Physics Motivation for Detector and Trigger Upgrades at HL-LHC

Bryan Dahmes (Minnesota)

Introduction

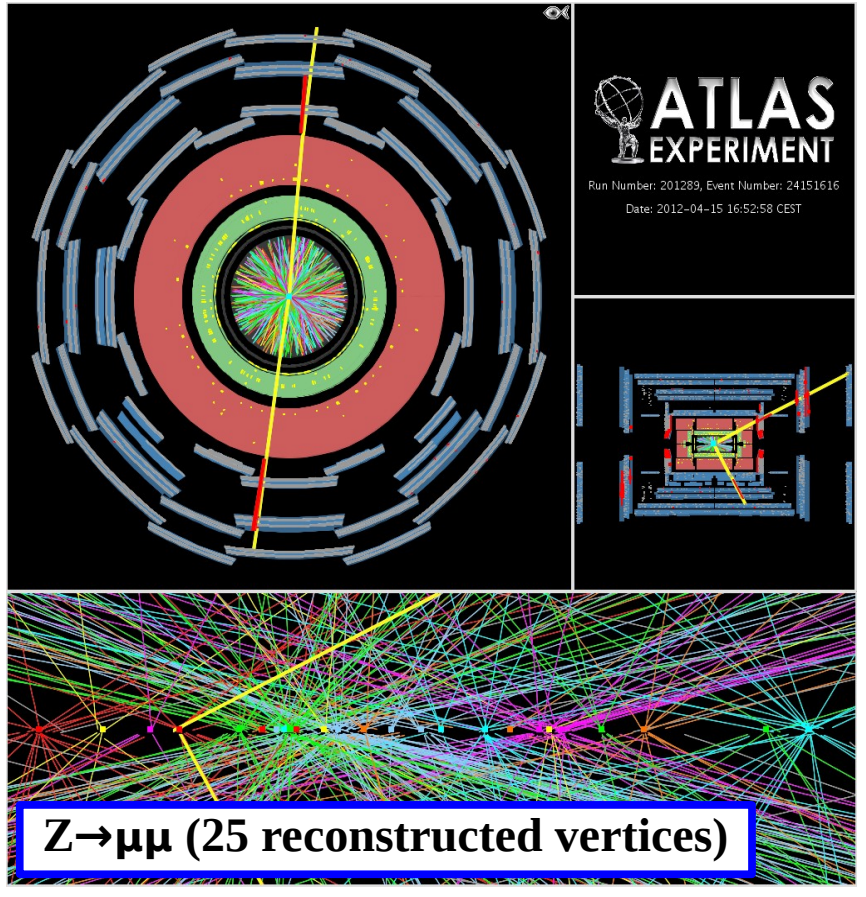
- Rich physics program anticipated at HL-LHC
  - Precision Higgs measurements, rare decays
    - Is the 125 GeV Higgs SM? Other Higgs bosons?
  - Search for New Physics signatures, study the properties of particles discovered in Run 2+
- Degraded performance for current ATLAS and CMS detectors in HL-LHC environment
- Sensitivity to HL-LHC physics will require detector upgrades
  - Tracker replacement due to radiation damage, high occupancy
    - Upgraded tracker must be able to handle HL-LHC occupancies
  - Trigger upgrade to deal with inst. luminosity of 5×10^{34} $cm^{-2}s^{-1}$
- Upgrades can improve our physics sensitivity
  - Demonstrate the positive impact of upgrades on physics objects

Simulation

- ATLAS detector response functions derived using full simulation
  - 300 fb^{-1} scenario assumes 50,80 PU events on average
    - Includes IBL and LAr trigger upgrades
  - 3000 fb^{-1} scenario assumes 140,200 PU events
    - Includes ITK
- CMS detector response uses a combination of full and fast (DELPHES) simulation
  - Phase 1 detector with PU=0, 140
    - Phase 1 PU=140 scenario used for comparison of full simulation and DELPHES
  - Two Phase 2 detector (PU = 140) scenarios considered using DELPHES
    - “Configuration 3”
      - Replace ECAL endcap, retrofit HCAL endcap
      - Phase 2 tracker in barrel, endcap
      - Full muon system coverage to $|\eta| < 2.4$
    - “Configuration 4”
      - Full endcap calorimeter replacement
      - Full tracker, muon coverage to $|\eta| < 4.0$

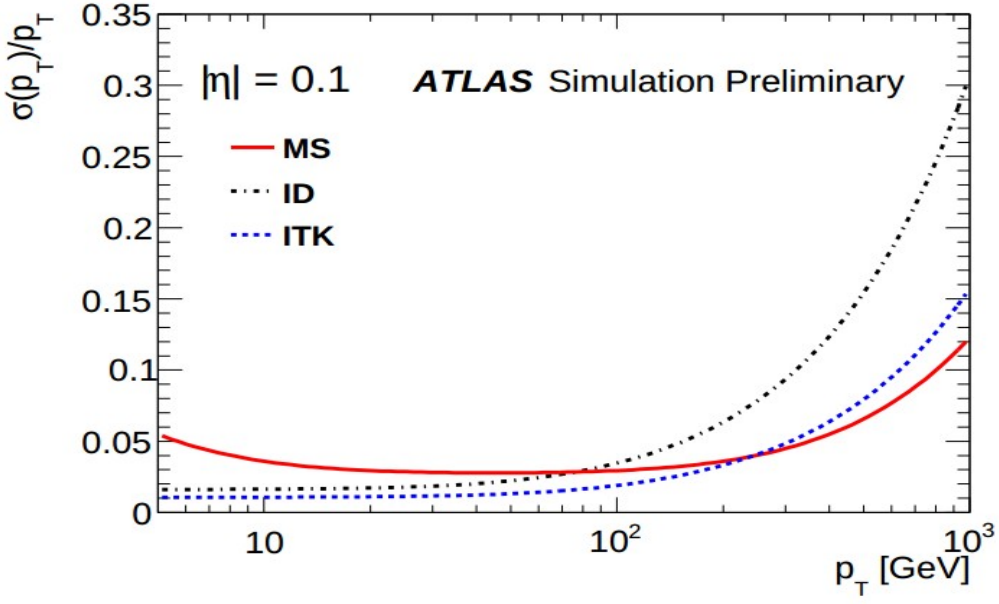
Tracker Upgrade

- Tracker performance critical to the success of HL-LHC physics program
  - Lepton, photon identification and isolation
  - b-jet tagging, jet energy, missing E_T
    - Remove jets produced from pileup collisions
    - Pileup mitigation via track-based missing E_T
  - Reconstruct primary vertices, identify interesting hard scatter
- Upgraded tracker must be able to handle HL-LHC occupancy
  - Balance track efficiency vs. rate of fake tracks
  - Flexibility for high pileup scenarios (going beyond 140 PU events)

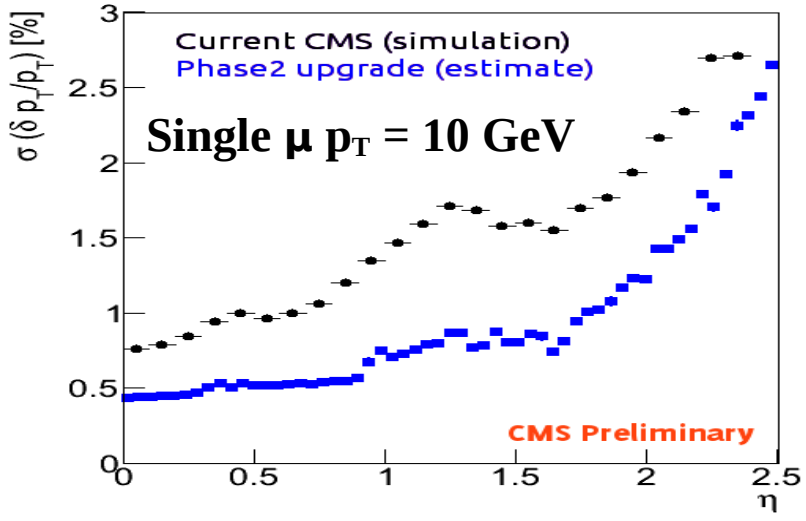


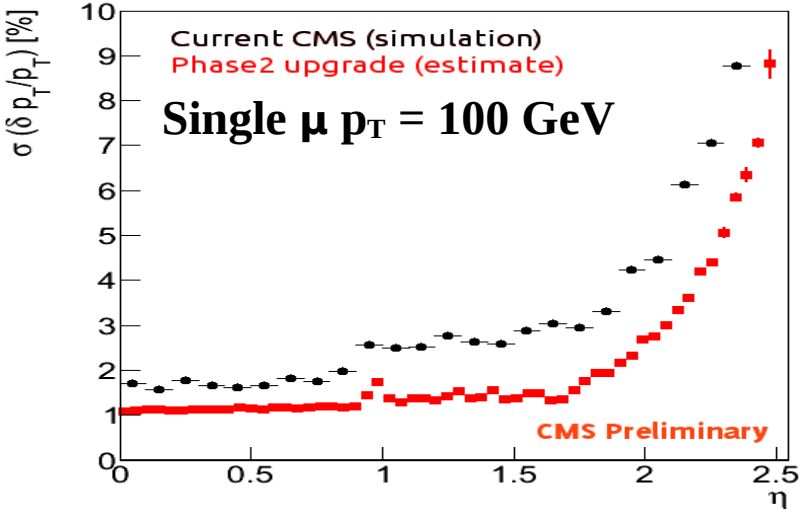
Muon Performance

- Muon p_T resolution comparisons between existing trackers and Phase 2 upgrades
- Important gains seen for low p_T muons with the upgrade
  - Excellent resolution needed to maximize H→μμ sensitivity



Transverse momentum resolution

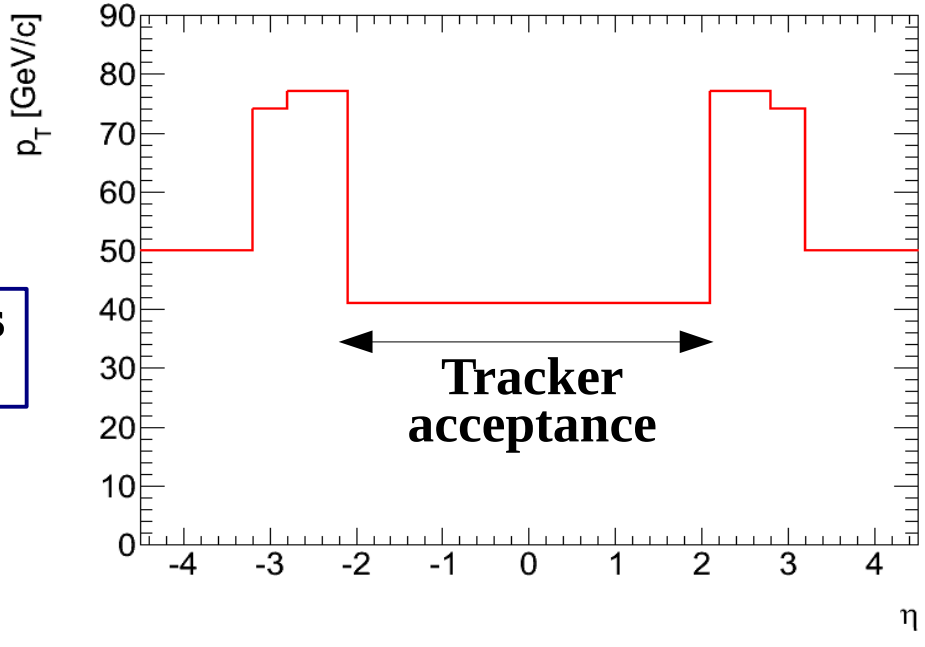




Jet Performance

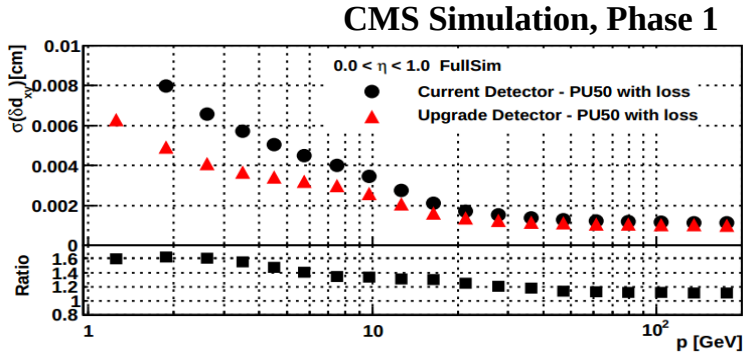
- Jets combine calorimeter deposits with track information when available
- Pileup is a serious problem for jet reconstruction in HL-LHC era
  - Jet thresholds can be set to minimize pileup contamination
  - Tracker coverage enhances pileup suppression
- Increased p_T thresholds beyond tracker acceptance limits sensitivity to physics

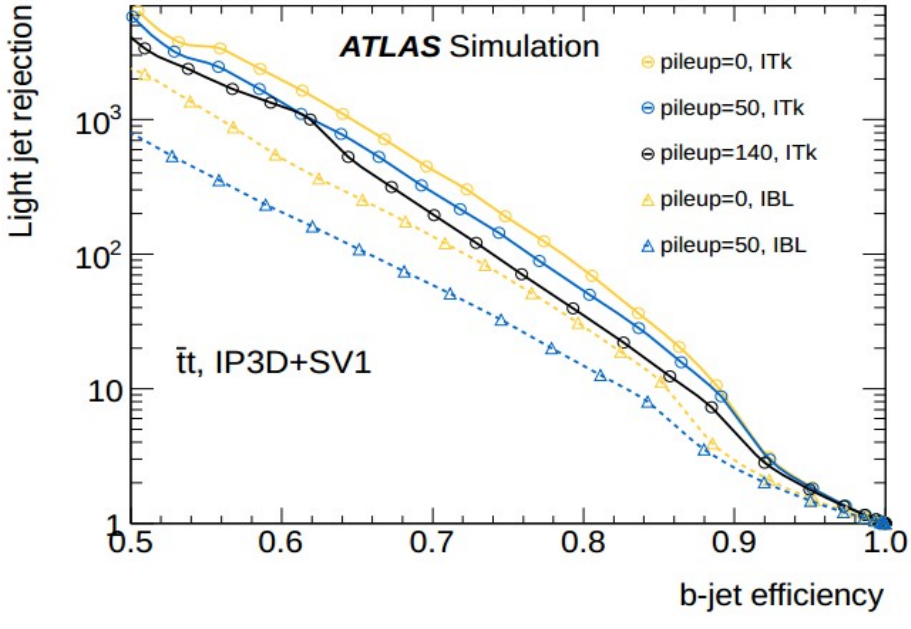
(ATLAS, PU=140) Jet p_T thresholds necessary for 1% pileup fake rate

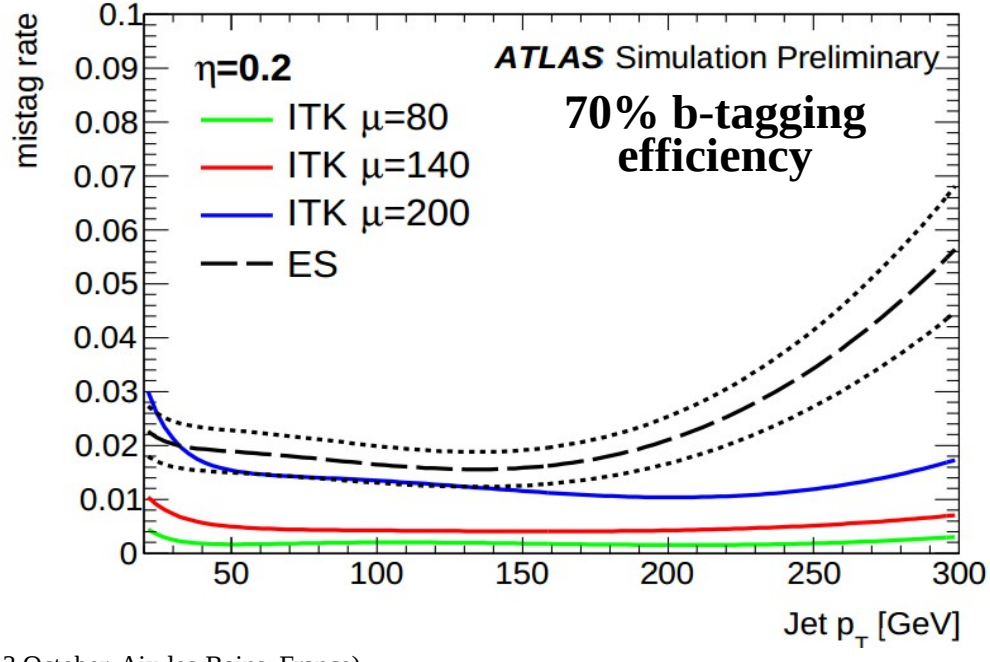


B-Jet Tagging

- Upgraded tracker improves b-tagging performance
  - Additional layers
  - Inner layer closer to beam pipe
  - Smaller pixel sizes, improved granularity
  - Reduced detector mass

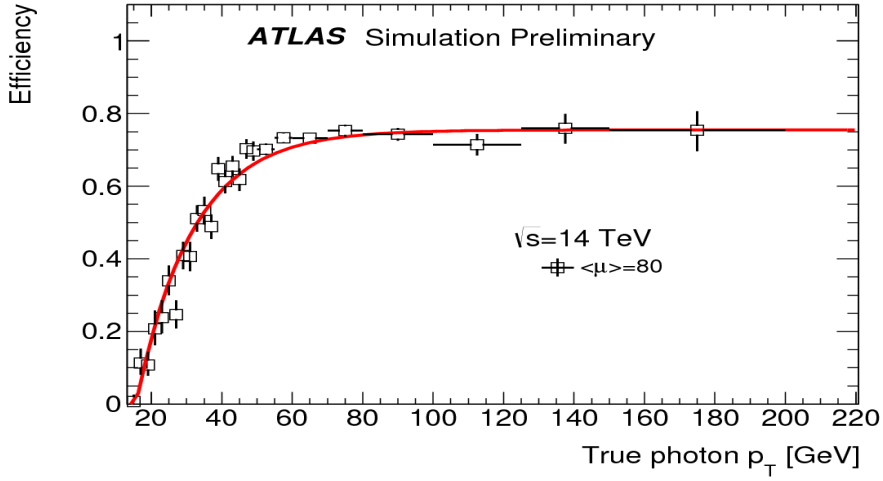


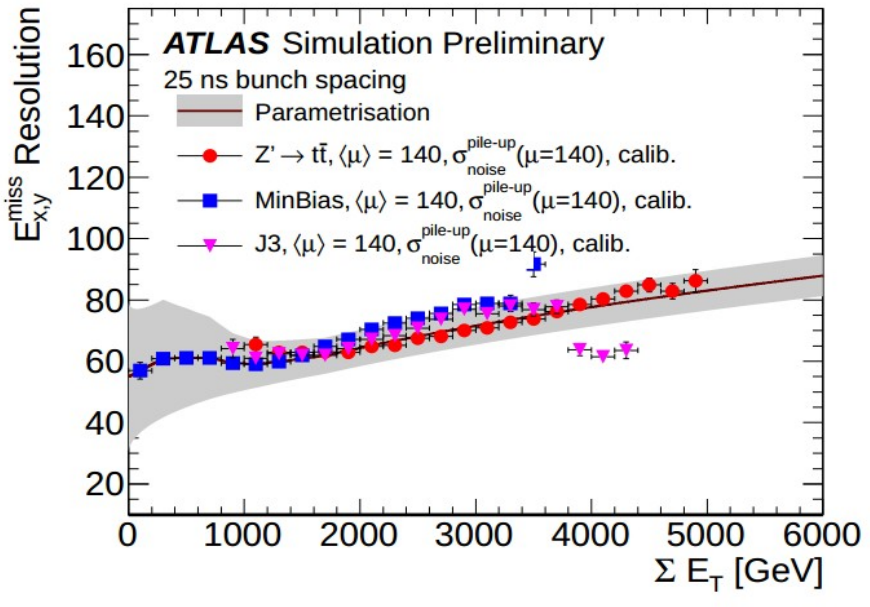




Additional Object Performance

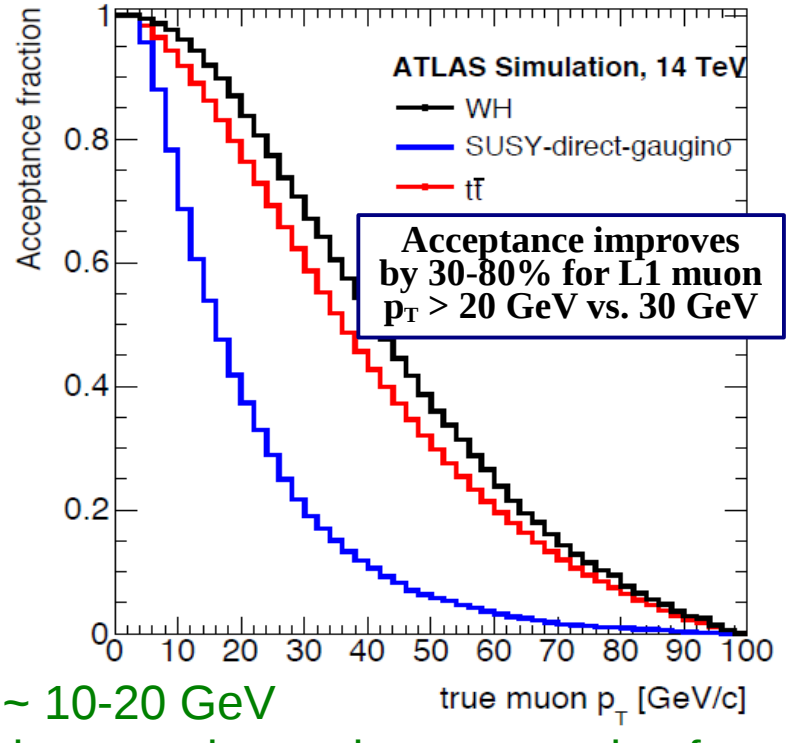
- ATLAS Photon ID and isolation efficiency using current algorithms and PU=80
  - Expected to apply to PU=140 after tuning
- ATLAS missing E_T parametrization





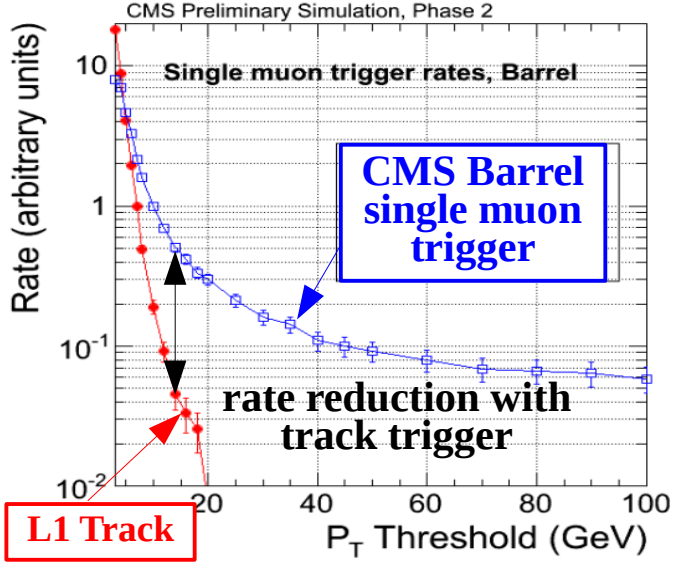
Trigger Upgrade

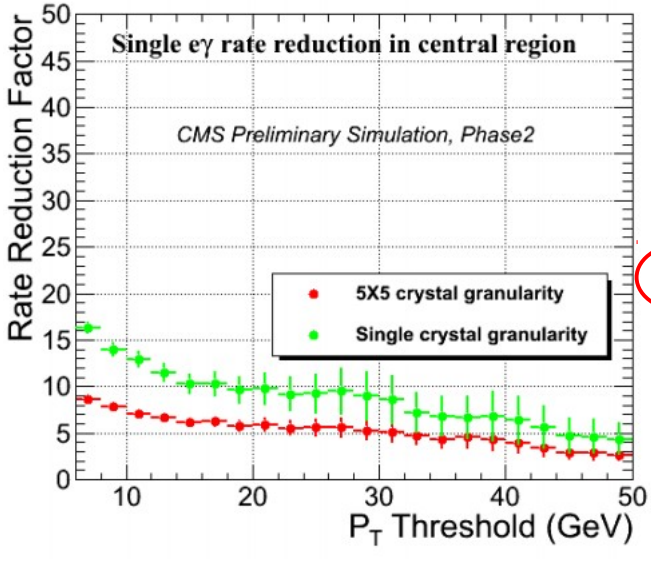
- Maintaining our current physics sensitivity at HL-LHC challenging for trigger
  - EWK, top (and Higgs) scale physics remain critical for HL-LHC
  - 100 kHz L1 bandwidth saturated in 2012 with instantaneous luminosity below 10^{34} $cm^{-2}s^{-1}$
  - Cannot fit the same "interesting" physics events in the trigger at 14 TeV, $5x10^{34}$ $cm^{-2}s^{-1}$
- Increasing p_T thresholds reduces signal efficiency
  - Trigger on lepton daughters from H→ZZ at p_T ~ 10-20 GeV
  - Very easy to reach the worst case: thresholds increase beyond energy scale of interesting processes
- Backgrounds from HL-LHC pileup further reduces the ability to trigger on rare decay products
  - Leptons, photons no longer appear isolated and are lost in QCD backgrounds
  - Increased hadronic activity from pileup impacts jet p_T and MET measurements

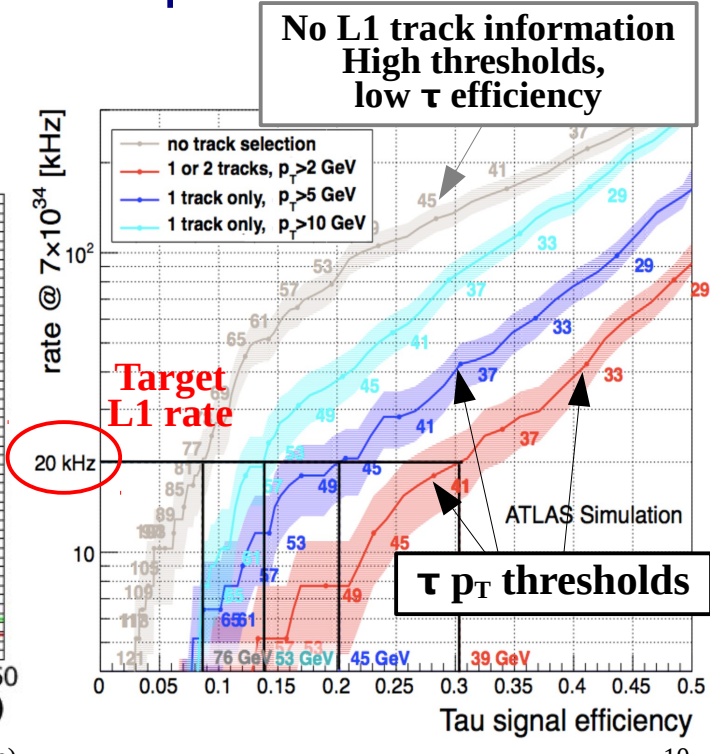


Lepton/Photon Triggering

- Improved performance by adding L1 track information
  - Improves the muon momentum measurement
  - Reduces fake electrons via tracker + calorimeter matching
  - Dramatically improved tau trigger efficiency
- Improved calorimeter granularity at L1 further improves EM fake rejection

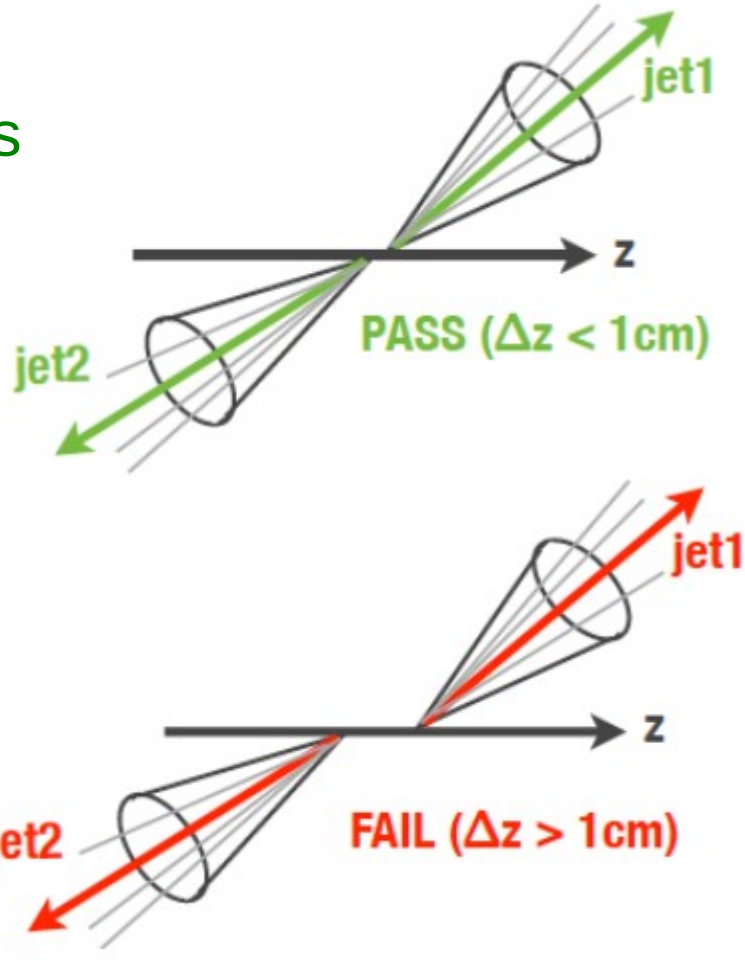






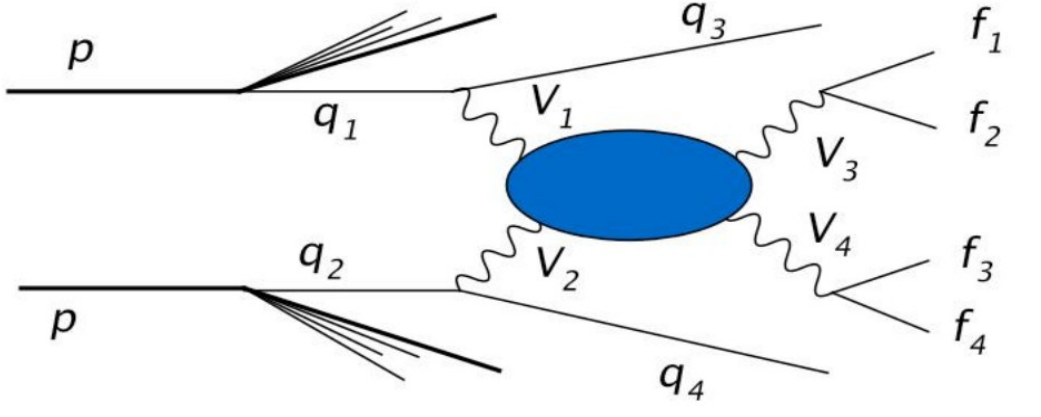
Hadronic Triggers

- Triggering on jets, missing energy
  - L1 track information can be used to reject jets from pileup interactions
- Loose (as loose as possible) trigger selection will be necessary to ensure high signal efficiency
  - Increase trigger bandwidth at each trigger stage and output to disk
  - Allows detailed processing for refined selection where resources are most plentiful



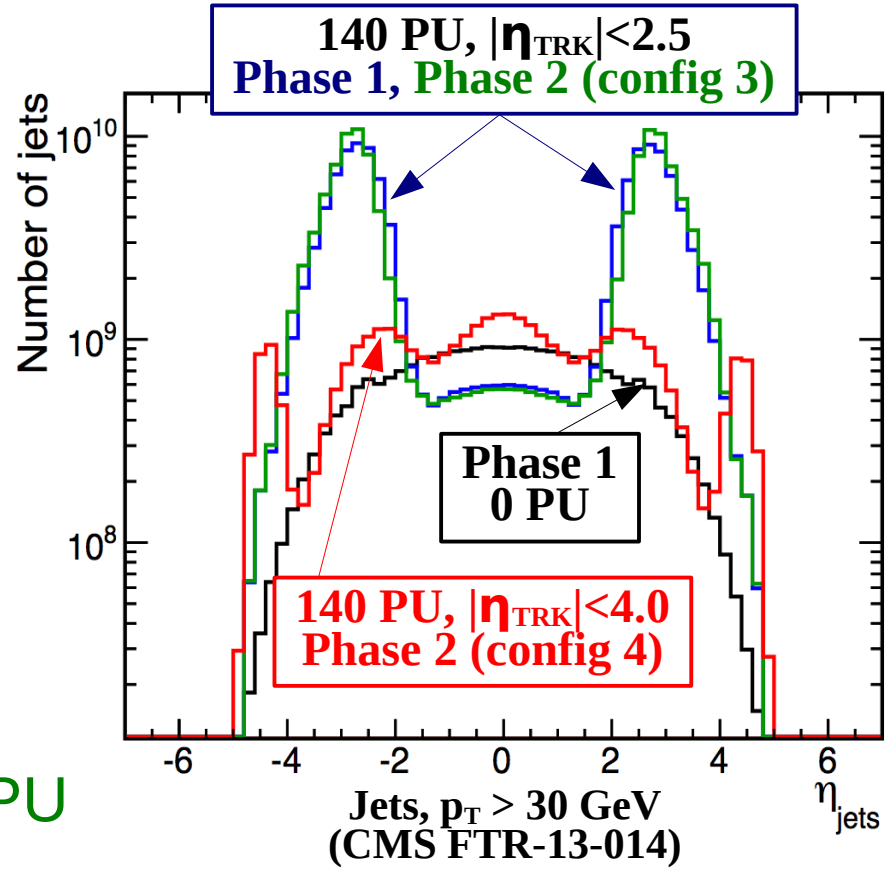
Extending Acceptance

- In addition to tracker upgrade, study the impact of extending the tracker coverage
- Increased physics sensitivity for VV scattering
  - Jets accumulate at |η| ~ 3
- Current tracker acceptance does not allow matching of forward jets to pp collision of interest
  - Not a problem in Run 1 due to low pileup
  - Significant challenge for HL-LHC



Forward Jets

- Pileup jet mitigation
  - Jet/Track matching, vertex association inside tracker acceptance
  - Raise p_T thresholds in regions with no tracker coverage
- At right, study jet distribution (p_T > 30 GeV) for W+jets events, PU=140
- Clear indication of PU jet pollution outside of tracker acceptance
  - Extending tracker coverage reduces jet contribution from PU

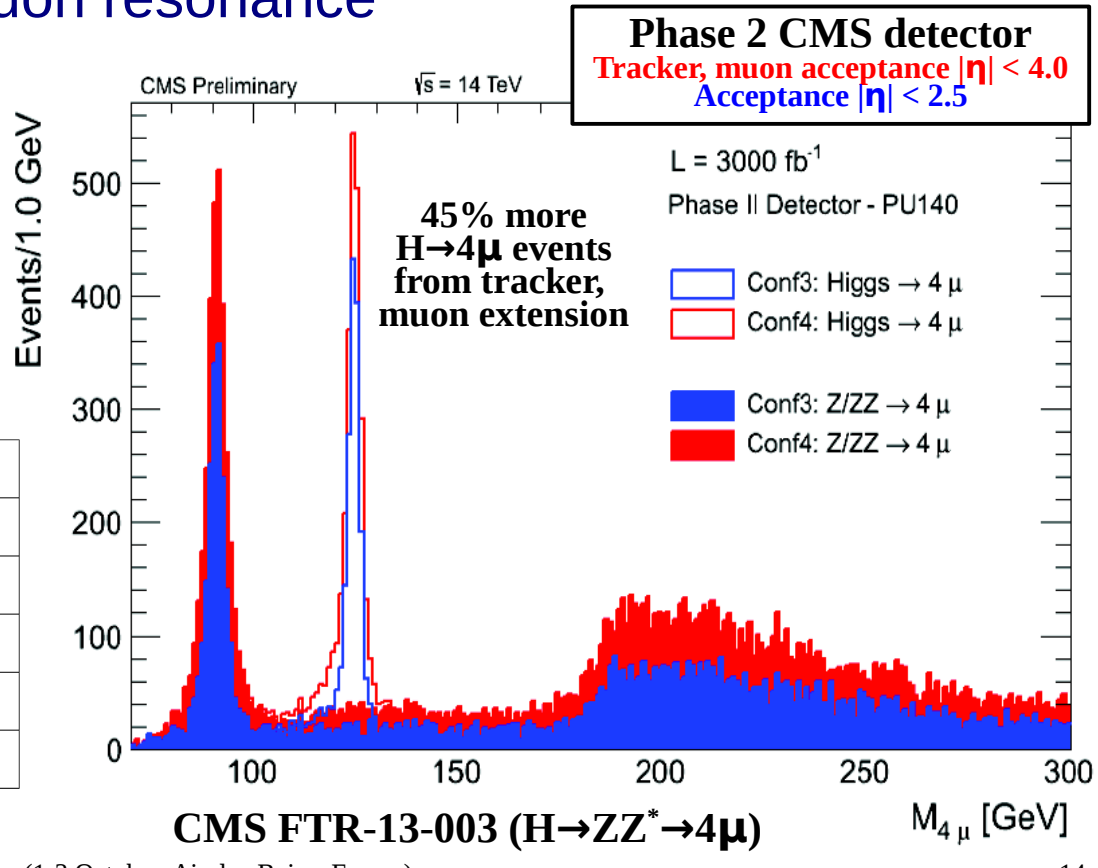


Forward Muons

- Increased muon acceptance increases number of reconstructed Higgs decays to muons
- New physics signatures: Forward muon acceptance will help refine theoretical picture of heavy dimuon resonance
- Muon p_T resolution in forward region critical for performance

CMS Assumptions (DELPHES)

$\|\eta\|$	$1<p_T<10$ GeV	$10<p_T<100$ GeV	$p_T > 100$ GeV
<1.5	1.3%	2% (<200 GeV)	5% (>200 GeV)
1.5-2.5	1.5%	4% (<200 GeV)	5% (>200 GeV)
2.5-3.0	3%	5%	30%
3.0-3.5	4%	7%	30%
3.5-4.0	5%	20%	80%

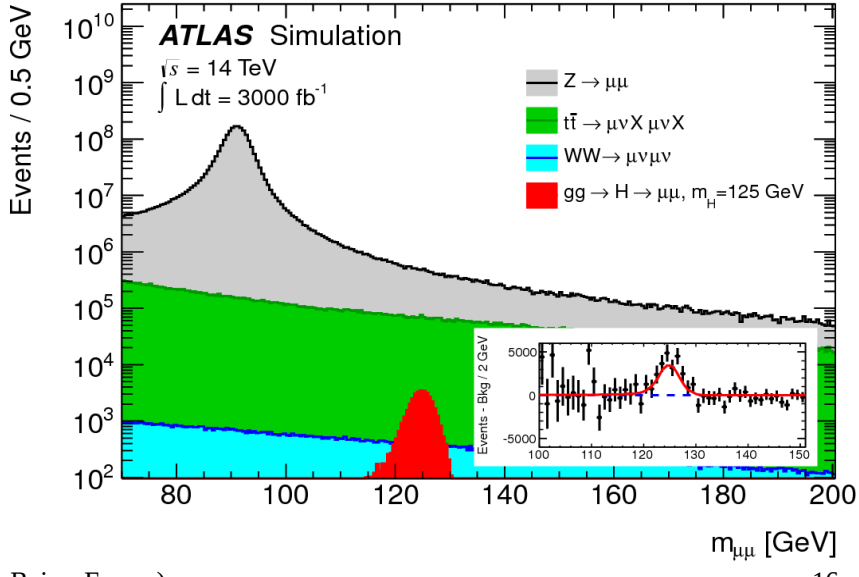


Forward Calorimetry

- Forward region is challenging for calorimetry
  - Interesting physics region for Higgs, VV scattering
  - Large particle flux due to pileup makes it difficult to resolve physics objects
    - Tracker coverage helps mitigate effect of pileup
- CMS will replace the endcap calorimeters for HL-LHC
  - Upgraded endcap will improve EM resolution
  - Improved segmentation will help mitigate pileup effects and improve measurements of jet p_T, H_T, missing E_T

Summarizing

- Detector subsystems will need to be replaced to account for radiation damage, high occupancy/rate, improve sensitivity in HL-LHC
- Important to maximize our sensitivity to HL-LHC physics
  - Rare processes that can only be seen with large datasets
    - Higgs pair-production requires good b-tagging, tau identification, lepton/photon isolation
    - H→μμ,γγ requires good resolution and acceptance for muons, photons
  - VV fusion, scattering processes
- Our interest in these rare HL-LHC processes implies that we still have work to do...



Work in Progress

- Studies have continued to grow in complexity over time
  - Generator level studies
  - Fast simulation
  - Full simulation
- The HL-LHC environment is vastly different than what we have seen during Run 1
  - Reoptimization of reconstruction and identification algorithms needed
    - Restructuring of software
  - Reoptimization of physics analyses to account for new collision energy and luminosity
  - New physics channels for HL-LHC

Continued Study

- Several physics channels have been studied which demonstrate the benefit of upgrades
  - Exploring design choices
- Not an exhaustive picture...more work is needed
  - Fully simulated Phase 2 samples for CMS
  - Additional physics channels to reinforce the performance of upgraded detectors and highlight physics sensitivity

Outlook

- The ATLAS and CMS detector upgrades will capitalize on the unprecedented physics reach of the HL-LHC
  - Action is clearly needed
  - Exciting potential for improved performance
    - Tracker and Trigger upgrades
    - Muon systems and forward calorimeters
- The ECFA meeting is an important milestone on the way to HL-LHC
  - Many challenges ahead
  - We expect even more results to motivate our upgrade design choices