

Triggering

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on behalf of the ATLAS and CMS Collaborations

LHCP, 16-20 May 2022



Trigger

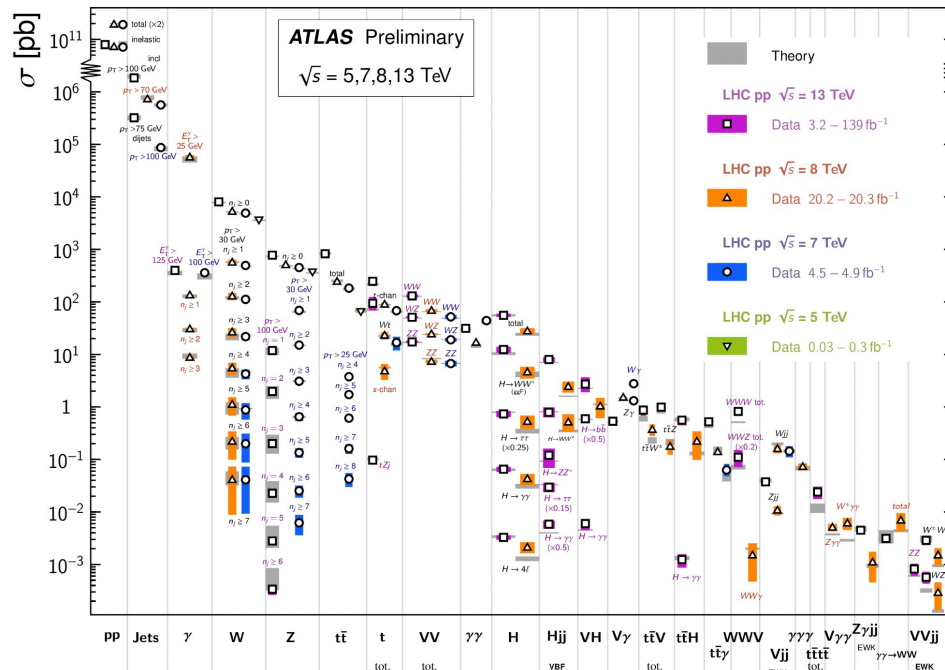
- **Online event selection for permanent storage**
- The trigger decision is irrevocable, not selected events are lost forever
- Rate reduction: 40 MHz \rightarrow O(1 kHz) :
 - ttH \sim 0.01 Hz expected @ 13 TeV, 2e34
- Literally like finding a needle in a haystack



Room on the Broom

Standard Model Production Cross Section Measurements

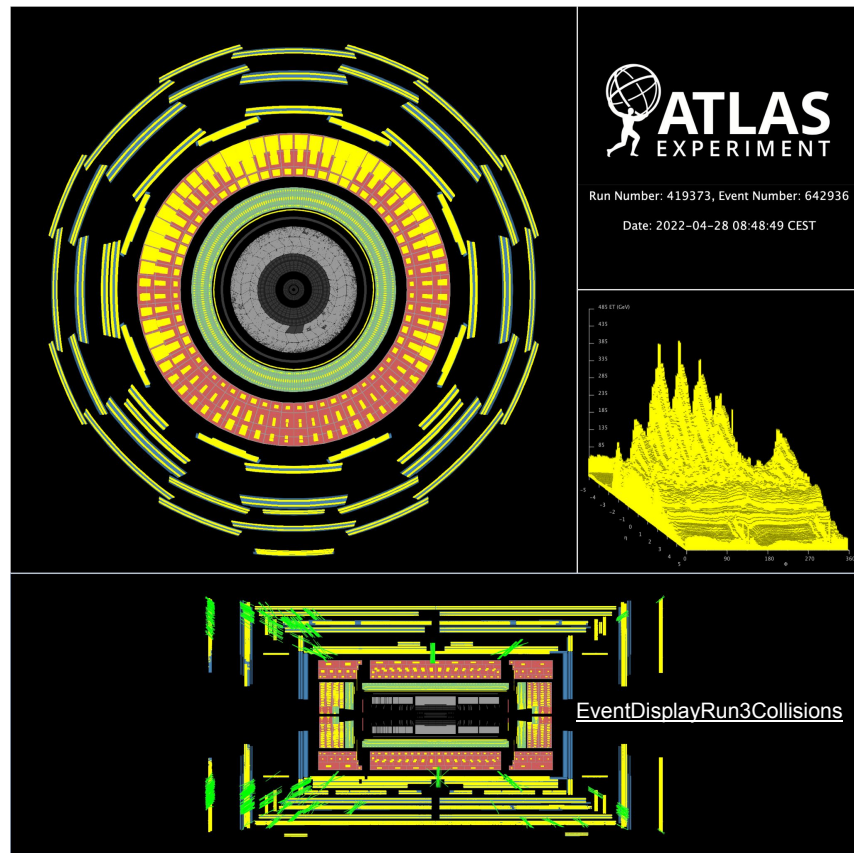
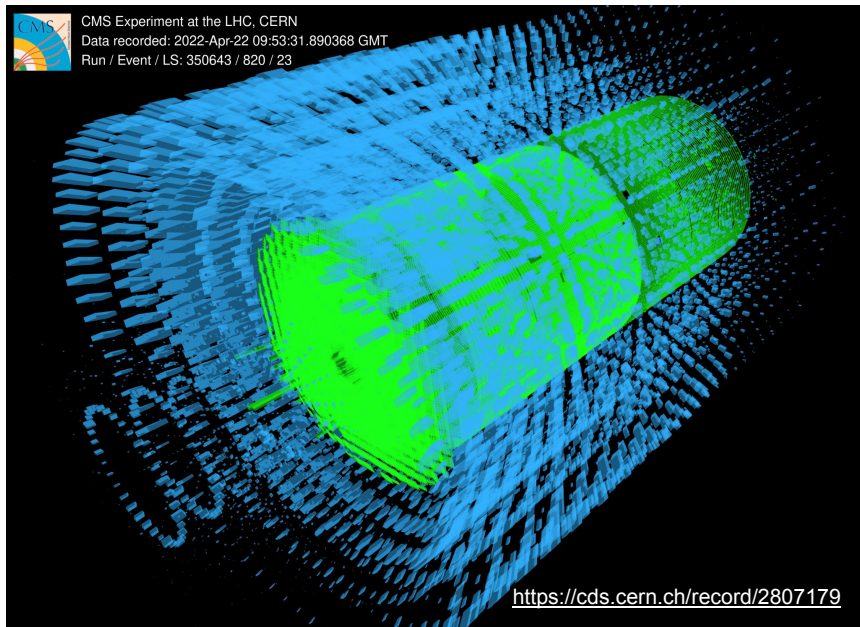
Status: February 2022



ATL-PHYS-PUB-2022-009

Run 3 has started!

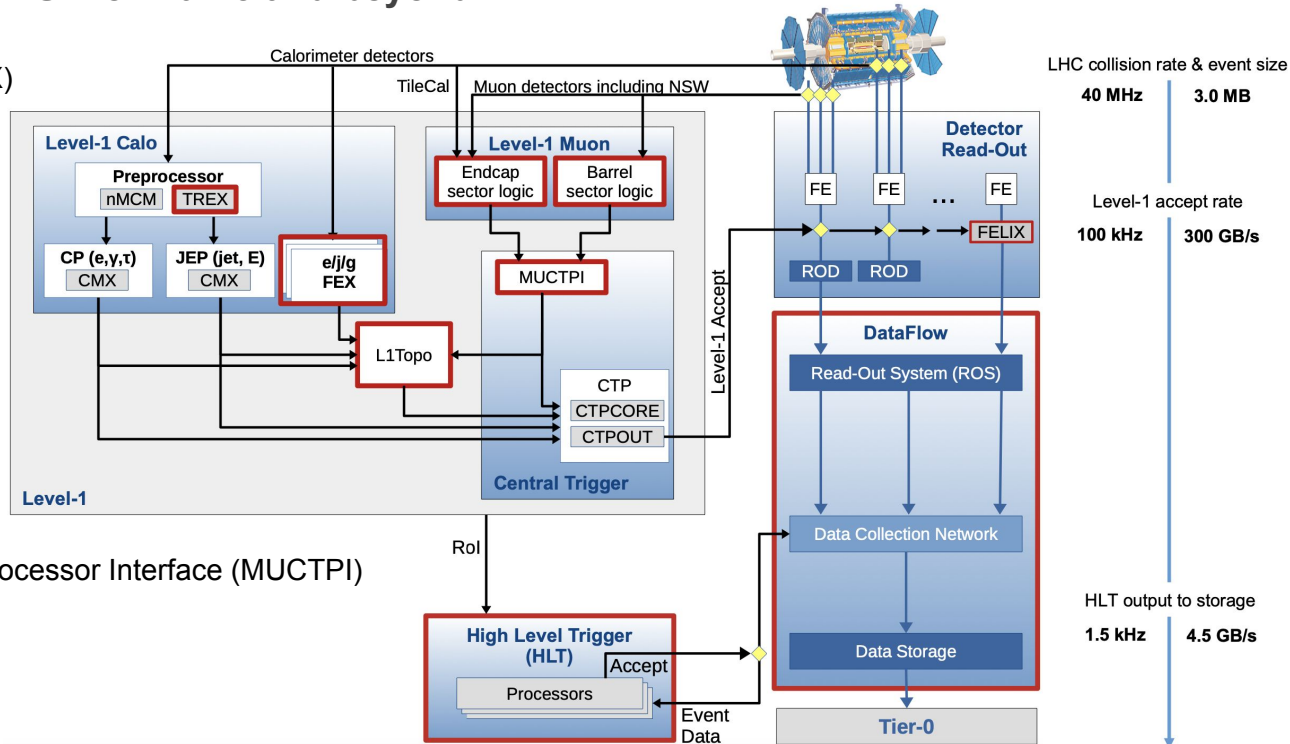
Beams in the machine since 22 April!
2022 beam splashes seen by ATLAS and CMS
LHC commissioning: 900 GeV \rightarrow 13.6 TeV
Very exciting time ahead of us!



Run 3 Trigger and Data Acquisition system

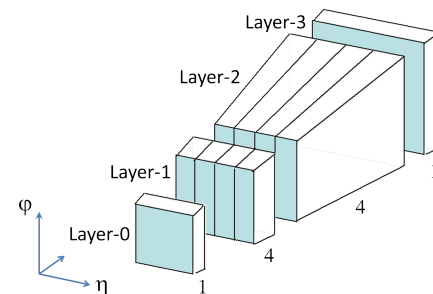
New hardware installed during LS2 for Run 3 and beyond:

- **Level-1 Calo:**
 - Tile Rear Extension (TREX)
 - e/j/gFEX
- **Level-1 Muon:**
 - New Small Wheel
 - RPC BIS78
 - Barrel Sector Logic
 - Endcap Sector Logic
- **L1Topo:**
 - 1 object-counting board
 - 2 multi-object topological combination boards
- **Central Trigger:**
 - Muon to Central Trigger Processor Interface (MUCTPI)
- **FELIX** readout
- **ROS** refurbishment
- **HLT** farm upgraded



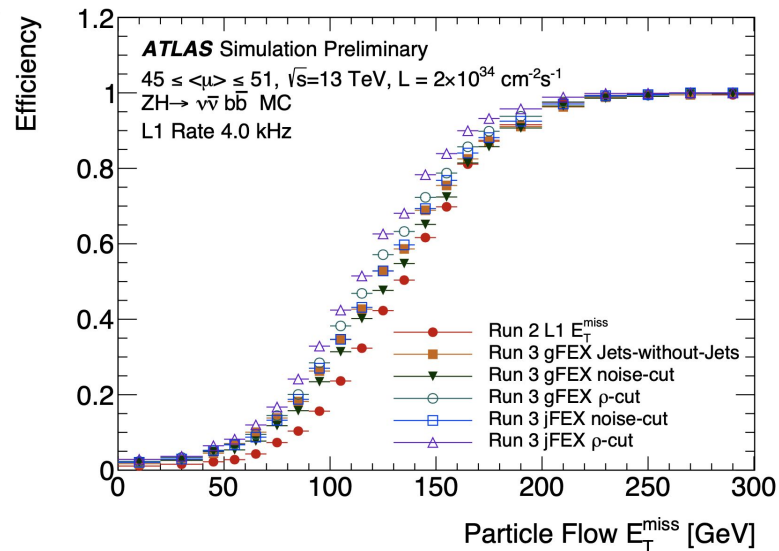
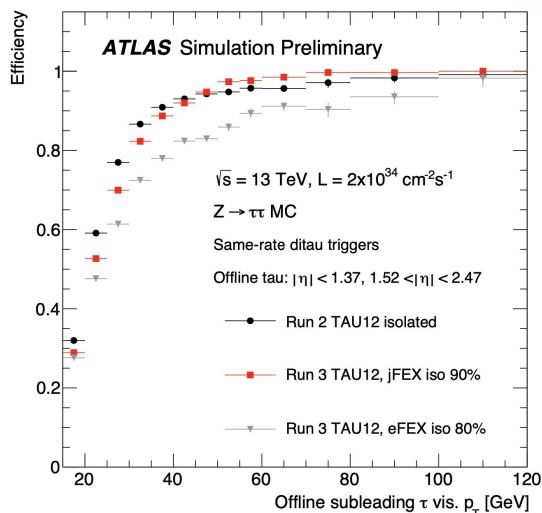
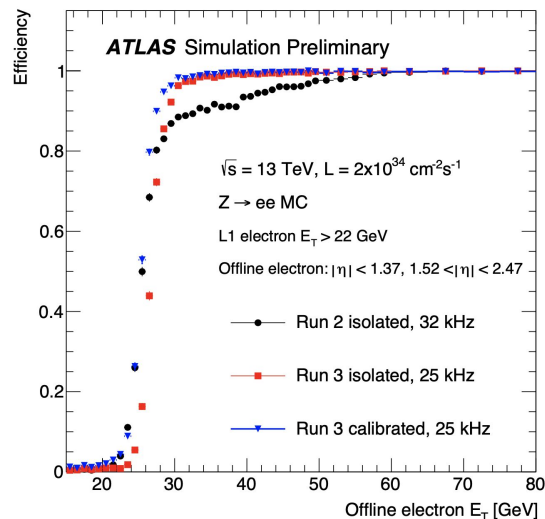
ATLAS Phase-I upgrades for Run 3

- **Phase-I LAr upgrade ([ATLAS-TDR-022](#)):**
 - Finer granularity LAr digital signal to L1Calo:
 - Run 2: 0.1 x 0.1 trigger tower
 - Run 3: 10 E_T values from “1-4-4-1” samples (SuperCells)
- **Phase-I TDAQ upgrade ([ATLAS-TDR-023](#)):**
 - TREX (Tile Rear Extension): digitizes analogue signals from Tile for the FEX processors
 - electron/jet/global Feature EXtractors (e/j/gFEX)
 - L1Topo: Increase number of p_T thresholds for L1Calo based triggers
 - L1Muon Sector Logic: finer p_T granularity and charge information available for the muon endcaps
 - MUCTPI: Increase number of p_T thresholds for L1Muon based triggers
- **Phase-I New Small Wheel ([ATLAS-TDR-020](#)):**
 - Reduction of rate dominated by fakes in the endcaps ($1.3 < |\eta| < 2.7$)
- **Phase-I RPC BIS78:**
 - Fake rejection in the Barrel-Endcap transition region ($1 < |\eta| < 1.3$)



In Run 3:

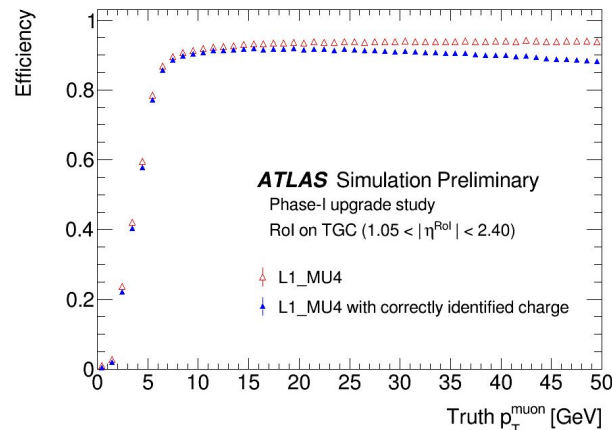
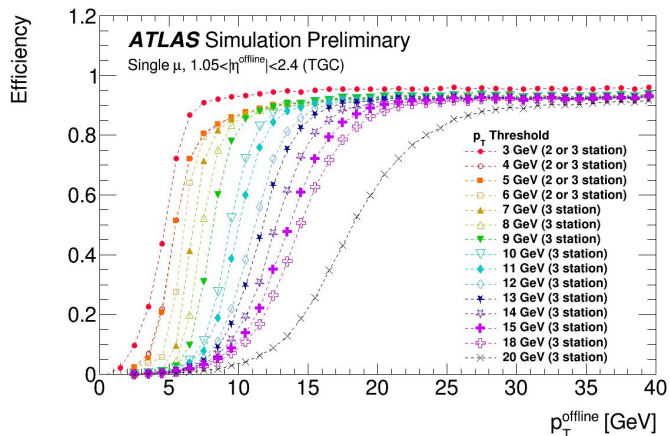
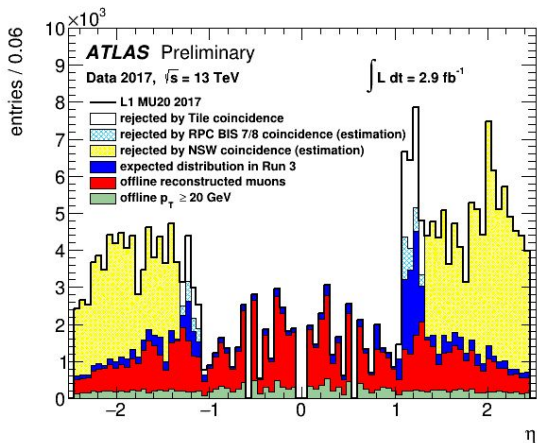
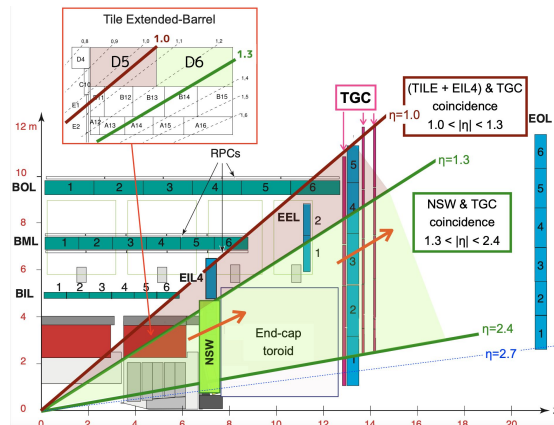
- **L1 eFEX EM trigger:** sharper turn-on curve and 20% rate reduction with respect to the legacy Run 2 trigger by applying more sophisticated jet discriminant cuts (R_{η} , R_{had} , w_{stot}) using the higher LAr calorimeter granularity
- **L1 combined (eFEX/jFEX) TAU trigger:** isolation requirement on jFEX matches Run 2 ditau trigger performance
- **L1 jFEX and gFEX MET trigger:** various algorithms proposed, outperforming the legacy Run 2 trigger for same rate



Phase-I L1Muon

Important improvements in the L1Muon endcap for Run 3:

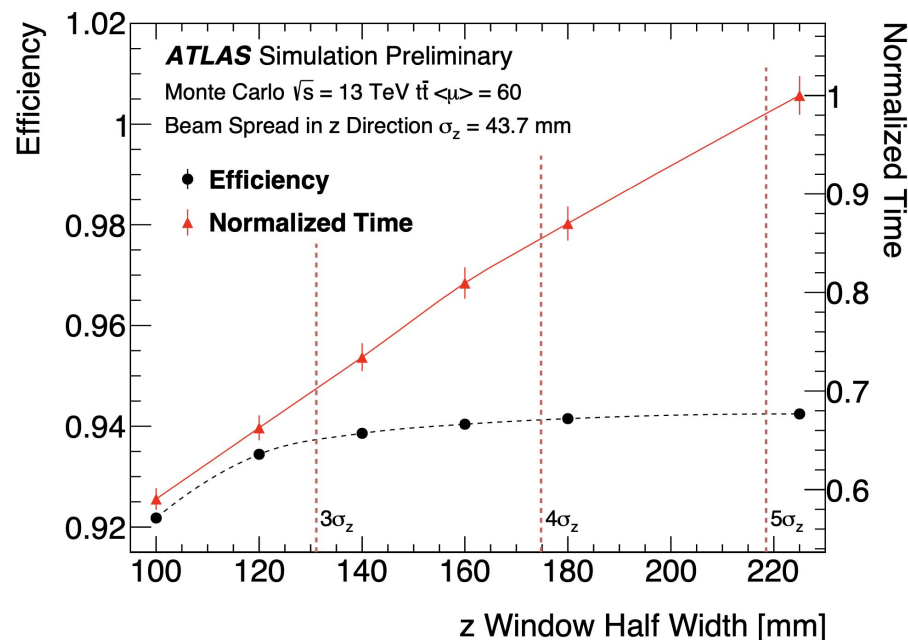
- Rate dominated by fakes in the endcap in Run 2 will be suppressed in Run 3 by requiring TGC coincidence with NSW ($1.3 < |\eta| < 2.7$) and RPC BIS78 ($1 < |\eta| < 1.3$)
- Higher p_T granularity available for the muon endcaps can be used to improve dimuon invariant mass resolution used for L1 B-physics triggers
- Muon charge information will be exploited to further reduce L1Muon rate in the endcaps



HLT improvements for Run 3

- HLT software framework fully redesigned to be **multi-threaded compliant** (AthenaMT for Run 3)
- **Run 3 trigger menu** selections aligned with latest offline reconstruction techniques
- **Full scan tracking** to be used for hadronic signatures
 - Processing time optimization as tracking is CPU intensive by using dynamic RoI size
- **Large radius tracking** to increase acceptance for displaced signatures, long-lived particles
[\[ATL-PHYS-PUB-2017-014\]](#)
- **Egamma**: moving from sliding window reconstruction to superclusters (as offline) [\[JINST 14 \(2019\) P12006\]](#)
- **Jet**: moving from EM topological clusters to Particle Flow reconstruction (as offline) [\[EPJC 77 \(2017\) 466\]](#)
- **b-jet**: moving from MV2 to the more performant DL1 tagger (multivariate classification algorithm based on deep learning techniques) [\[ATL-PHYS-PUB-2017-013\]](#)

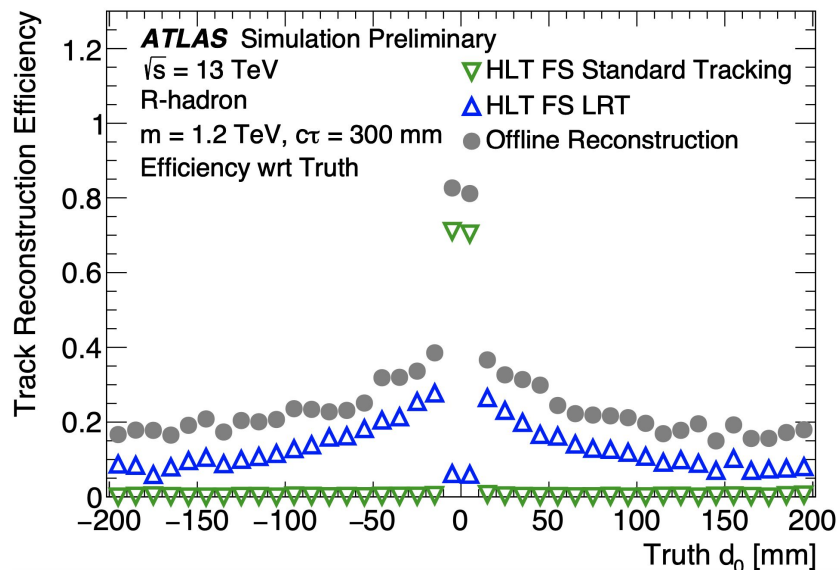
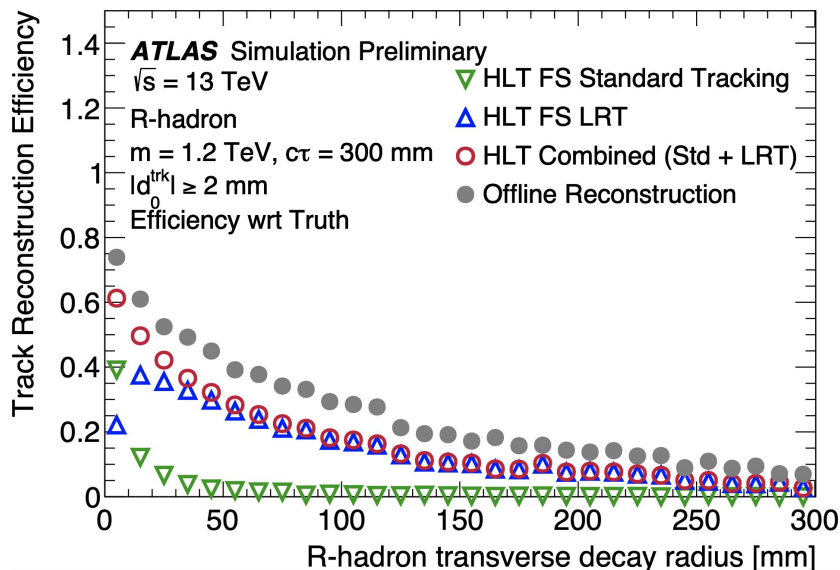
See [Zuchen Huang's poster](#)



HLT improvements for Run 3

- Standard tracking optimized for particles that point back to the interaction point with displacements of a few mm
- Large radius tracking targets charged particles with displacements up to 300 mm improving acceptance for long-lived particles

See [Benjamin Philip Kerridge's poster](#)

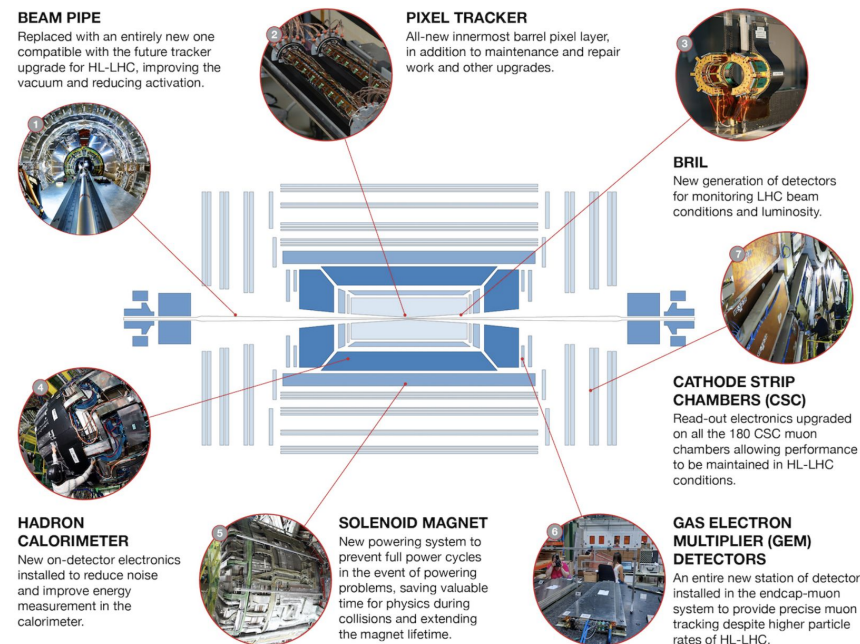


CMS Phase-I upgrades for Run 2 and 3



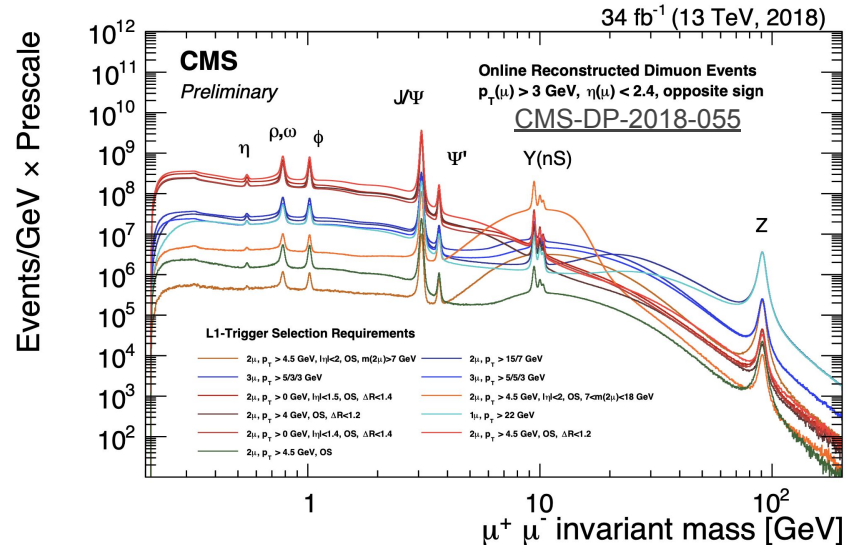
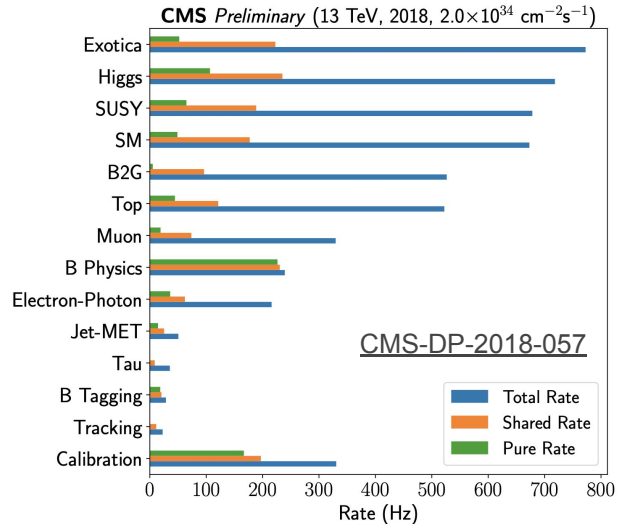
- Level-1:
 - Phase-I L1 trigger upgrade [[CMS-TDR-12](#)] in 2016 exploited finer calorimeter granularity to give better energy and position resolutions while remaining within rate constraints
 - Run-2 L1 trigger performance benefitted from pileup subtraction [[JINST 15 \(2020\) P10017](#)]
- HLT:
 - In Run-2, HLT included improvements from:
 - Phase-I Pixel Upgrade [[CMS-TDR-11](#)] (during LHC EYETS 2016-2017)
 - Phase-I HCAL Upgrade [[CMS-TDR-10](#)]
 - Endcap included in 2018, but not exploited in the trigger
 - Barrel completed in 2019
 - 30k CPU cores at the end of Run 2

<https://home.cern/press/2022/CMS-upgrades-LS2>



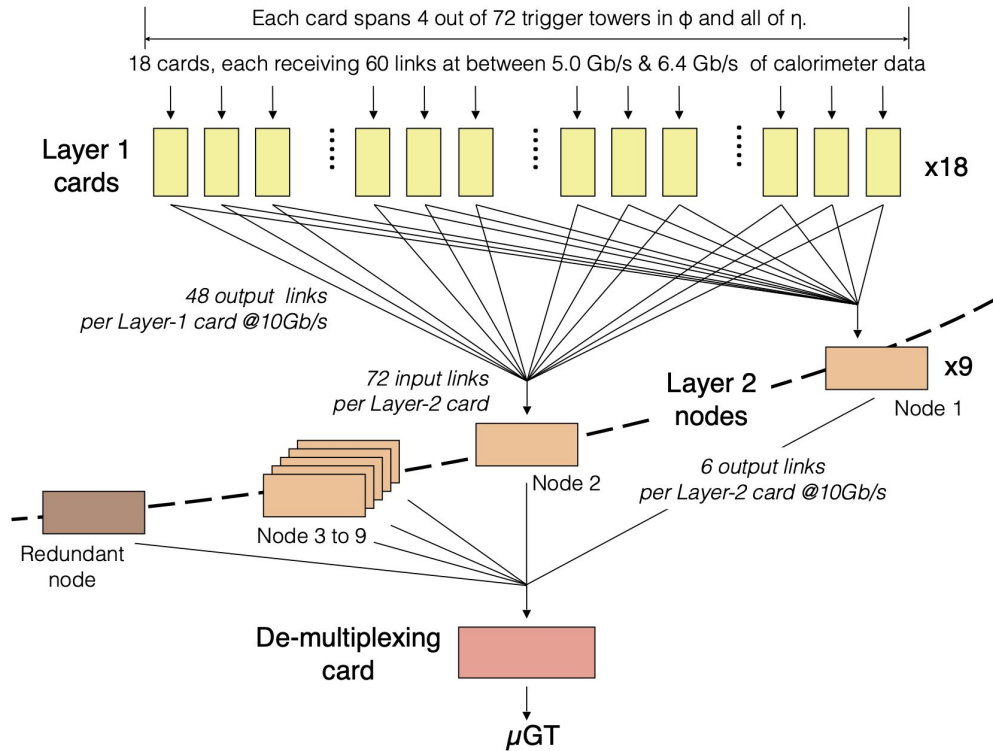
Run 2 Trigger highlights

- Level-1 results: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/L1TriggerDPGResults>
- HLT results: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/HighLevelTriggerRunIIResults>
- Non-conventional trigger program:
 - Well established CMS scouting program
 - Data parking for B-physics: unbiased B hadron sample collected at 2 kHz and 2 GB/s in average (<https://doi.org/10.1051/epjconf/202024501025>)

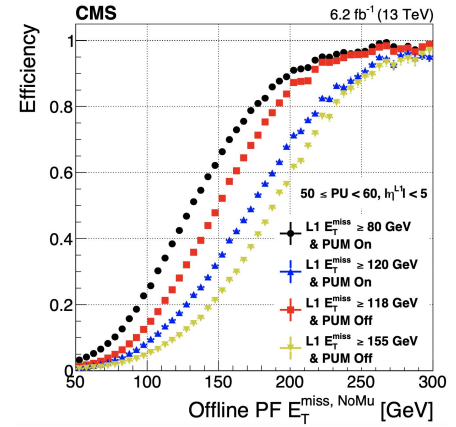


Run 2 Trigger highlights

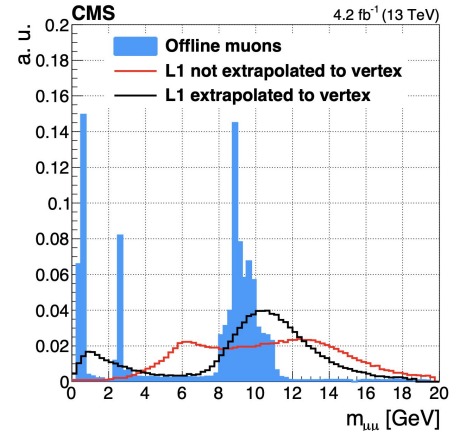
Time multiplexing for L1 calo trigger allowing to process a full event



Pileup mitigation for MET (better turn on for same rate)



L1 invariant mass reconstruction, used in several dimuon B-physics seeds

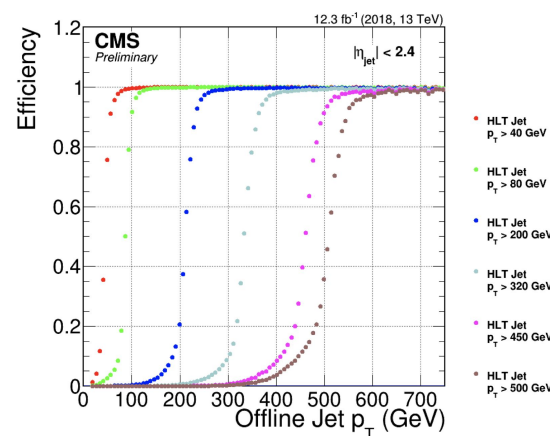
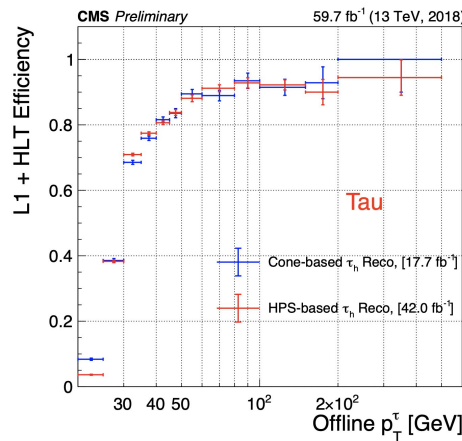
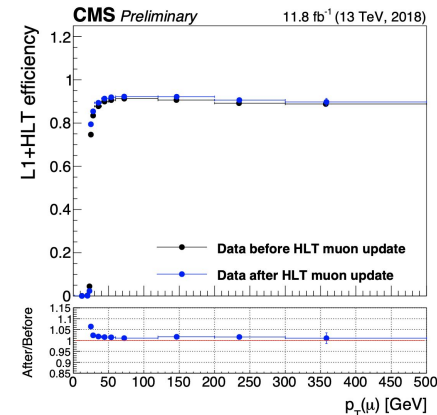
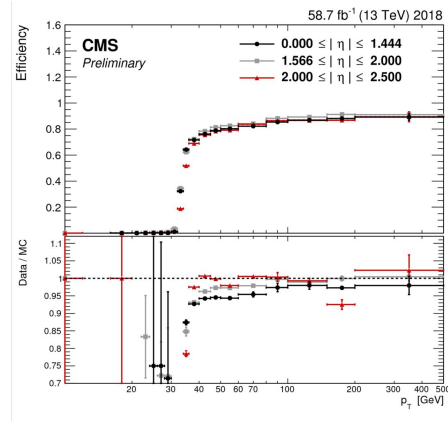


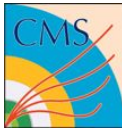
Run 2 Trigger highlights



HLT efficiencies in 2018:

- [CMS-DP-2020-016](#): Efficiency of HLT_Ele32_WPTight_Gsf with respect to offline candidates for different $|\eta|$
- [CMS-DP-2018-034](#): Efficiency of the isolated single muon with $p_T > 24$ GeV with respect to offline candidates requiring tight identification and Particle Flow isolation
- [CMS-DP-2019-012](#): Hadron-Plus-Strip (HPS) based algorithm compared to cone based algorithm for taus, efficiency for a $\mu\tau_h$ trigger with respect to offline taus
- [CMS-DP-2018-037](#): Efficiency of the jet triggers with respect to offline candidates using anti- k_t $R=0.4$ and Particle Flow for $|\eta| < 2.4$





Run 3 Trigger improvements

Run 3 preparation: <https://ep-news.web.cern.ch/content/cms-experiment-prepares-run-3>

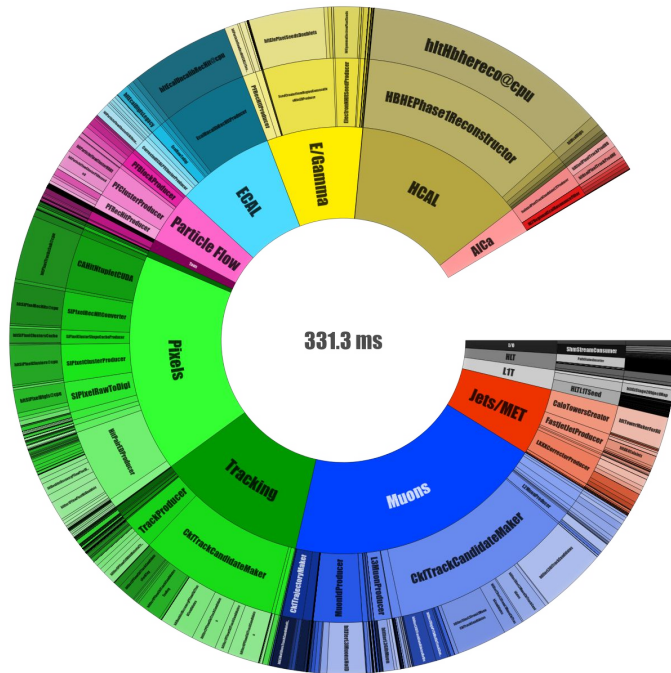
- Planning to start using a heterogeneous architecture for the online reconstruction, comprising CPUs and GPUs:
 - The HLT system will be equipped with GPUs in order to accelerate some online reconstruction tasks
 - Part of the HLT reconstruction, namely pixel and pixel-based tracking, and ECAL and HCAL local reconstruction have been already ported and are able to run on GPUs for a total of 25% of CPU time offload to GPU
 - Porting of more code, including particle flow algorithms, is envisioned in the near future
 - GPU reconstruction is more efficient and will allow track reconstruction on a larger fraction of the events triggered at Level 1, increasing the sensitivity of the scouting program to lower masses
- Boost the non-conventional trigger program further:
 - Dedicated LLP triggers implemented at L1 to expand physics reach
 - CMS' scouting program will be expanded in scope, this is based on the idea of carrying out analysis only using the information reconstructed in real time from both L1 and HLT
 - Data parking for B-physics

Run 3 HLT menu timing

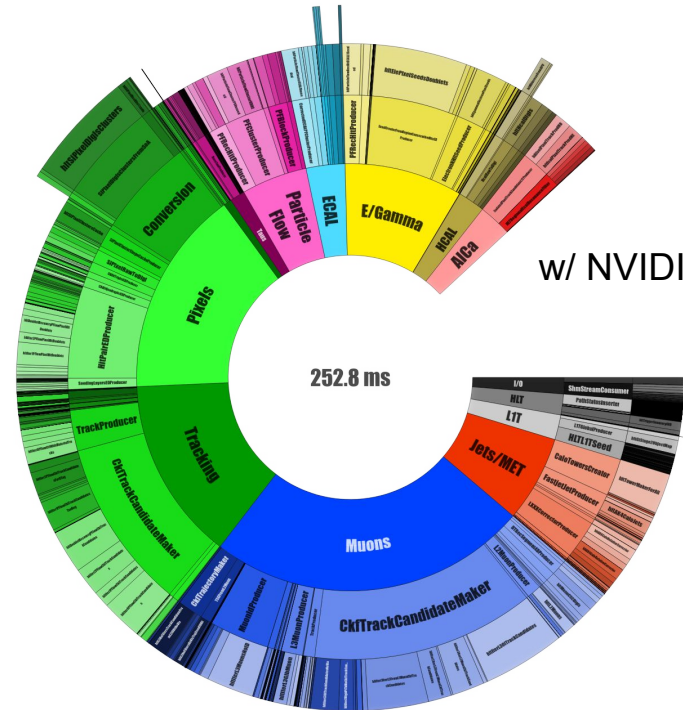
Exercise heterogeneous GPU architecture [[PhaseIIHLTRecoAndGPUPerformance](#)]

4 jobs in parallel, with 32 threads each, on a full node (2× AMD “Rome” 7502) with SMT enabled

w/o GPU



w/ NVIDIA T4 GPU



Conclusions



- LS2 and Phase-I upgrades will bring many improvements delivered by both experiments
- ATLAS:
 - Phase-I L1Muon endcap improvements will reduce fakes with NSW, TGC SL, MUCTPI
 - Phase-I LAr / L1Calo will allow higher granularity, more sophisticated algorithms and higher efficiencies / resolutions
 - Brand new HLT software framework with better sharing of offline code, MT compliant
 - Run 3 trigger menu aligned with most performant offline reconstruction techniques
- CMS:
 - Exploit Phase-I upgrades
 - Heterogeneous architecture for the online reconstruction, comprising CPUs and GPUs
 - Boosting the non-conventional trigger program further
- ATLAS and CMS trigger systems ready for Run 3 data taking
- Run 3 just around the corner!