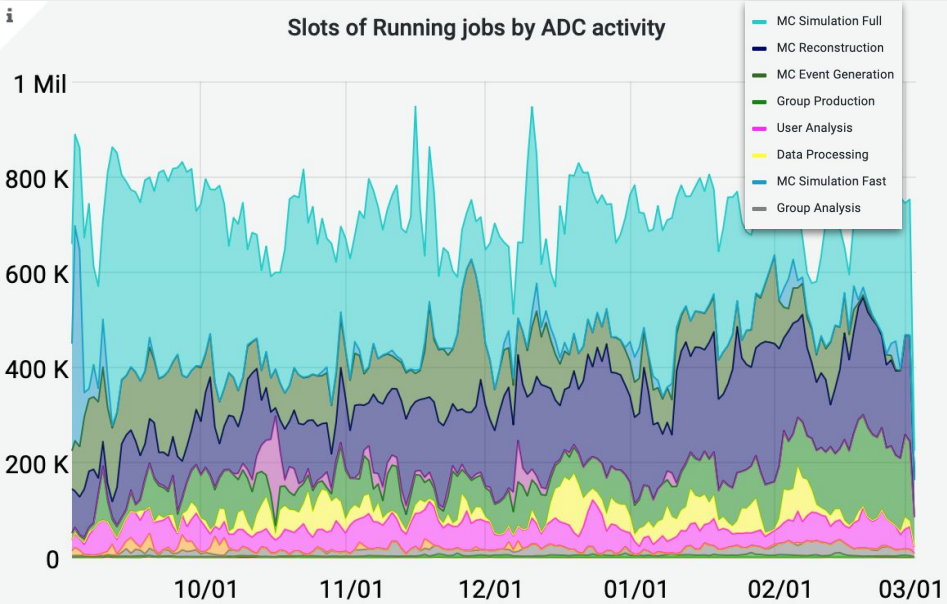
L1Topo

## Preparations of Run-3 data taking in full swing

- Consolidation of online and offline Data Quality in new framework
- Re-establishing calibration loop and prompt reconstruction at Tier0, 'reconstruction lessons learned' from pilot run and at dedicated commission week mid February
- Initial tags for Run 3 detector conditions available for both data and simulation.



Many more event displays at <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayPublicResults>



- Excellent performance of computing centers worldwide, including T1s & T2s
- incl. 100k cores from HLT farm, and HPC resources like large EuroHPC Vega (Slovenia) & Karolina (Czech Republic) (opportunistic resources)
- Active usage of tape data carousel to manage storage challenge

- Major effort to prepare Run 3 software release

- Full re-processing of Run-2 data almost complete
- Will have coherent Run-2 + Run-3 dataset

- Reconstruction

- first production relying on multi-threading
- 3.5x memory savings, 20% workflow speed-up

- Simulation

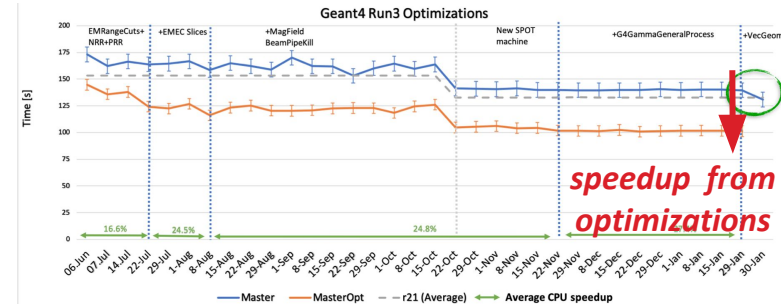
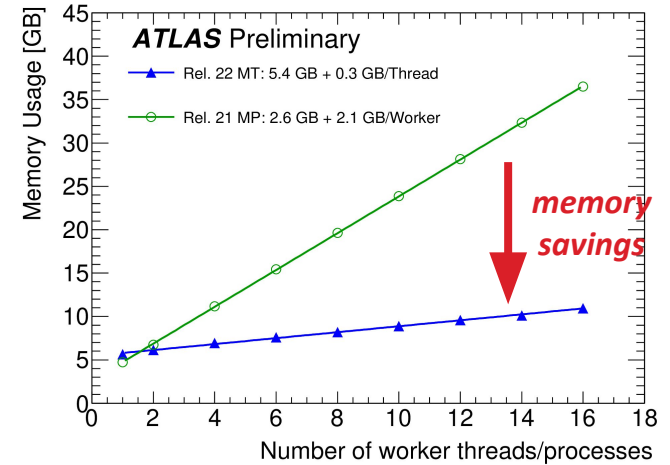
- Geant4 ~35% faster due to ~10 different optimizations, (~55% more events), More optimizations in the works
- Digitisation: factor 3-6 faster depending on the pile-up  $\mu$  value (30-50) by using presampled overlay of pile-up events
- New fast simulation Atlfast3: With FastCaloGAN - First ML production application in ATLAS simulation used for Run 2 reprocessing, Run 3 tuning on-going

- All Phase-I updates ready for Run 3

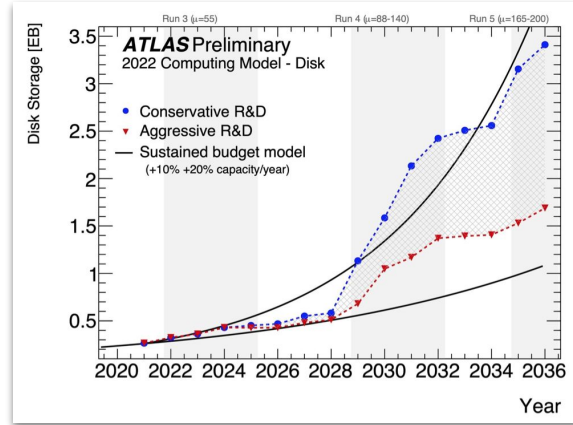
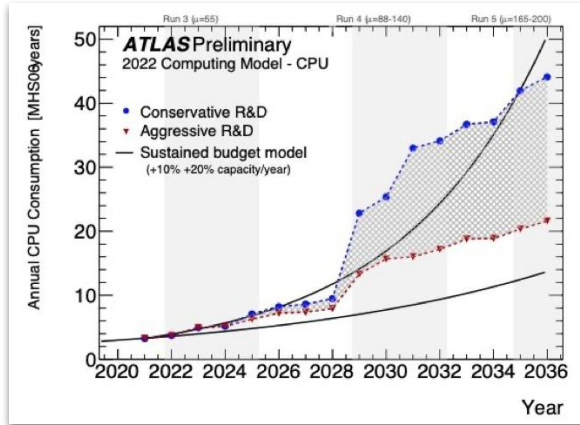
- On-going tuning of muon SW with New Small Wheel

- New Analysis model for Run 3

- DAOD\_PHYS: validated, ~30 kB/event for Run-2 data + MC
- DAOD\_PHYSLITE: under development, ~12 kB/event for Run-2 data + MC, Validation on-going



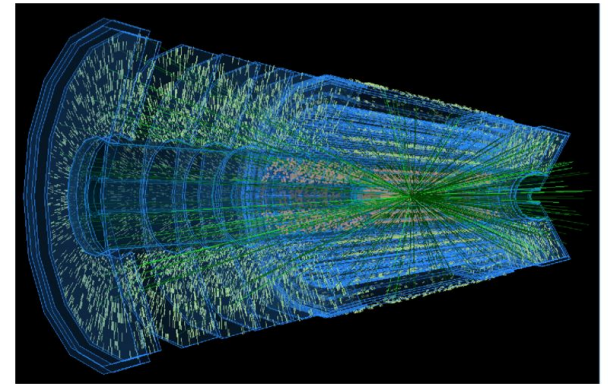
- The HL-LHC roadmap document is now available as public document at <https://cds.cern.ch/record/2802918> and [CERN-LHCC-2022-005](#)
- Milestones and deliverables for all our software and computing various areas
- Update to the new HL-LHC timeline



- Many on-going R&Ds: Integration of new tracking (ACTS), integration of GPUs, ARM, new Detector description, RNTuple, FastChain simulation and much more



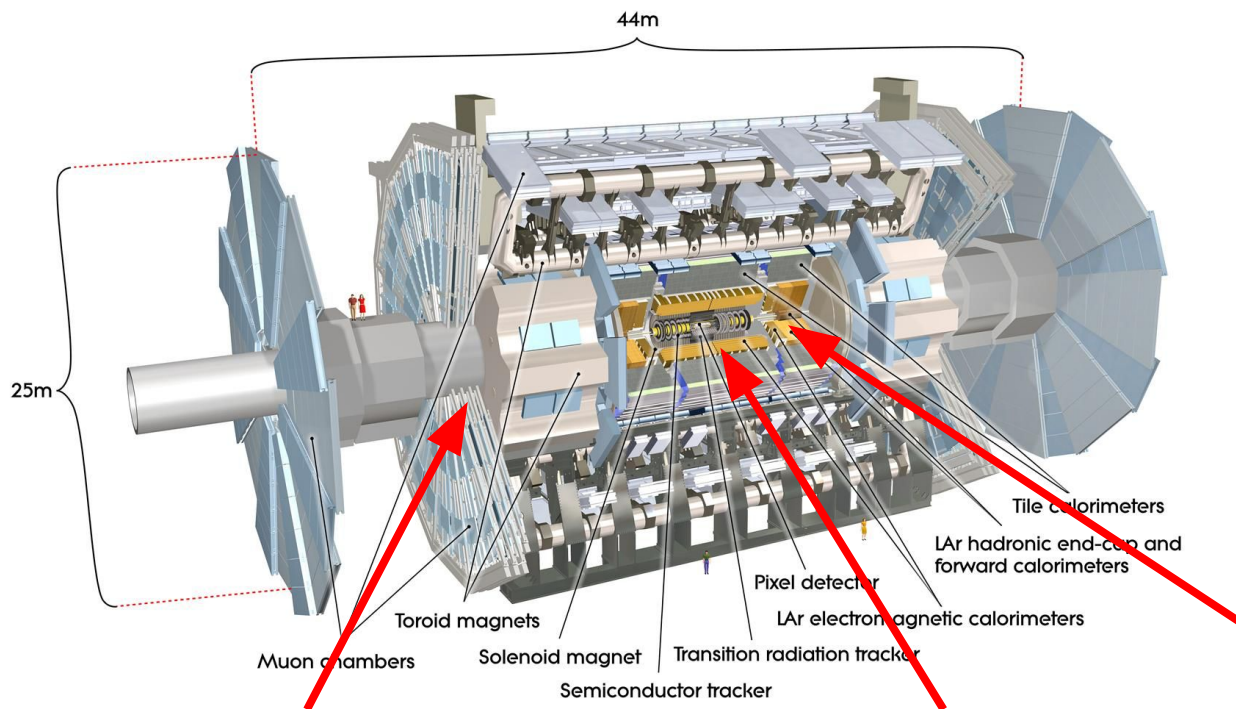
## ATLAS Software and Computing HL-LHC Roadmap



Reference:

Created: 1 October 2021  
Last Modified: 28 January 2022  
Prepared by: The ATLAS Collaboration

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## New Muon Chambers

- Inner barrel region with new Resistive Plate Chambers and new Monitored Drift Tubes (SMDT) detectors

## New Inner Tracking Detector (ITk)

- All silicon (9 layers), up to  $|\eta| = 4$

## Upgraded Trigger and Data Acquisition system

- Level-0 Trigger at 1 MHz
- Improved High-Level Trigger (150 kHz full-scan tracking)

## Electronics Upgrades

- On-detector and off-detector electronics upgrades of:
  - LAr Calorimeter
  - Tile Calorimeter
  - Muon Detectors

## High Granularity Timing Detector (HGTD)

- Forward region
- Precision time recon. (30 ps) with Low-Gain Avalanche Detectors (LGAD)

## Additional small upgrades

- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)

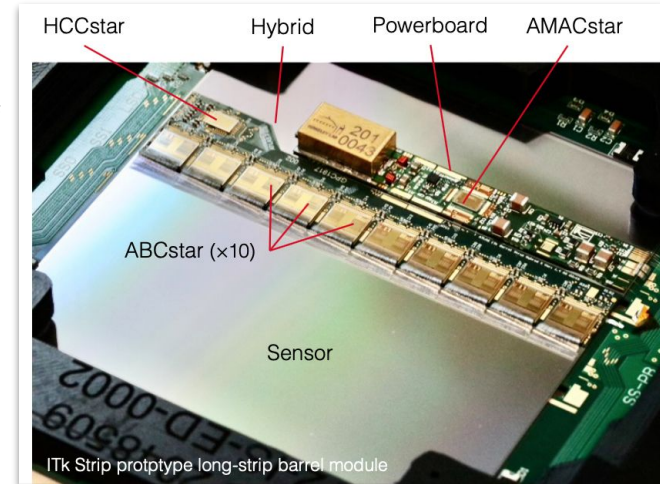
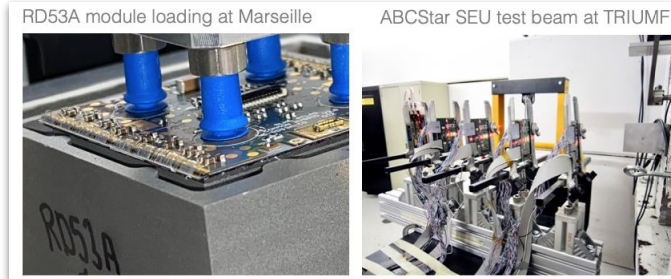
## Projects continue to move from final design to production

### • ITk Pixel

- 3D and planar (100  $\mu\text{m}$  & 150  $\mu\text{m}$ ) sensors in pre-production
- Hybridisation procurement started (4 vendors, thermal cycling for bump stress studies revealed problems at one vendor)
- RD53A module production & testing delayed but ramping up, modules being delivered to loading sites, important to complete this and move to ITkPixV1.1 modules
- FE ASIC testing overall successful (few issues being followed up), V2 submission target 1st half of 2022 (collaboration with RD53 and CMS)
- Loaded local supports, services, global mechanics FDRs all in 2nd half of 2022

### • ITk Strip

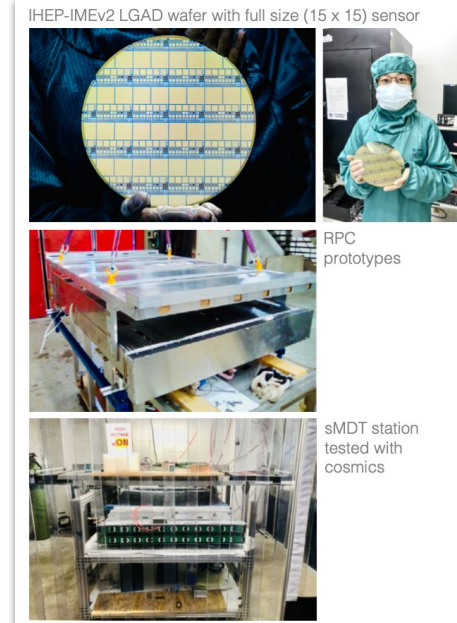
- All on-detector FDRs completed, focus on site qualification and pre-production; schedule dominated by  $\sim 3.5$  years of module production
- First production sensors received, production catching up with plan
- ABCStar PRR passed in Oct, production ongoing (1st batch arrived);
- HCCStar & AMACStar returned from foundry, preliminary tests (wafer probing and single chip boards) successfully, irradiation test @ Louvain with HI ongoing for Single Event Upsets
- Qualification of production sites for hybrids, power boards and modules advancing, delays in endcaps being addressed



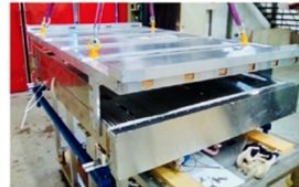
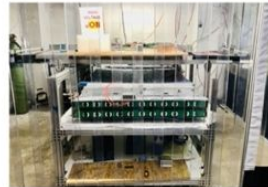
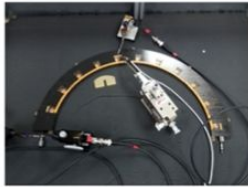


Good progress also on the other projects, less impacted yet by lack of contingency

- **Liquid Argon Calorimeter :**
  - Critical on-detector component is front-end board (FEB2) with new two-gain preamplifier / shaper (final prototypes being tested), followed by 14-bit ADC ASICs (prototype test starting); FEB2, Calibration, LASP prototype board testing underway
- **Tile Calorimeter:**
  - Mechanics, electronics, power supplies, high voltage system, cesium source and laser calibration systems, and ~10% of the PMTs will be upgraded or replaced. Good overall progress (PMT PRRs passed, Mainboard and Mini-drawer services PRRs in Dec)
- **High Granularity Timing Detector (HGTD):**
  - Sensor market survey concluded, testing of final prototypes before irradiation. ALTIROC2 (full size 15×15 channels) tests progressing well; hybrids in production and under test; good progress on demonstrator
- **Muon System:**
  - SMDT chamber production progressing well in the two sites.
  - RPC: FE ASIC 2nd prototype now received and tests successfully so far, targeting start of production August, new gas gaps built early January and first tests successful w/ IV curves within specification
  - TGC: good progress on chamber prototype and electronics
- **LUCID-3 (luminosity measurement) HL-ZDC (for forward neutrals)**
  - approved as small Phase-II projects. 4 LUCID-3 PMTs prototypes installed in ATLAS for tests during Run 3
- **TDAQ:**
  - Amendment of the TDAQ TDR with Event Filter Tracking reviewed by LHCC and UCG
  - First prototypes of GCM v2 for Global and MDT-TP demonstrator for L0Muon available



# Impressions of Phase-II upgrades



SR1 at CERN for ITk integration

ITk Pixel IS, OB, OE local support prototypes

Irradiation of ITk Strip endcap modules (2 sensors) at DESY

SMDT station tested with cosmics

RPC prototypes

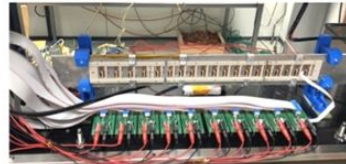
TGC-EIL4 chamber prototype



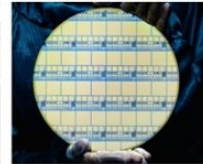
ITk Strip sensor probing at KEK



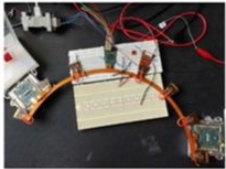
ABCStar SEU test beam at TRIUMF



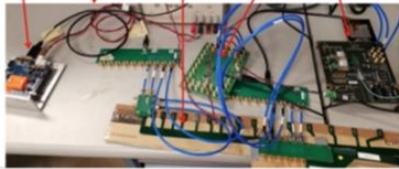
HGTD heater demonstrator to test thermal stability of CO2 cooling



IHEP-IMEv2 LGAD wafer with full size (15 x 15) sensor



ITk Pixel Outer Endcap (left) and Inner System (right) test bench setup



Rd53a + DP cable + 70cm FLEX + GBCR2 + VLDB+ + DAQ



LUCID-3 prototype PMTs on JFC3

new R1635 PMTs



LAR Signal Processor (LASP)



Tile Minidrawers



TDAQ L0 Global Comm Module prototype



Phase-II FELIX prototype

