ATLAS upgrades

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for ATLAS UK

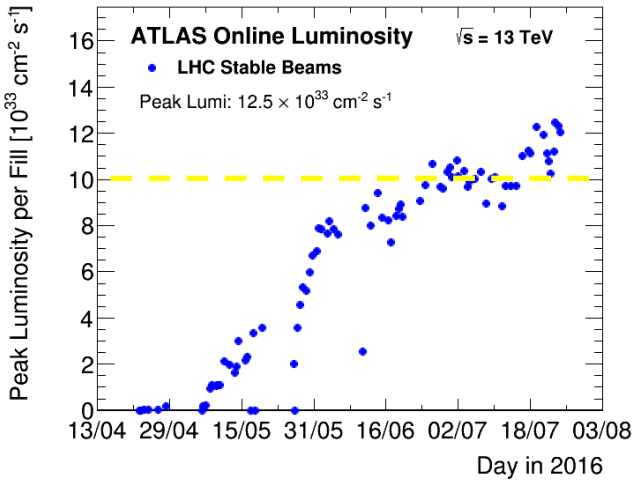
PPAP Community Meeting 2016

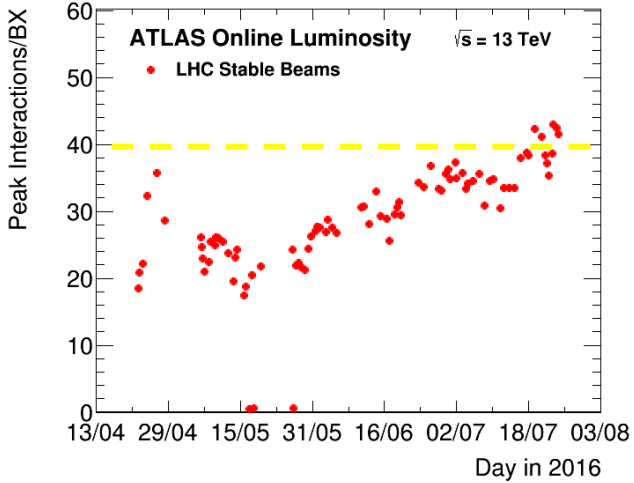
Outline

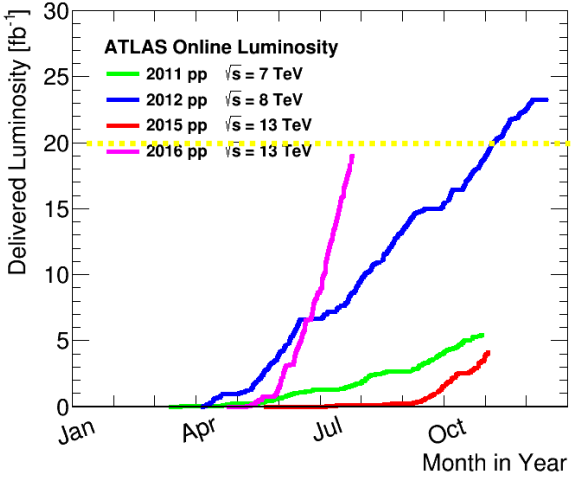
- Current status of the LHC and ATLAS
- Highlights of 13TeV results
- Towards HL-LHC: timelines, challenges, prospects
- Overview of Phase-1 and Phase-2 ATLAS upgrade
- Highlights of UK contributions

LHC in 2016 – Brilliant performance!

- 2016 re-start very efficient!
  - Stable & robust running at 13TeV with 25ns bunch crossing
- Already running above design luminosity – reached $1.25 \times 10^{34} cm^{-2} s^{-1}$
  - Record peak lumi, record fill length, record integrated lumi in one fill
  - Consistently delivering ~0.4-0.5fb^{-1} per day
  - Set to surpass 2016 target of 25fb^{-1} by quite a bit more!

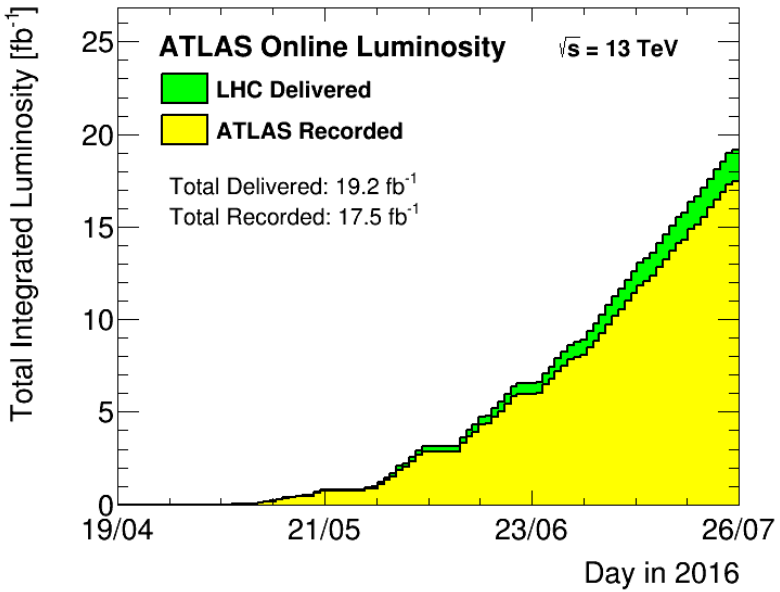






ATLAS in 2016 – Stable operation

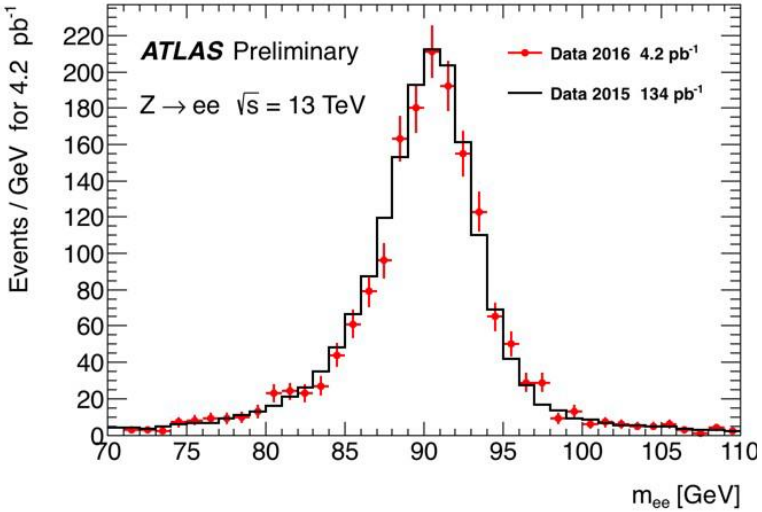
- All detector systems operational close to 100%
- Level-1 rate approaching 100kHz (from 75kHz in Run-1)
- Data taking efficiency >90%
  - Thanks to huge efforts from detector, trigger, data processing experts to maintain and improve it!

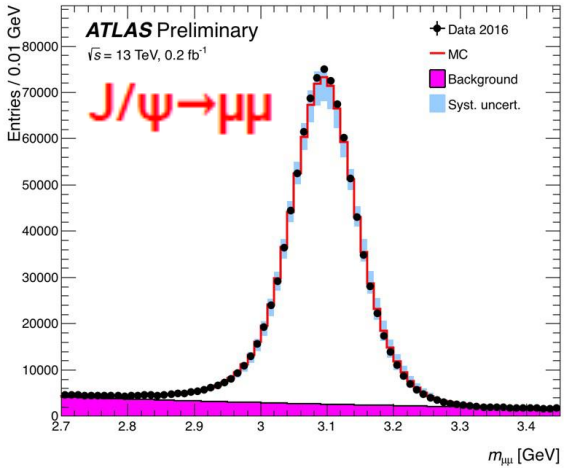


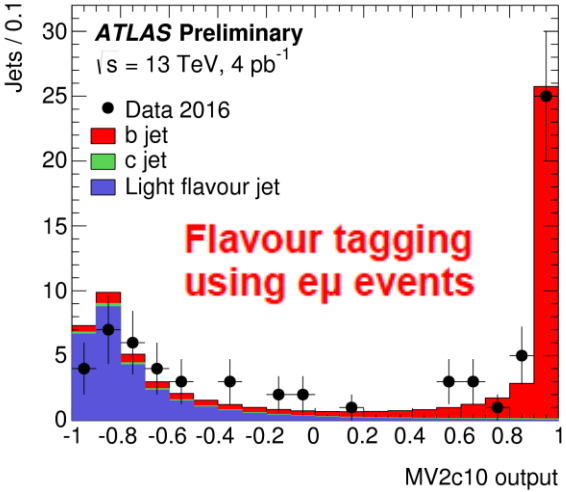
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	98.2%
SCT Silicon Strips	6.3 M	98.7%
TRT Transition Radiation Tracker	350 k	97.2%
LAr EM Calorimeter	170 k	100%
Tile calorimeter	5200	100%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.7%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	383 k	99.8%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	357 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Chambers	383 k	96.6%
TGC Endcap Muon Chambers	320 k	99.6%
ALFA	10 k	99.9 %
AFP	188 k	98.8 %

ATLAS in 2016 – Data Quality

- Recording data of excellent quality
  - Fast work from detector & combined performance groups to understand & optimize object reconstruction in 2016 data

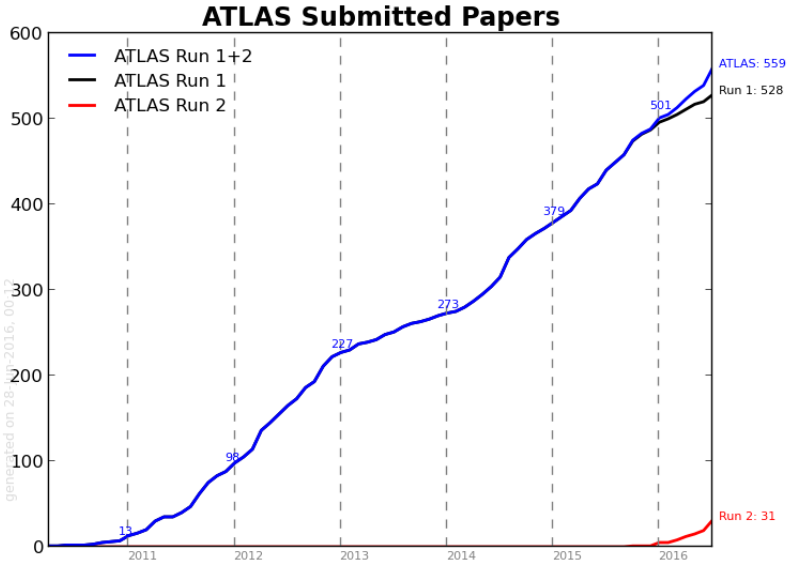


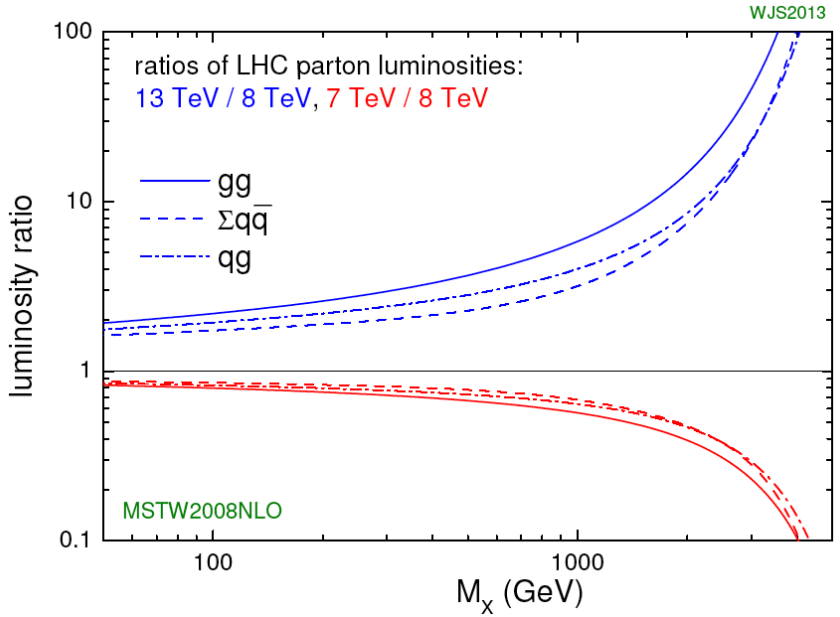




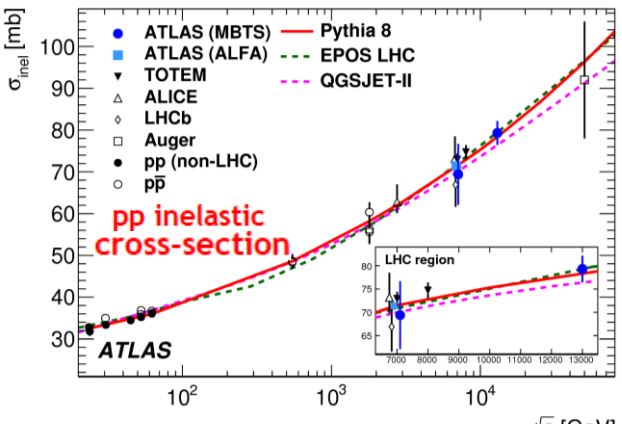
13TeV results with 3.2fb^{-1} from 2015

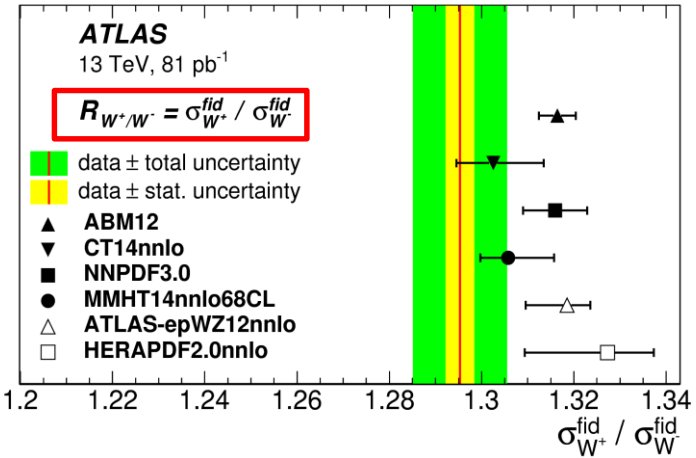
- More than 30 papers published with the 2015 data
- First glimpse at the new energy frontier!
  - First measurements testing the Standard Model at 13TeV
  - Some searches for BSM signals already more sensitive than Run-1

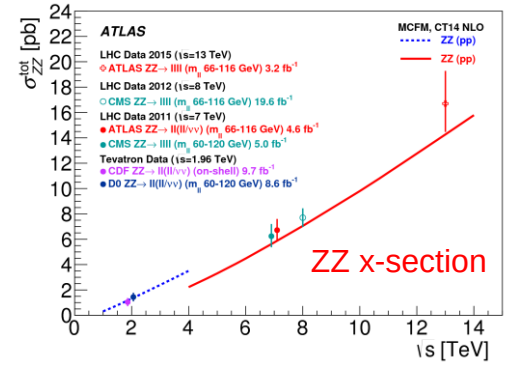


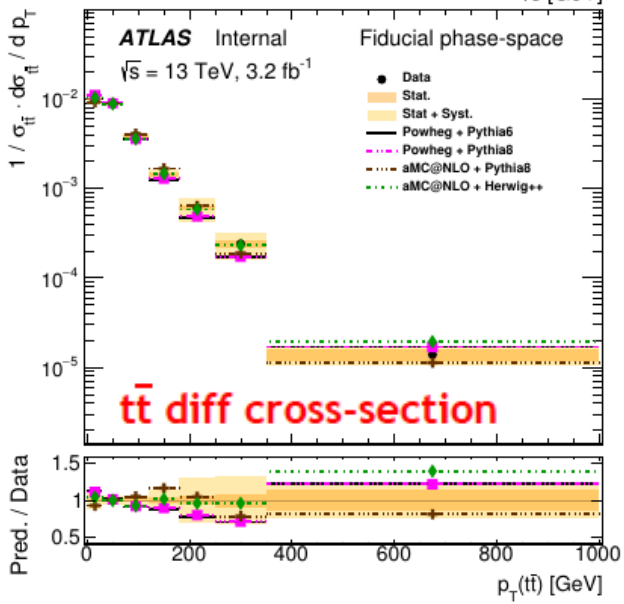


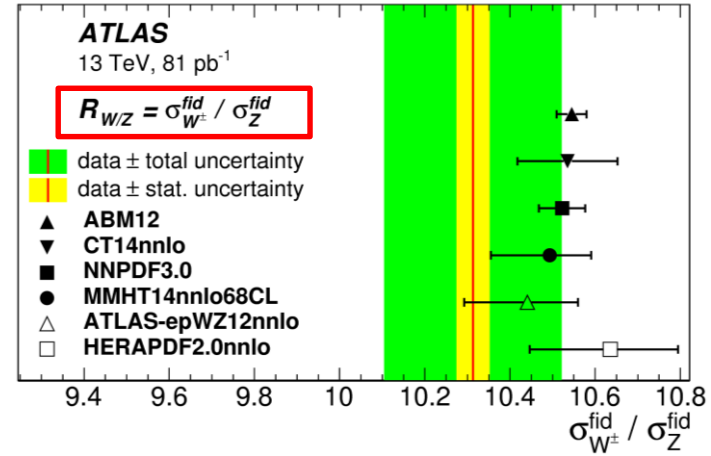
13TeV results – Measurements

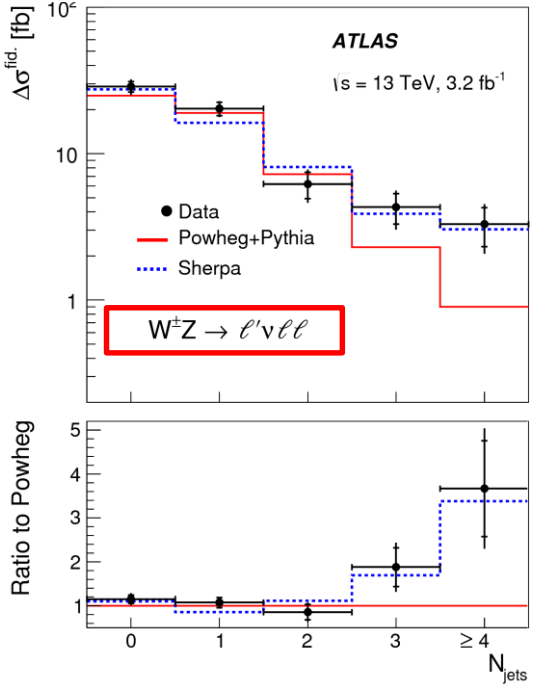




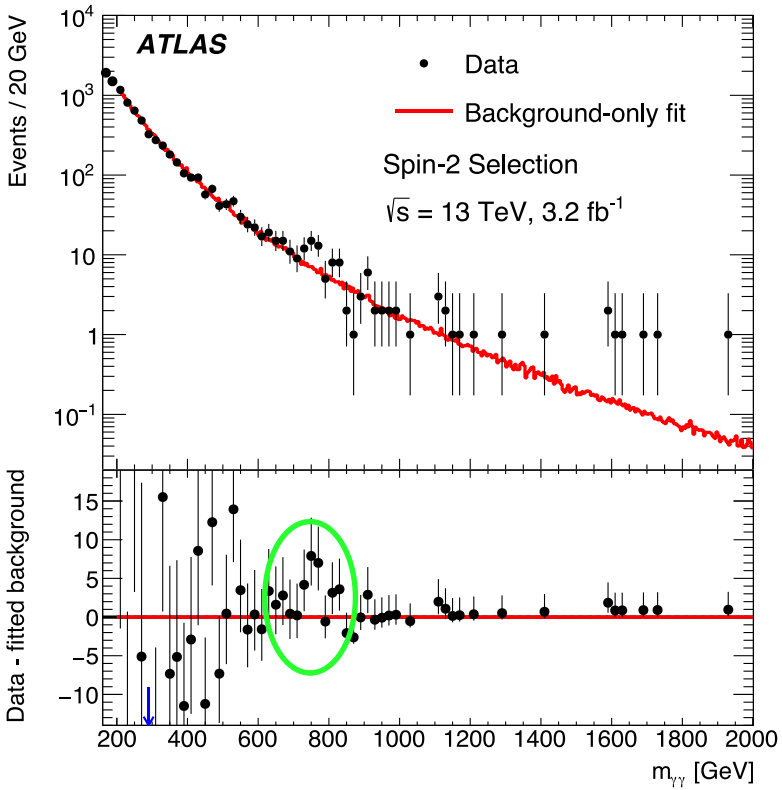




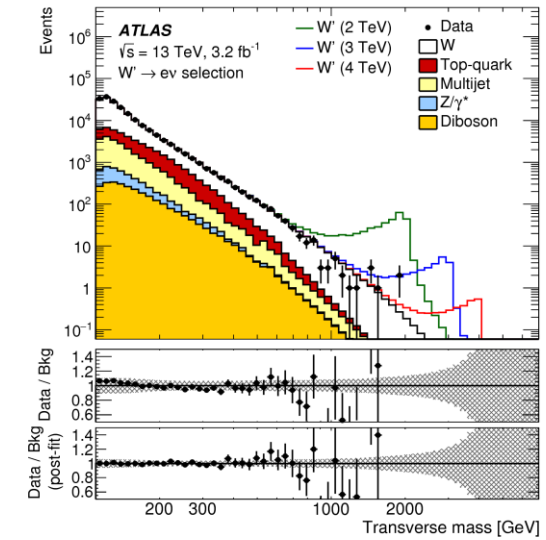


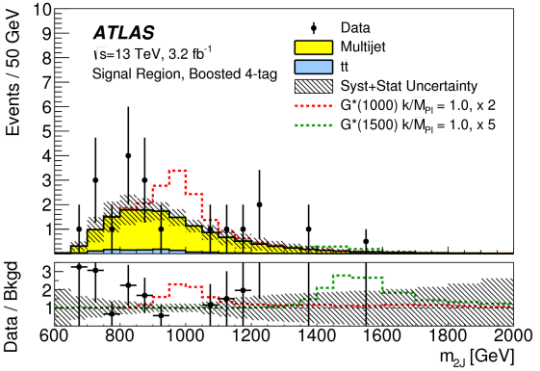


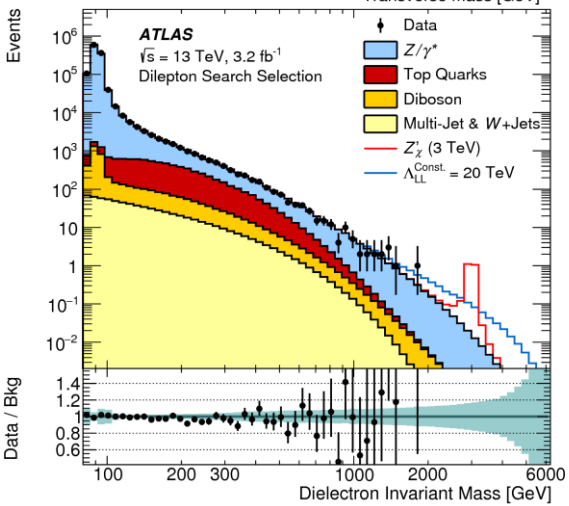
13 TeV results – Searches

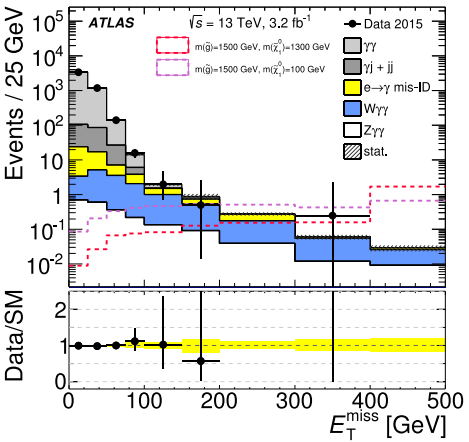


Intriguing ~3σ (local) excess in di-photon mass spectrum around ~750GeV!





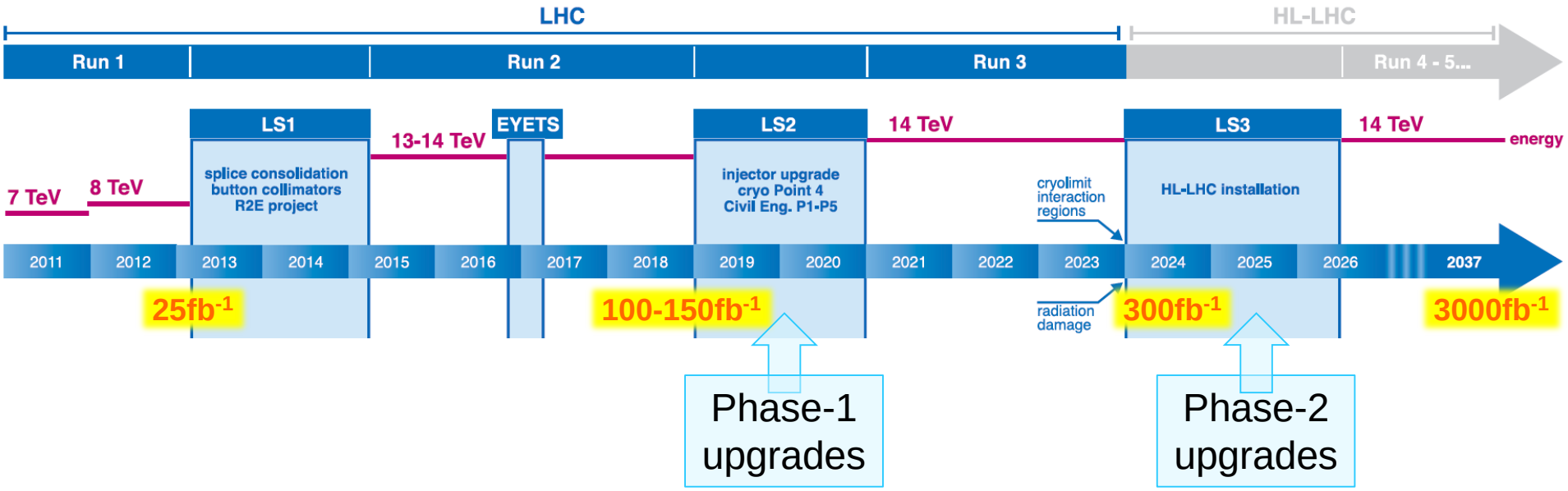




UK involvement in ATLAS & upgrades

- ATLAS-UK: 14 universities + STFC/RAL
  - ~300 authors: ~10% of ATLAS collaboration
  - ~70 academics: ~1/3 of UK PP community
- Much bigger role in ATLAS
  - ~20% of senior management including:
    - Spokesperson (Charlton), InDet Project leader (Robinson), ITk Project Leader (McMahon)
    - Current or incoming leads in Physics (Tovey), Run Coord. (Cerri, Oh), Data Prep. (Laycock, Frost)
  - ~20% of coordinators in Physics and combined performance groups
  - Several other senior roles in recent past
    - e.g. Upgrade Coordinator, Trigger Coordinator, PubCom Chair, Physics Coordinator…
- Major UK roles in ATLAS construction: Silicon Strip detector (SCT), L1Calo Trigger, High Level Triggers (HLT) & DAQ, Software & Computing
  - Delivered timely and within budget!
  - Continues to lead the M&O efforts in these projects
- Taking forward this expertise and leadership to Phase-1 & Phase-2 upgrades

Timelines towards HL-LHC



Run 3

- Peak lumi up to ~3x10^{34}cm^{-2}s^{-1}
- Peak <pile-up>~80
- ~100fb^{-1}/year ➔ ~300fb^{-1} by LS3

==> Upgrades mainly to cope with higher L1 trigger rates

HL-LHC

- Peak lumi up to ~7.5x10^{34}cm^{-2}s^{-1}
- Peak <pile-up>~200
- ~300fb^{-1}/year ➔ ~3000fb^{-1} in 10 years

==> Upgrades to cope with occupancies, radiation levels, trigger rates etc…

ATLAS Upgrades – Overview

Phase-1(for Run 3)

- Muon New Small Wheels (NSW)
  (for improved L1Muon Trigger)
- ECAL trigger electronics
  (for finer granularity inputs to L1Calo)
- TDAQ upgrades
  - L1Calo Trigger electronics
    - L1Muon Trigger electronics
    - L1 Topological Trigger hardware
    - FTK (hardware track finder at start of HLT)
  - HLT software and Readout System (ROS)
- Software & Computing
- Forward detector system

UK construction project funded to Q1/2019

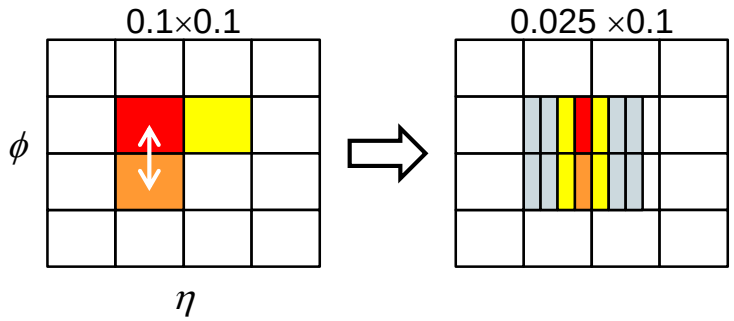
Phase-2 (for HL-LHC)

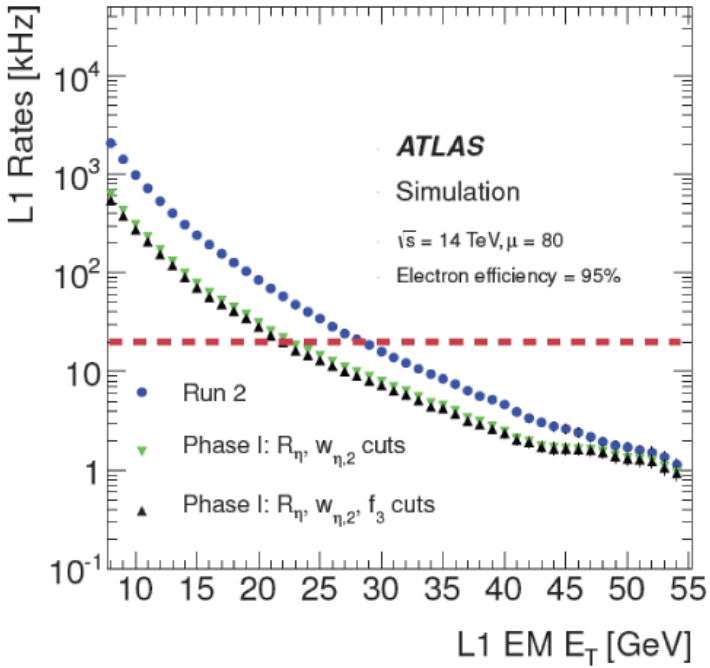
- New all-Si tracker (ITk): Pixels + Strips
- Calorimeters
  - New electronics
  - New forward Calorimeter (sFCAL)
  - High granularity timing detector
- Muon system
  - New electronics
  - Inner Barrel layer (better trigger coverage)
  - Muon tagger 2.7<|η<|4.0
- TDAQ
  - Major overhaul to cope with higher trigger rates and higher detector readout bandwidth
    - L1Calo upgrade
    - New Level-1 Track Trigger
      - FTK++
    - Event Filter (HLT) & DAQ upgrades
- oftware & Computing

UK R&D (ITk & L1Track) funded to Q1/2018

Phase-1 highlights – L1Calo upgrade

- LAr Calo upgrade will provide finer granularity data to L1 Calo
- Run-3 L1Calo will achieve (for >~95% signal efficiency):
  - Reduced L1_EM rate by factor ~3; or
  - 7 GeV lower E_T threshold
- UK developing electron feature extractor (eFEX) and associated readout driver (ROD)



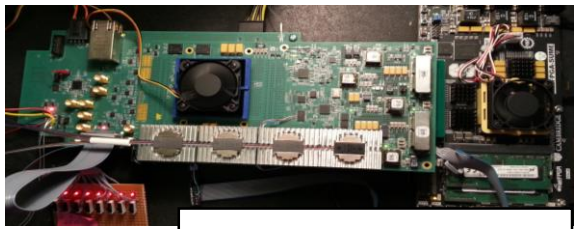


L1Calo UK – Status

- eFEX module
  - Challenging PCB design
    - 424 signal pairs @ 11.2 Gb/s
    - Data sharing between FPGAs requires tracks ≤ 30 cm with complex topology
  - First prototype received Feb'16
    - Tested successfully with prototype LAr electronics
    - 99% 11.2 Gb/s tracks with BER $< 10^{-14}$
  - Technology, design & method validated
  - Full characterisation continues
    - Multi-Gb/s links, power, cooling, FPGA utilisation…

The eFEX Prototype

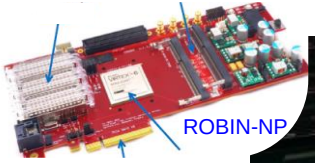
- ROD
  - Mezzanine to sit on Hub module
  - Prototype received Dec' 15
  - All 48 data outputs & 24/72 inputs tested @ 10 Gb/s with BER $< 10^{-14}$
  - Hardware to test remainder in development
  - System tests scheduled for Oct'16

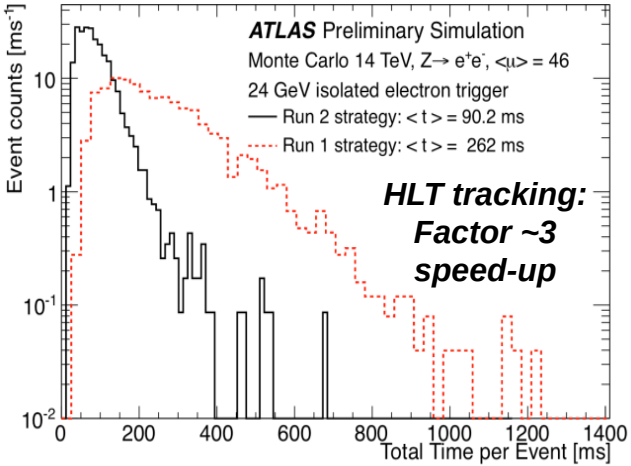


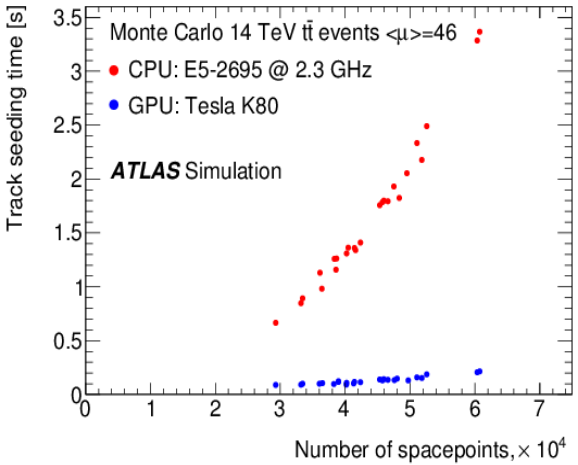
ROD Prototype under Test

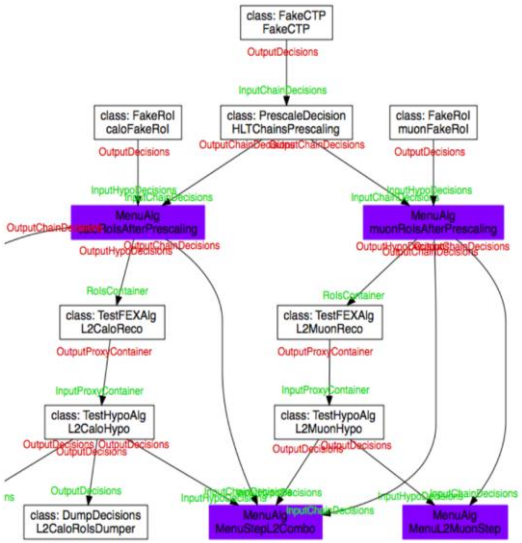
Phase-1 highlights – DAQ & HLT Upgrades

- Readout system upgraded during LS1
- HLT tracking software redesigned resulting in factor ~3 speed up
- GPU demonstrator shows promising speed-up in parts of HLT tracking code
- AthenaMT (MultiThread) common HLT/offline framework: HLT prototype and code migration advancing

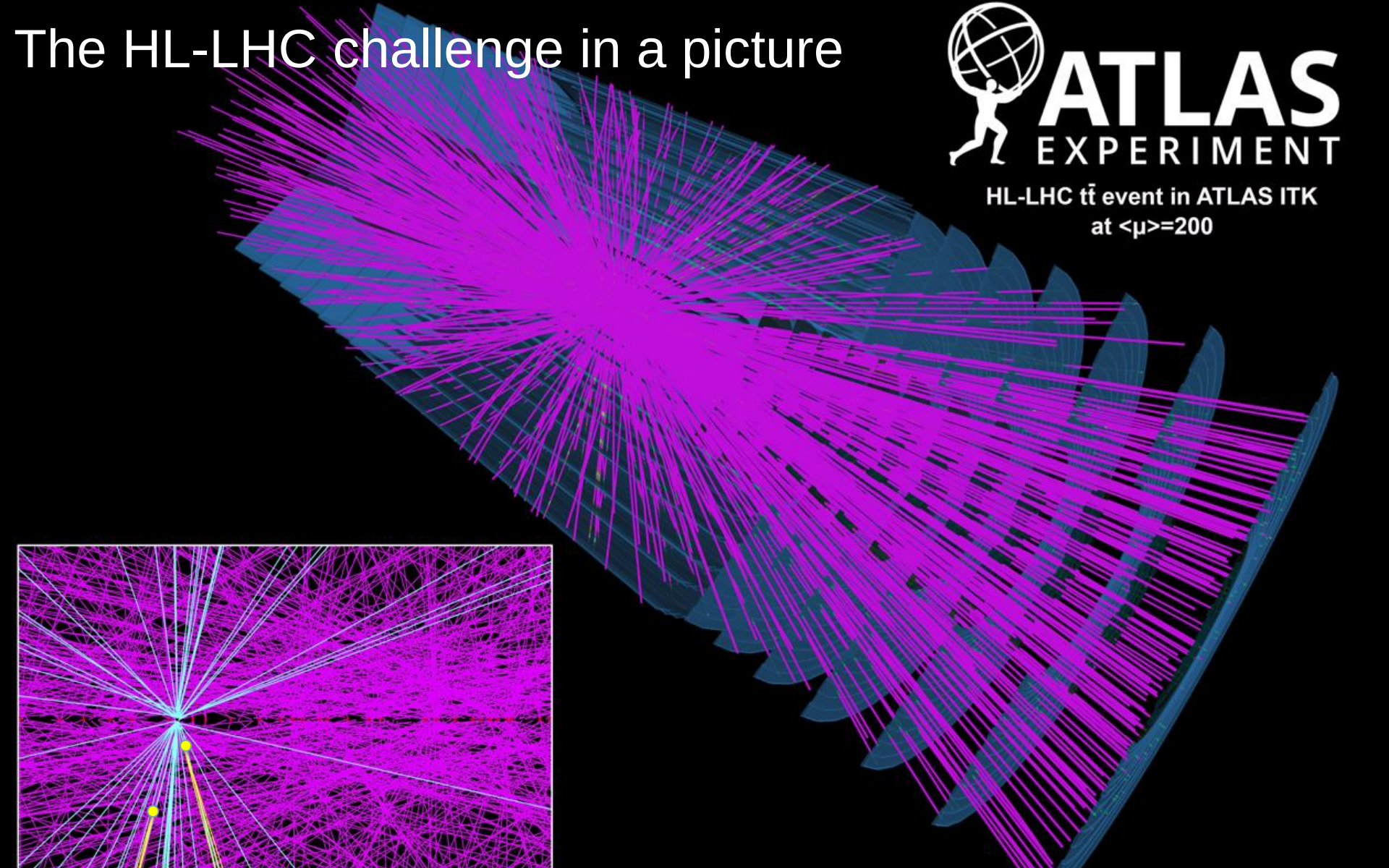








The HL-LHC challenge in a picture



Prospects with 3000fb^{-1} at HL-LHC

- Detailed study of Higgs properties and EWSB mechanism
  - Higgs couplings measured down to the few % level
  - Higgs pair-production and self-coupling measurement
  - Vector Boson Scattering cross-section at ~1TeV

- Full exploration of TeV scale and deep into multi-TeV scale
  - Both through direct searches (Dark Matter, SUSY, …) & precision SM measurements
  - Sensitivity to rare/low cross section BSM processes

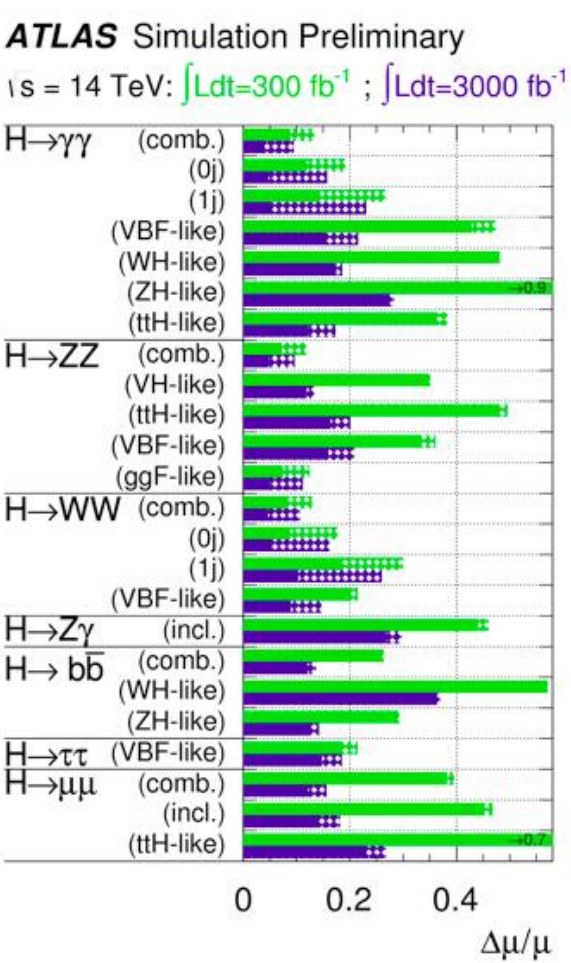
- If discovery with 300fb^{-1}, full investigation with 3000fb^{-1}
  - Measure precisely properties of newly discovered states
  - Pin down the parameters of the underlying theory

Higgs prospects at HL-LHC

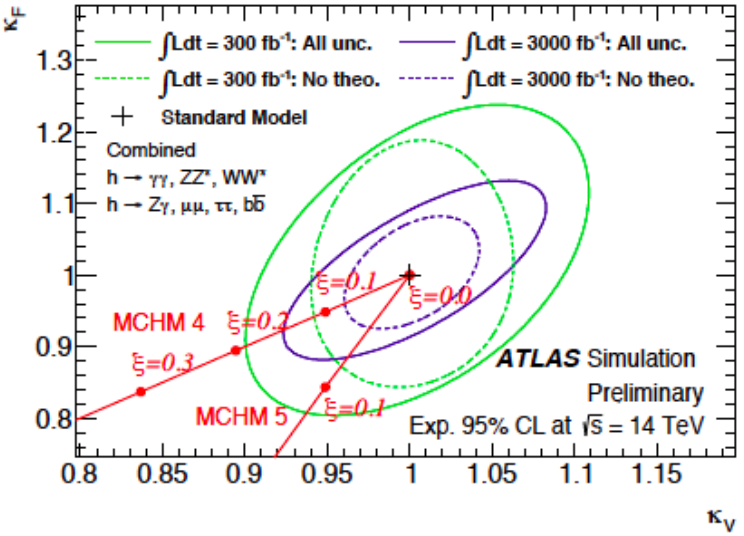
HL-LHC: a Higgs factory!

	Higgs bosons at √s=14TeV
HL-LHC, 3000fb^{-1}	170M
VBF (all decays)	13M
ttH (all decays)	1.8M
H->Zγ	230k
H->μμ	37k
HH (all)	121k

- m_H=~125GeV is blessing!
- Most production & decay modes accessible!
- Relative couplings:
  - Phase-1: 10-80%
  - Phase-2: 5-30%



Combined fit of fermionic (κ_F) vs. bosonic (κ_V) couplings:



Precision vital for BSM searches in the Higgs sector!

Highlights of prospects with 3000fb^{-1}

ATL-PHYS-PUB-2013-003, 2014-007

ATLAS Mass reach for Exotic signatures

ATLAS @14 TeV	Z' → ee SSM 95% CL limit	g_{KK} → t t RS 95% CL limit	Dark matter M* 5σ discovery
300 fb^{-1}	6.5 TeV	4.3 TeV	2.2 TeV
3000 fb^{-1}	7.8 TeV	6.7 TeV	2.6 TeV

ATL-PHYS-PUB-2014-010 , 2013-011, 2015-032

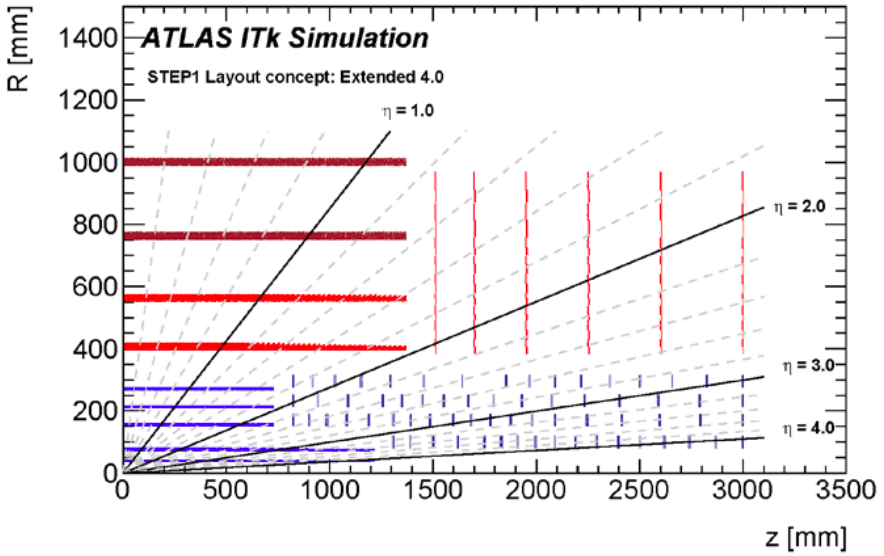
ATLAS Mass reach for SUSY particles

ATLAS projection	gluino mass	squark mass	stop mass	sbottom mass	χ_1^+ mass WZ mode	χ_1^+ mass WH mode
300 fb^{-1}	2.0 TeV	2.6 TeV	1.0 TeV	1.1 TeV	560 GeV	None
3000 fb^{-1}	2.4 TeV	3.1 TeV	1.2 TeV	1.3 TeV	820 GeV	650 GeV

Phase-2 highlights – ITk

- All-Si tracker (Pixels + Strips) with coverage to $|\eta|=4$
  - Essential for Vector Boson Fusion/Scattering measurements, for missing E_T resolution etc…
- Layout to be finalised by Dec'16
  - TDRs: Strips Dec'16, Pixels Dec'17

- The UK has been leading the R&D in many critical areas
  - Sensor & hybrid design
  - Testing of ASICs
  - Irradiation tests
  - Fabrication & test of modules
  - Design & test of bus tapes
  - Mechanical design for support & services
  - Readout & system tests
  - simulation & performance studies



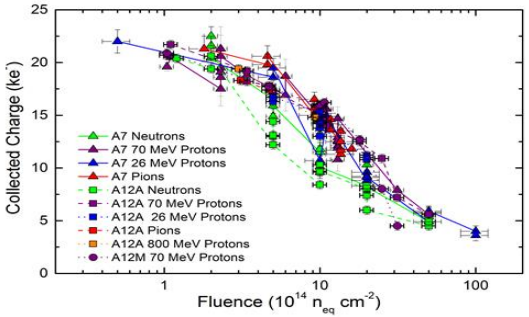
UK proposes to build:

- Half of barrel Strip layers
- One Pixel endcap

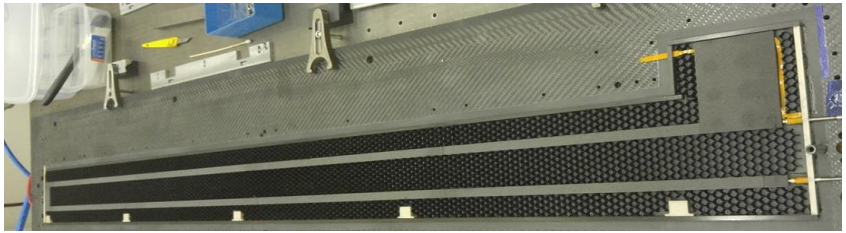
(including all services & support structures)

ITk Strips R&D highlights

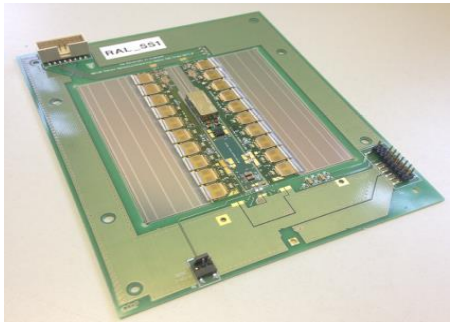
Irradiation tests of p-in-n Si detctors



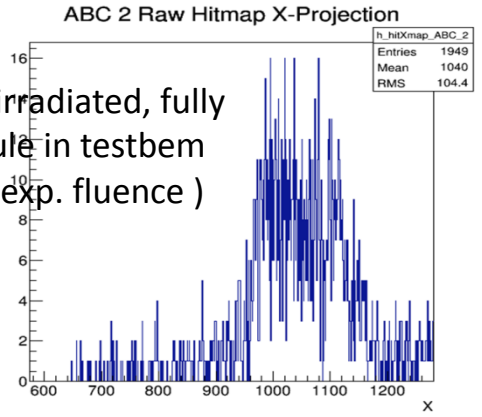
Stave being assembled. Carbon fibre honeycomb.



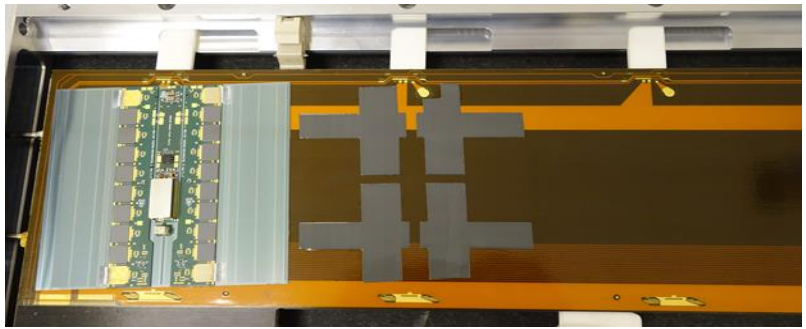
Barrel hybrid with ABC130 chips



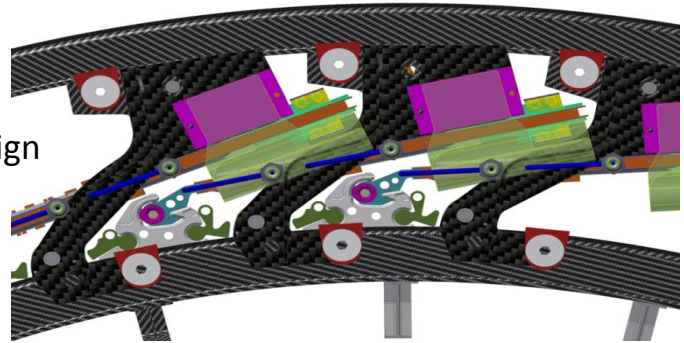
Functionality of irradiated, fully assembled module in testbem (~7e14 neq/cm^2 exp. fluence)



Thermo-mechanical module mounting on a stave

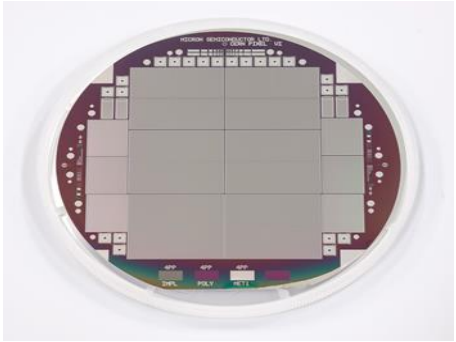


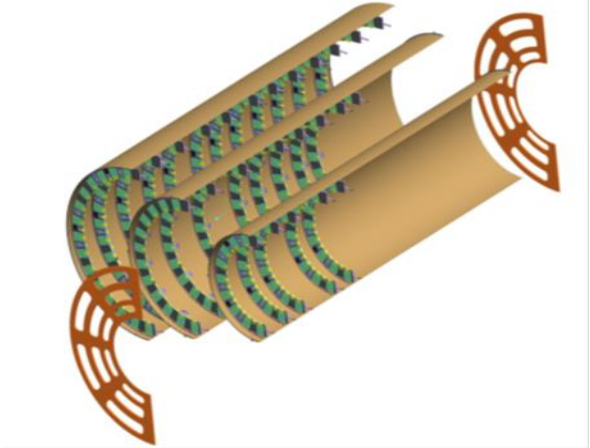
Interlink design



ITk Pixels R&D highlights

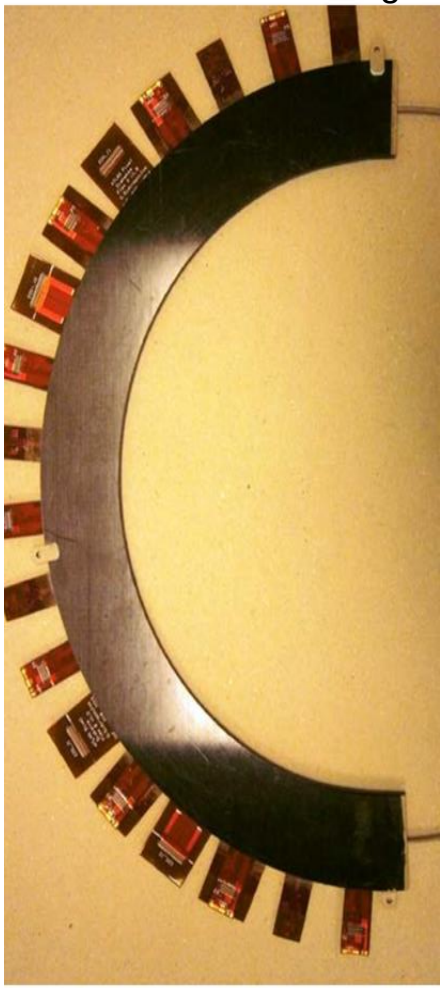
silicon wafer with 6 quad modules manufactured n the UK (Micron)

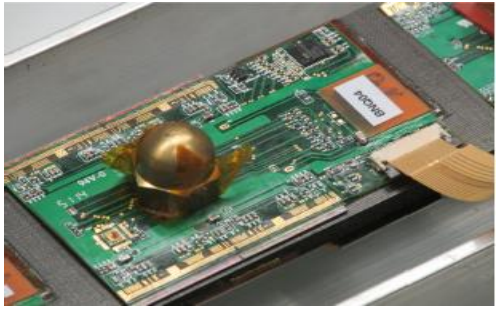




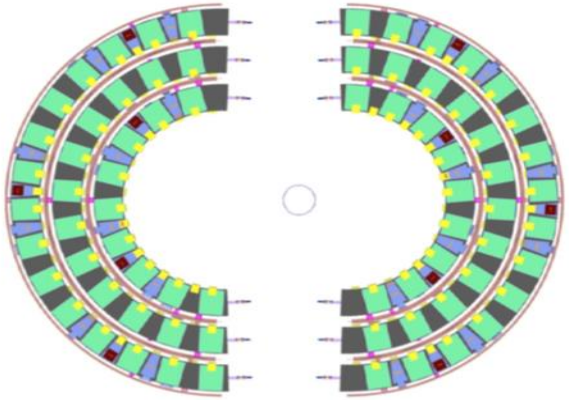
CAD drawings of the mechanical design for the pixel endcap disks

mechanical prototype of a carbon fibre half ring





Prototype of a quad pixel module



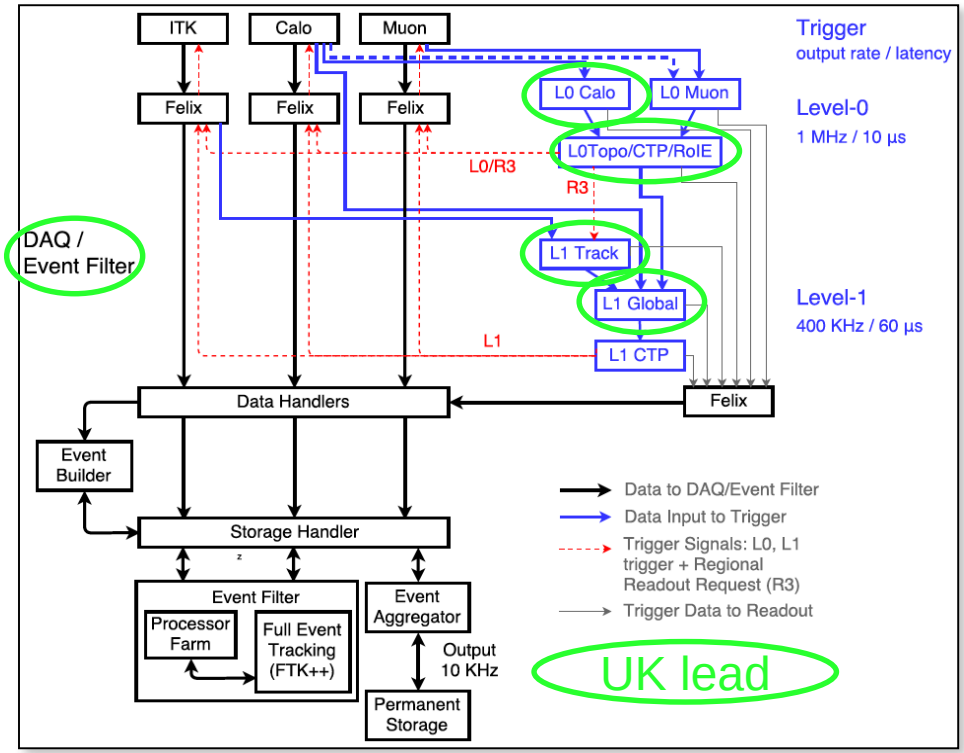
Phase-2 highlights – TDAQ architecture

- HL-LHC Physics programme (Higgs etc) needs same trigger thresholds as in Run-1
- UK-proposed two-level scheme, L0/L1
  - Phase-1 L1 becomes Phase-2 L0: brings rate down to ~1MHz (<~10μs)
  - L1 Track Trigger (regional hardware tracking) reduces rate to ~0.4MHz (<~60μs)

- Initial Design Review in Apr'16 considered also a single-level architecture (full readout at 1MHz)
  - Trade-off between flexibility and simplicity

- Decision on architecture by Oct'16
  - TDAQ Phase-2 TDR by Dec'17

- UK well positioned to continue its leadership role in both scenarios
  - L0Calo, RoI Engine, L1Global, L1Track
  - EF Tracking, EF Core Software, Trigger Menus and Signatures, DAQ



HL-LHC project - International Context

- October 2015: Following a scoping exercise for the Phase-2 upgrades of ATLAS and CMS, the LHCC recommended a funding level between the reference and middle scoping scenarios
  - Endorsed by the RRB
  - ATLAS and CMS given green light to proceed to TDRs
  - For ATLAS: hardware cost of 275-235 MCHF
- June 2016: CERN Council approved HL-LHC accelerator project
- ATLAS Phase-2 TDRs to LHCC between Q4/16 and Q4/17
- ATLAS-UK Phase-2 construction bid to PPRP by mid-2017
  - For construction project in 2018-2024

Summary

- Impressive performance of LHC in 2016 at 13TeV!!!
  - ATLAS collecting high quality data – already >15fb^{-1} on disk (cf ~3fb^{-1} in 2015)
  - Big shot at new physics in energy frontier – many preliminary results at ICHEP
  - Major discovery potential in coming years!

- UK leadership in ATLAS construction, operations, physics exploitation and upgrades

- ATLAS Phase-I Upgrades: vital to cope at luminosities up to $3x10^{34}cm^{-2}s^{-1}$

- HL-LHC: a broad and exciting programme at the energy frontier
  - ATLAS has a well defined upgrades programme to maintain and optimise the detector performance at the extreme conditions of HL-LHC
  - The UK has a leading role in this programme and, following a successful R&D period, now moving towards Phase-2 construction