The ATLAS HL-LHC, upgrade and physics prospects

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MANCHESTER 1824
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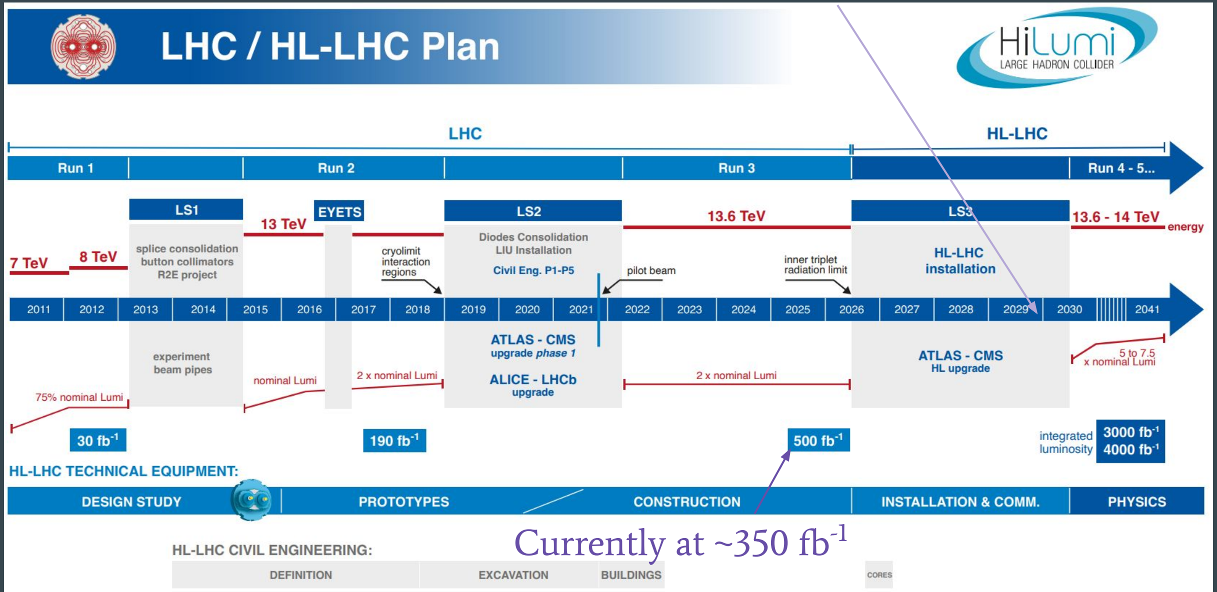
The HL-LHC

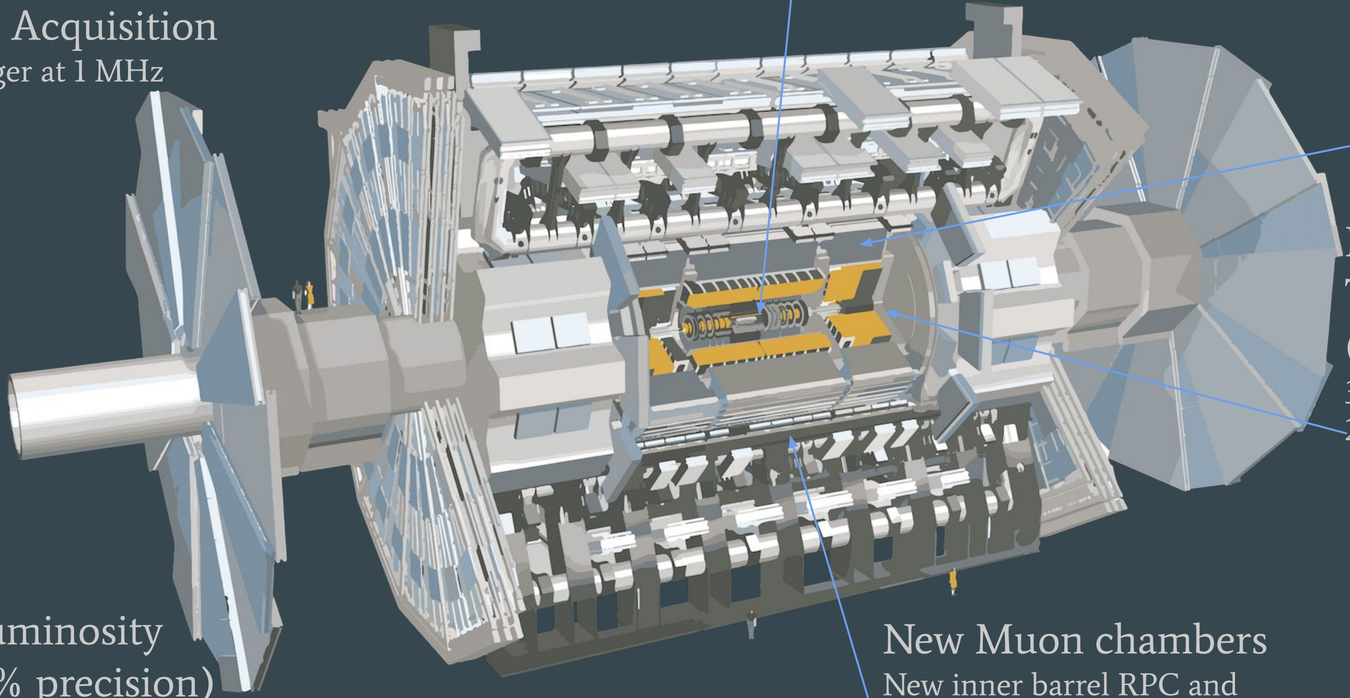
2.5-4 times the instantaneous lumi, and 2-3 times the interactions/bunch crossing



hl-lhc-project

- What does ATLAS need for a successful HL-LHC program?
  a. A detector that can withstand harsher running conditions
  b. To select the data to record and reconstruct it offline with high efficiency
  c. Interesting physics that will make use of the large data set

ATLAS Phase-II Upgrade



New Inner Tracking Detector (ITk)
Silicon, up to |η|=4

Upgraded Trigger and Data Acquisition
Level-0 trigger at 1 MHz

Calorimeter electronics upgrades

High Granularity Timing Detector (HGTD)
30 ps track resolution, 2.4<|η|<4

Upgraded luminosity detectors (1% precision) and HL-ZDC

New Muon chambers
New inner barrel RPC and sMDT detectors

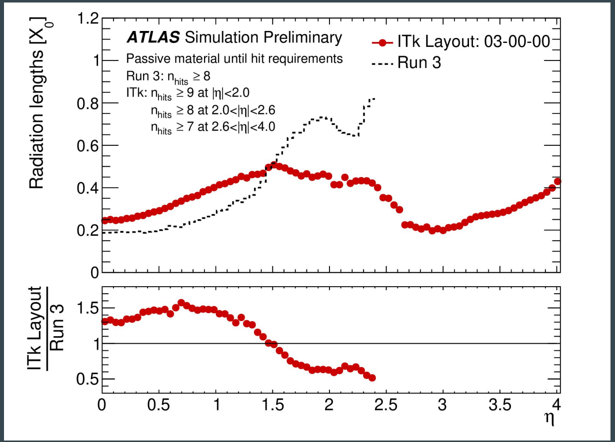
Inner Tracker (ITk)

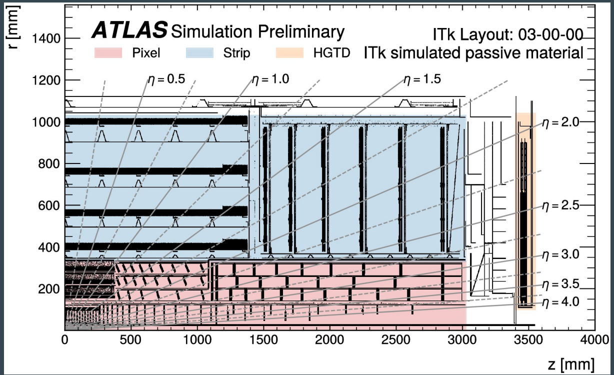
Barrel support

Photos

- Will completely replace the current Inner Detectors
  - Comprised of a 5-layer pixel system, and 4 barrel strip layers + 6 endcap disks
  - Increase coverage from |η|<2.5 to |η|<4.0, with finer segmentation and reduced material budget
  - Minimum number of hits on track up to 9 (compared to 8 for Run 3)
  - Production for many parts currently ongoing

End cap support

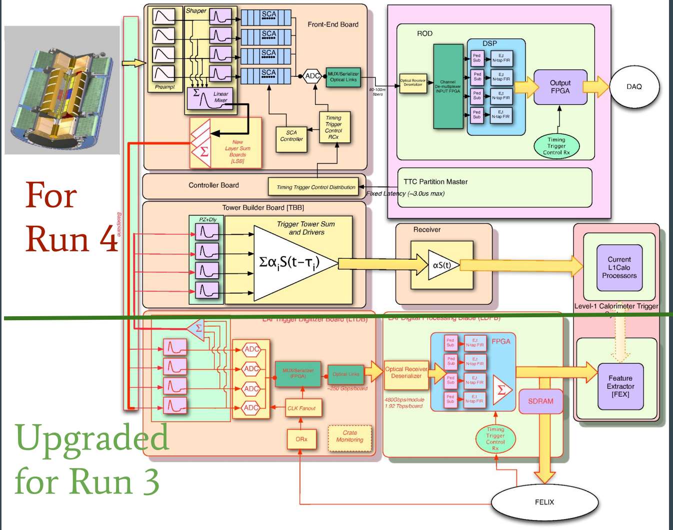




ITK-2023-001

Calorimeters

- Liquid Argon Calorimeter
  - Major upgrade for Run 3 to have finer granularity for hardware trigger
  - Electronics being upgraded to withstand higher radiation including new front end, calibration, and signal processing boards, and a new timing control system



[LAr TDR]

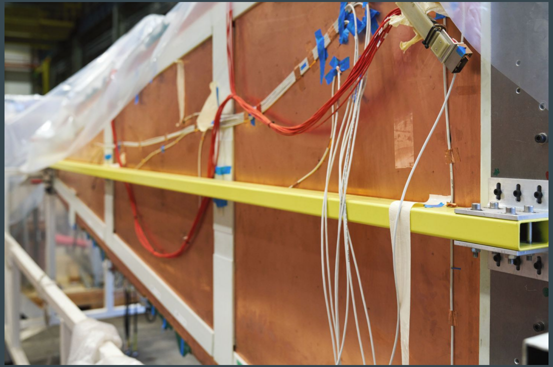
- Tile Calorimeter
  - Both on- and off-detector electronics being replaced, replacement of ~10% of PMTs, improvements in power systems, upgrade to calibration systems
  - Mechanical improvements to easier access on-detector electronics
  - Demonstrator module installed in ATLAS (in 2019) to complement information from testbeam

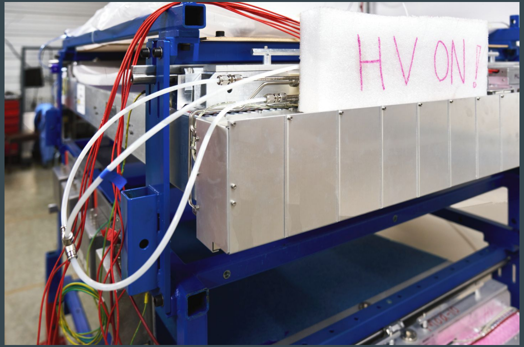
[Photo]

[Tile TDR]

Muon Detectors

- Additional inner barrel layers being added
  - Resistive plate chambers (RPCs) and small Monitored Drift Tubes (sMDTs)
  - Will improve detector and trigger coverage
- Readout and trigger electronics being upgraded

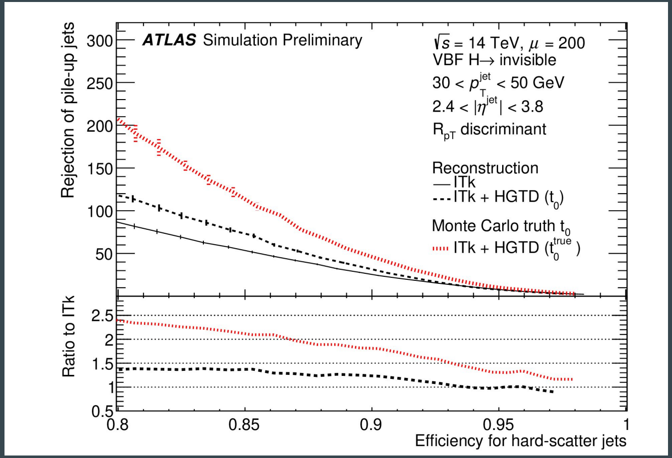




Photos   Muon TDR

The High Granularity Timing Detector (HGTD)

- Low gain avalanche diode detector technology covering 2.4<|η|<4 (between barrel and endcap calorimeters)
  - Provides average time resolution of 30-50 ps for tracks
  - Provides information for pileup rejection



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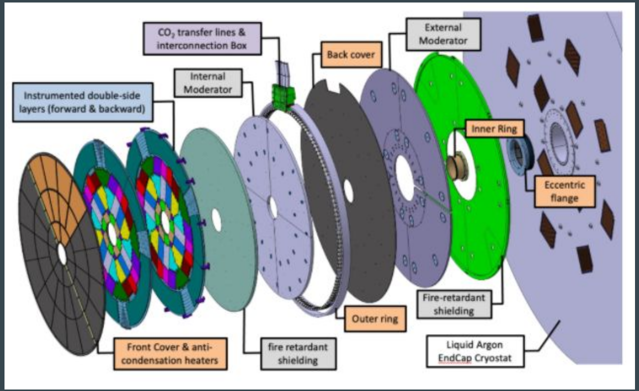
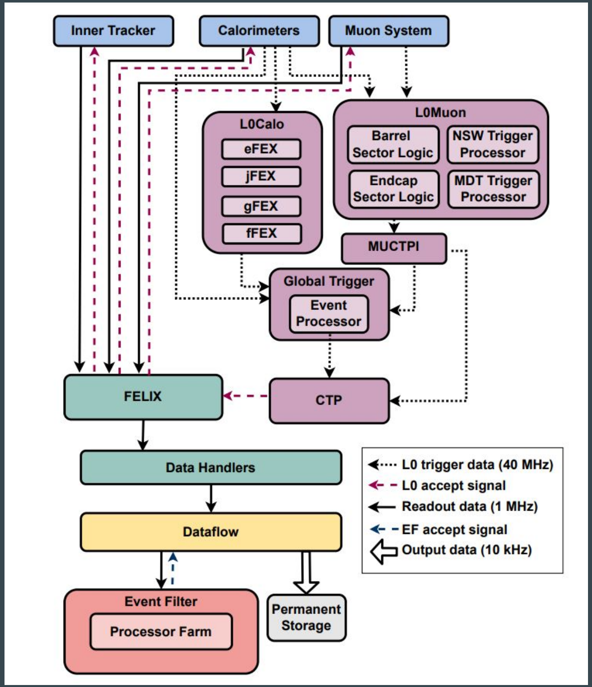


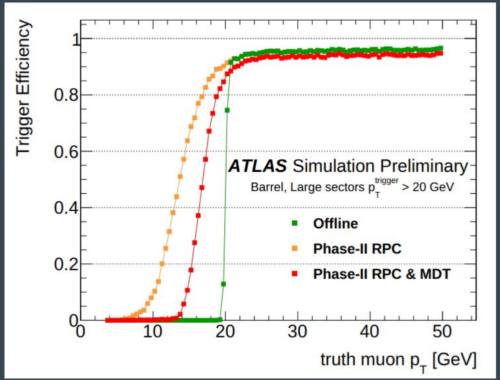
high-granularity-timing-detector-atlas-phase-ii-upgrade

HGTD TDR

Trigger and Data Acquisition

- Two level trigger system
  - L0 hardware based trigger, output 1 MHz
    - Includes MDT information in L0 muon trigger
    - New L0 'forward FEX' to trigger on forward calorimeter objects
    - Global trigger to provide more refined calculations of calorimeter objects, and provide topological selections of different objects



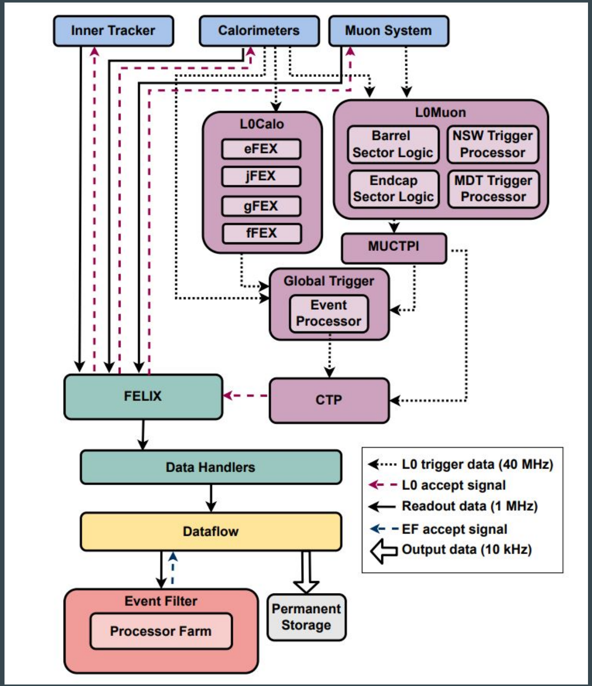


L0MuonTriggerPublicResults

TDAQ TDR

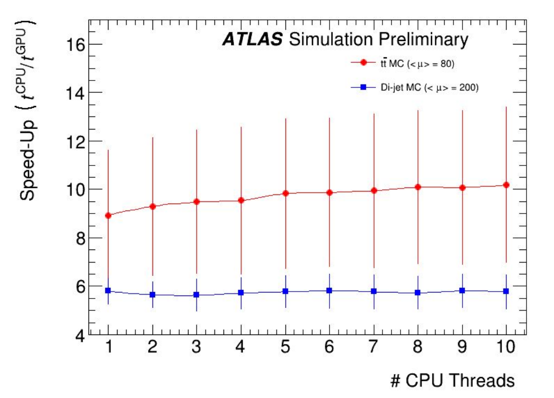
Trigger and Data Acquisition

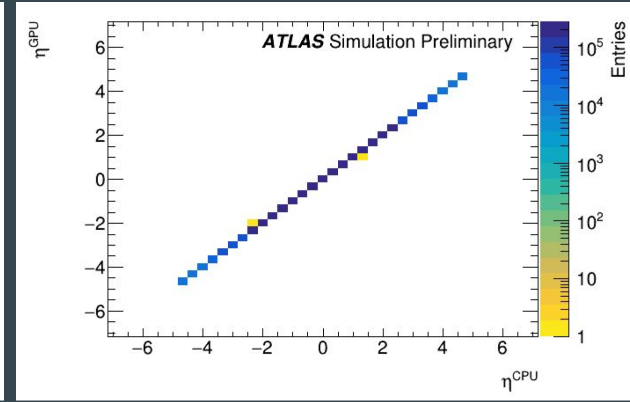
- Two level trigger system
  - L0 hardware based trigger, output 1 MHz
  - Software based Event Filter (EF) trigger, output 10 kHz
    - Includes running full detector tracking at 150 kHz
- Readout system to be upgraded to handle higher dataflow rates (up to 4.6 TB/s from detector, 60 GB/s from EF)



Reconstructing Physics Objects

- Need to be able to reconstruct various physics objects (muons/electrons/taus/jets/etc) both online and offline
  - Have to take into account new detector geometry
  - Needs to be efficient in terms of CPU usage at high luminosity/pileup
  - Need to maintain high efficiency and good resolution
- Architecture used for online and offline reconstruction also being considered (CPU/GPU/FPGA)

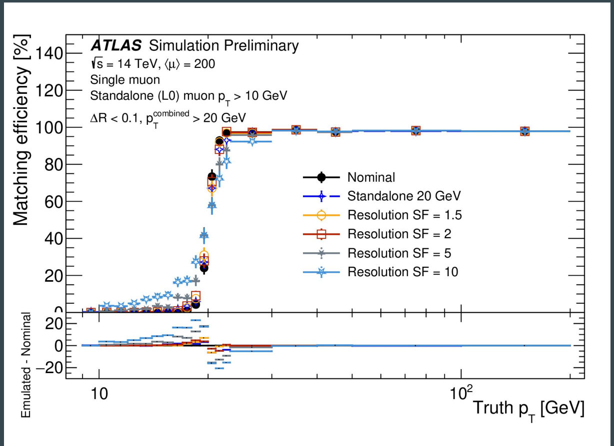




EFCaloPublicResults

Track reconstruction

- Online EF track performance estimated from offline tracks
  - eff/resolution (pT/d0/z0) degraded, higher min pT cuts applied, enhancing track duplicates
  - L0 emulated using offline objects
- Offline track efficiency measured as fraction of particles matched to a track
  - Efficiency and resolutions similar to Run 3



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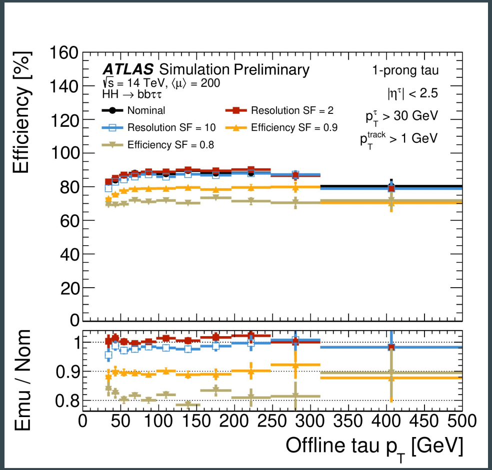
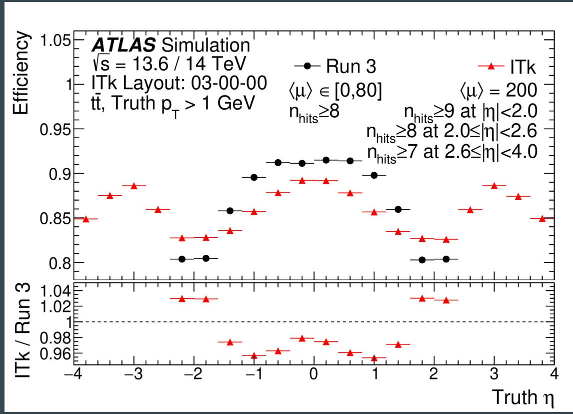
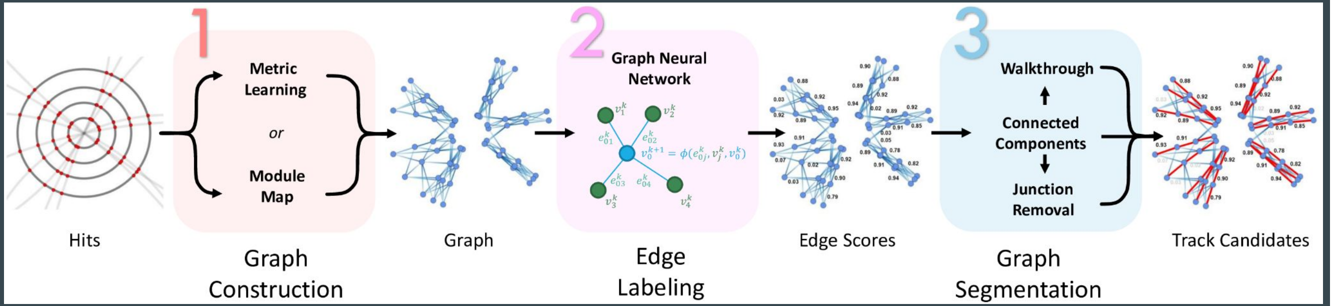
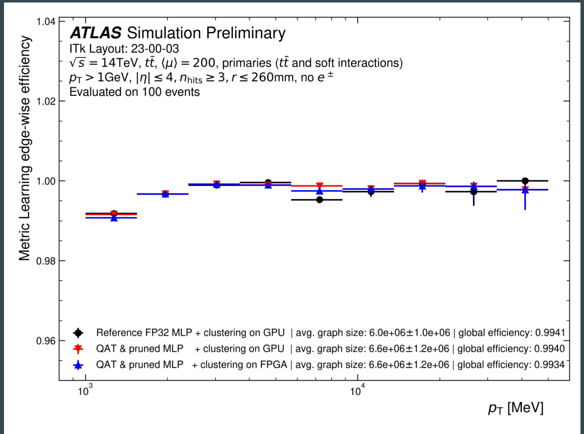




IDTR-2023-01

Track reconstruction improvements





EFTrackingPublicResults

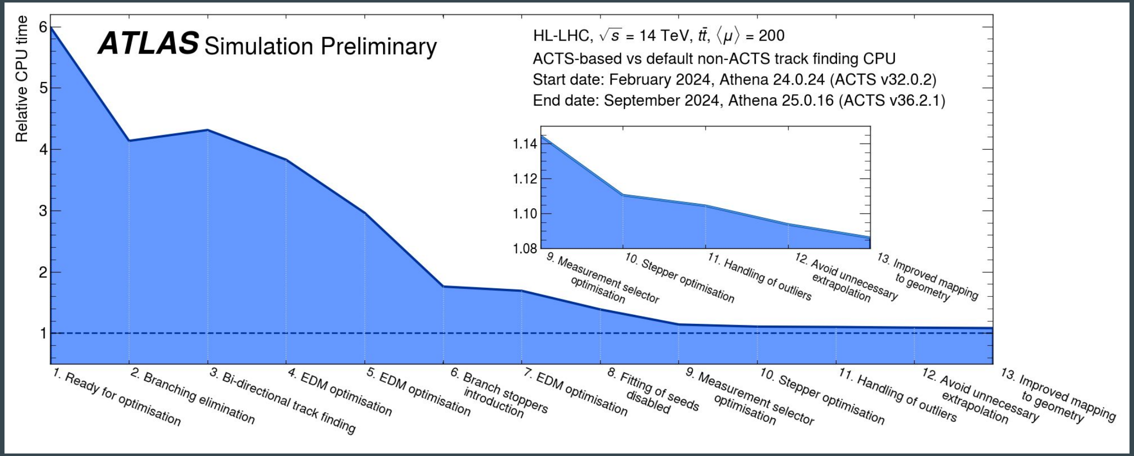
- Build a Graph Neural Network for track reconstruction
  - Each hit treated as a node, with two consecutive hits in same track being an edge
  - Goal to reduce latency/memory footprint, and increase throughout
  - Being tested on GPUs and FPGAs (also considered for online running)

Stage	Efficiency (Relative Difference, %)	Running Time (ms)
CTD23 Walkthrough	—	42,000
FastWalkthrough	+0.53	120
CC	−1.33	6.0
CC+JR	+0.93	40

ATL-PHYS-PUB-2024-018

Track reconstruction improvements

- A common (across experiments) tracking framework developed (ACTS)
  - Migration of ATLAS tracking software to this framework and optimisation ongoing
  - GPU version of this tracking via traccc project running hit clusterization, seeding, track finding and fitting on GPU



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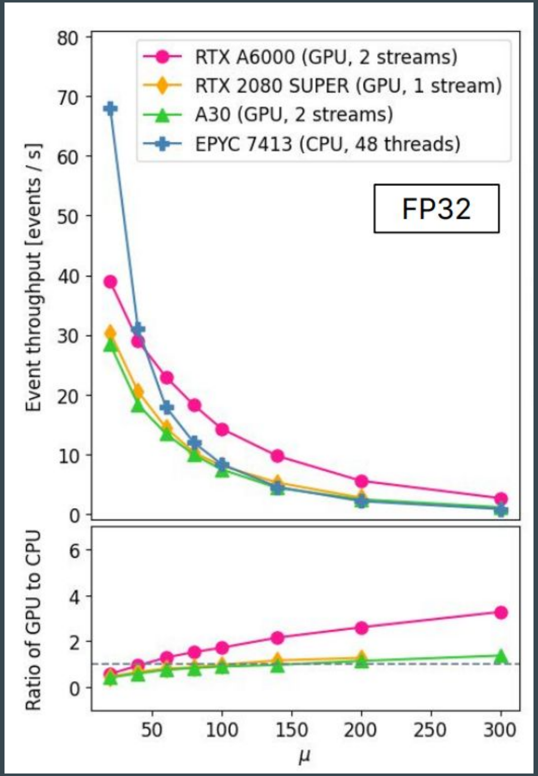
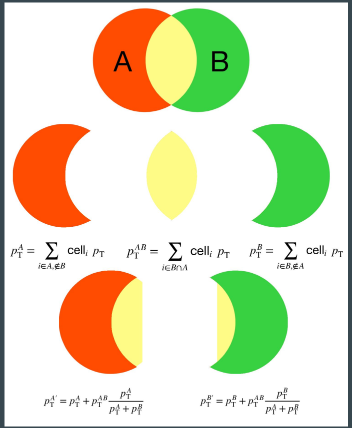
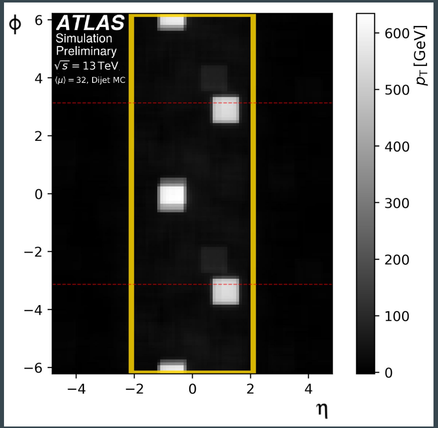


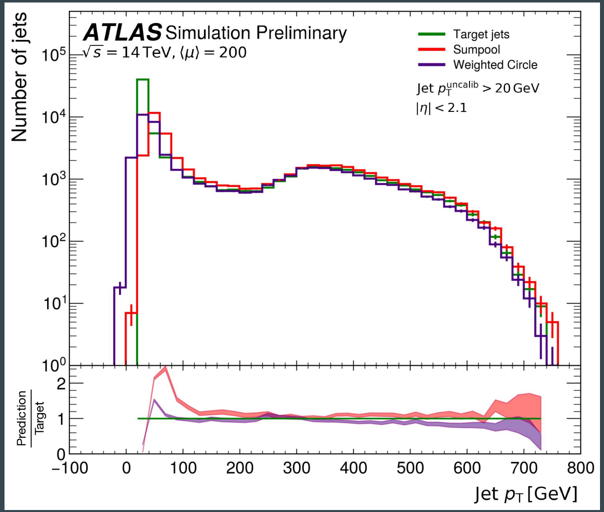
CHEP-traccc

Pileup rejection

- Important to be able to reject background events in early stages of triggering to reduce rate at which CPU intensive algorithms run
  - In particular, particle flow jets run the full detector tracking which is computationally expensive
- Preselection for jet finding that finds jets in calorimeter using CNN and estimates their properties instead of directly reconstructing topoclusters and anti-kT jets





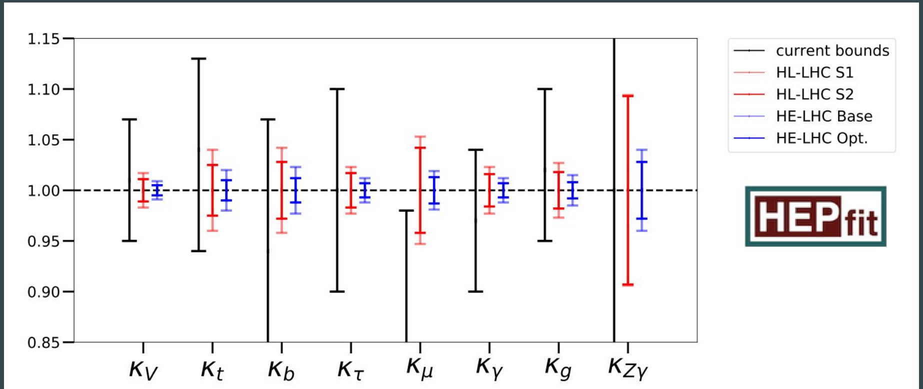


- CPU 12-24 ms/event (topoclustering + antikT calorimeter jets ~100 ms/event)

ATL-DAQ-PUB-2024-003

Intro Physics

- 3000 fb^{-1} is factor of ~10 more data than Run 2+Run 3 so far combined
  - This will grant access to rarer processes such as 4-top or HH production, or rare decay modes
  - Will allow to improve precision for tree-level couplings, and access couplings to 2nd generation fermions (via H->mumu)



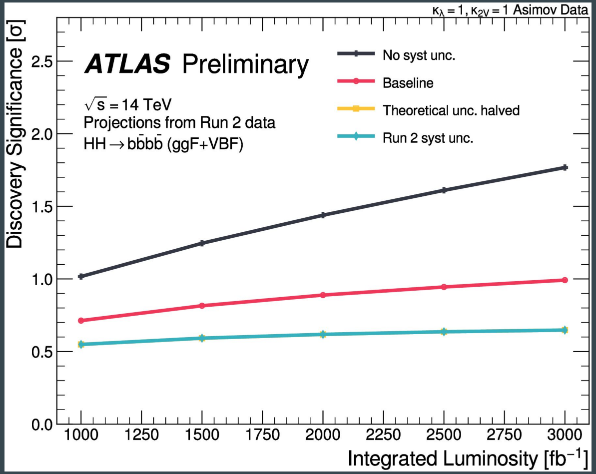
HL-LHC Physics

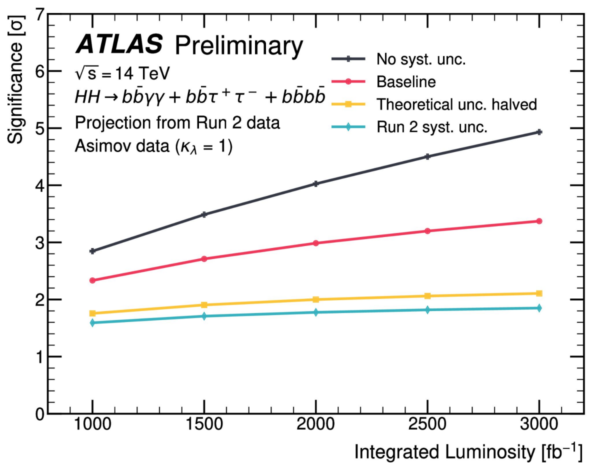
Physics Projections

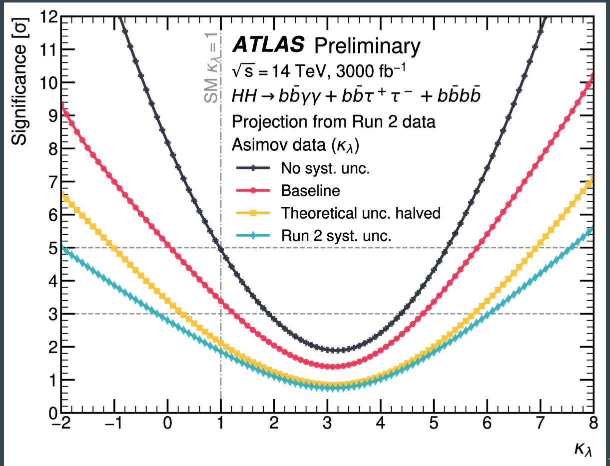
- Projections starting from Run 2 analyses
- Luminosity scaled to 3000 fb^{-1}
- Process dependent scaling of cross sections for 14 TeV center-of-mass energy
- Different uncertainty models considered
  - Usually most conservative is to use Run 2 uncertainties, but other scenarios accounting for increase in luminosity and improved performance also considered

Di-Higgs

- Limited by statistics in Run 2 and 3 due to low cross-section
- Different uncertainty models considered: Run 2 uncertainties, theory uncertainties halved, relevant experimental uncertainties are scaled down according to increased data (baseline), no systematic uncertainties
  - MC (and data driven fake) stat uncertainties scaled by sqrt(L1/L2)



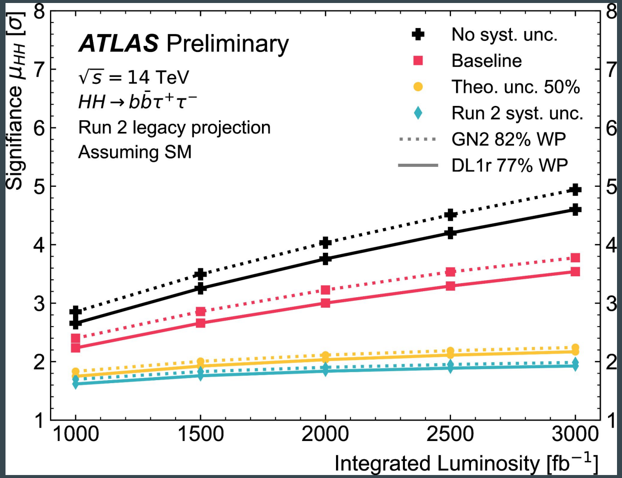


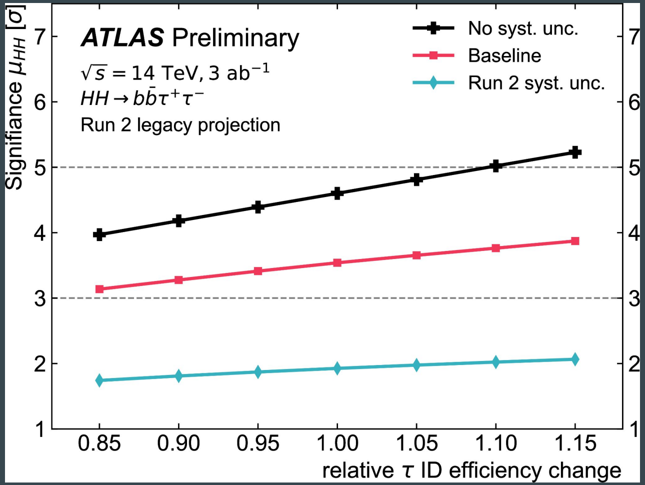


ATL-PHYS-PUB-2022-053

Di-Higgs

- More recent extrapolation for HH->bbtautau
  - Similar to previous studies, but additionally include extrapolation based on improved b-tagging (DL1r (DNN based)->GN2 (GNN based)) and tau-ID performance

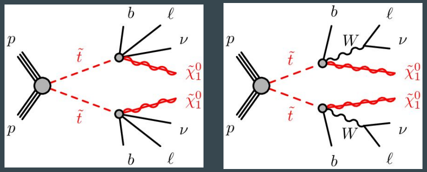


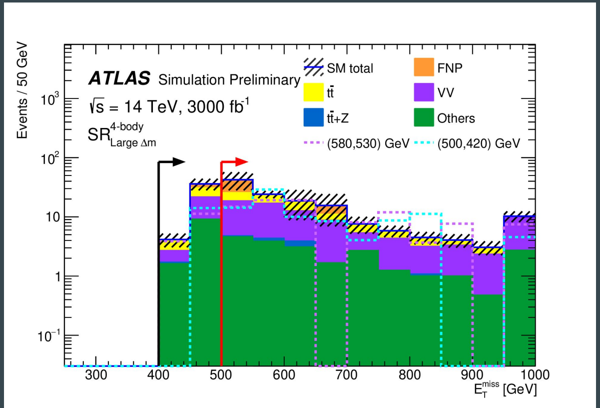


ATL-PHYS-PUB-2024-016

Top squarks

- Based on Run 2 analysis, but with reoptimised event selection to target a wide range of $\Delta m(\tilde{t}_1, \tilde{\chi}^0_1)$, with 3000 fb^{-1}
  - Two selection categories targeting 4-body and 3-body decays





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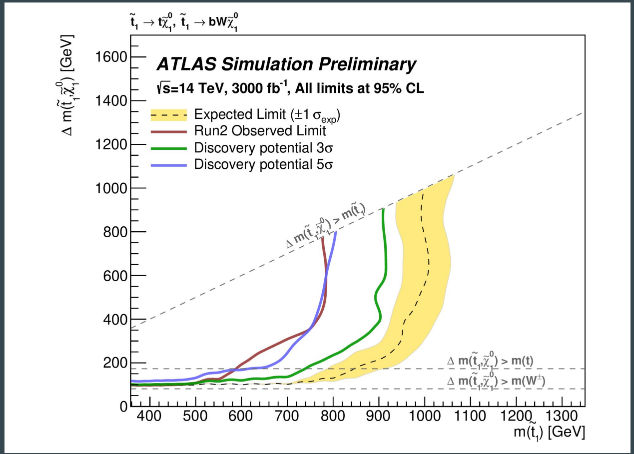
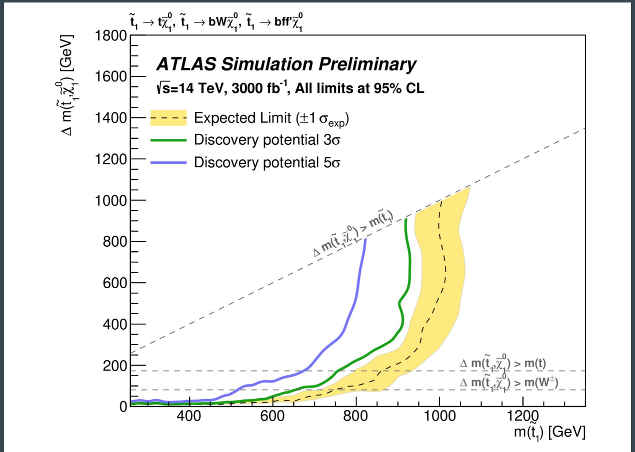


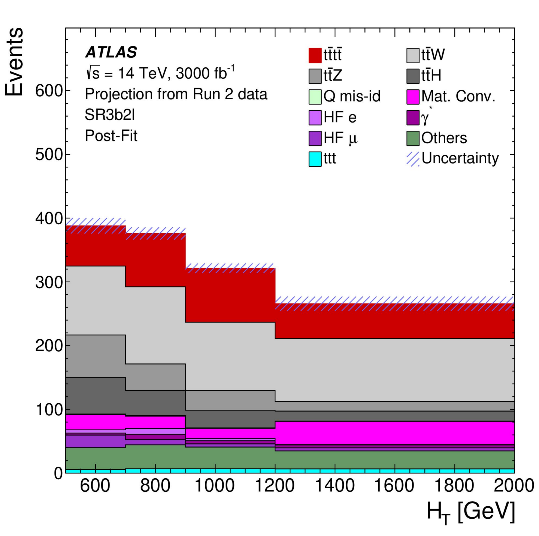
3-body selection

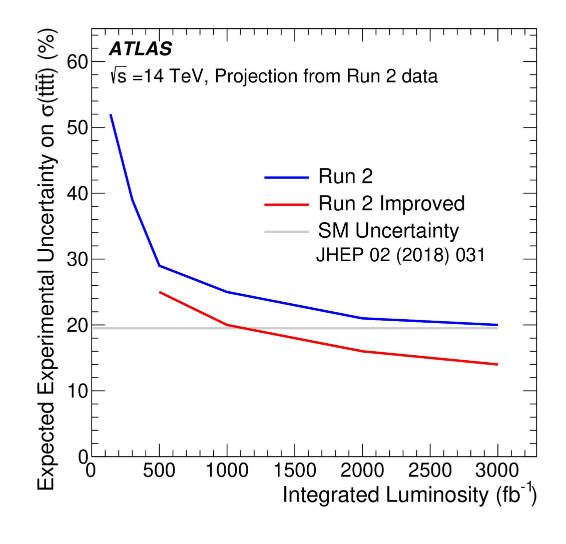


Combined 3-body and 4-body selections

Four top

- Considering $t\bar{t}t\bar{t}$ with two same sign leptons or at least 3 leptons in final state
- Extrapolating from Run 2 analysis, using H_T as fitted variable
  - Two models for uncertainties: one very close to Run 2, and one that assumes decrease in systematic uncertainties due to improvements in statistics, analysis techniques, theoretical predictions

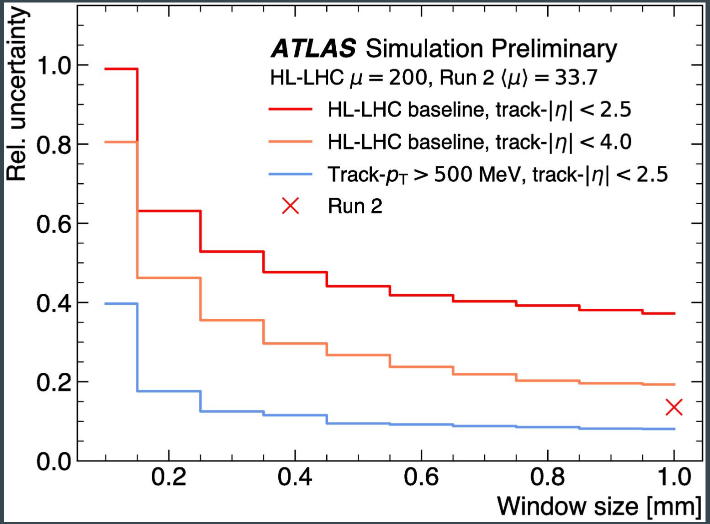


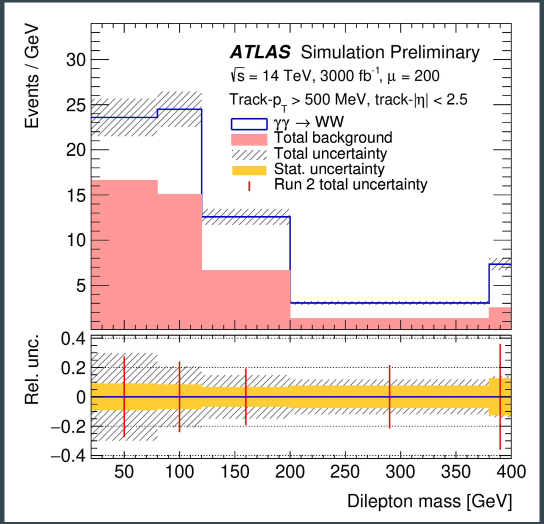


ATL-PHYS-PUB-2022-004

yy->WW

- Explored changes with respect to Run 2 analysis:
  - Exclusivity definition - require n(trk)=0 aside from window around lepton - varied size of window
  - Lower minimum track pT
  - Extended track acceptance to |eta|<4.0





ATL-PHYS-PUB-2021-026

Summary

- ATLAS preparing for HL-LHC
- Detector upgrades in production mode in many cases
- Offline and Online reconstruction being updated to handle new detectors and optimised for more challenging conditions
- Looking forward to the exciting physics opportunities that 3000 fb^{-1} will bring

Backup