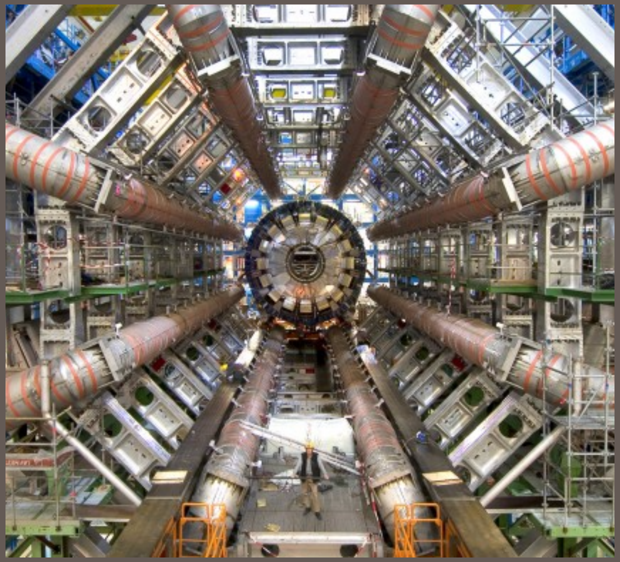
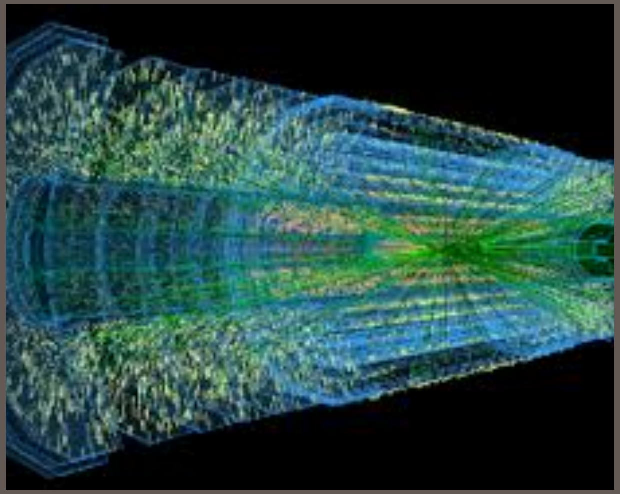
ATLAS Upgrade Plans and Potential





LHCP2015

August 31st - September 5th 2015

Anadi Canepa on behalf of the ATLAS Collaboration | TRIUMF

Talk Outline

Brief Physics Motivation

ATLAS Phase I Upgrades

New Small Wheel
L1 Calorimeter Trigger
Fast Track Trigger
TDAQ

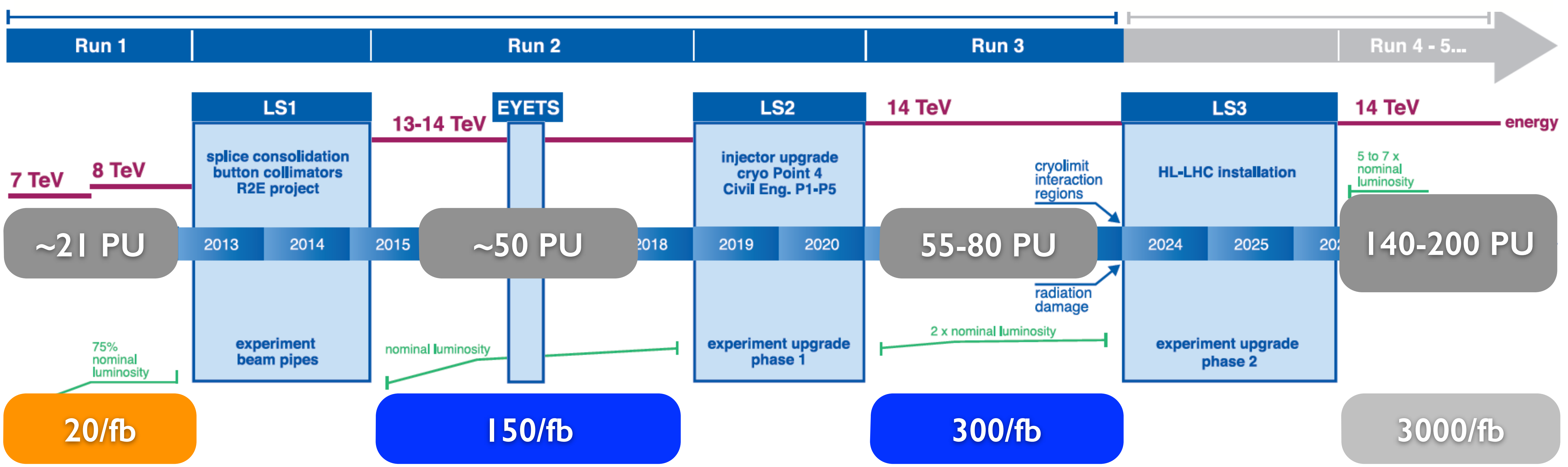
ATLAS Phase II Upgrades

Inner Tracker
Forward Calorimeter
TDAQ
(Upgrades to Electronics not included)

Physics Performance and Conclusions

The Future

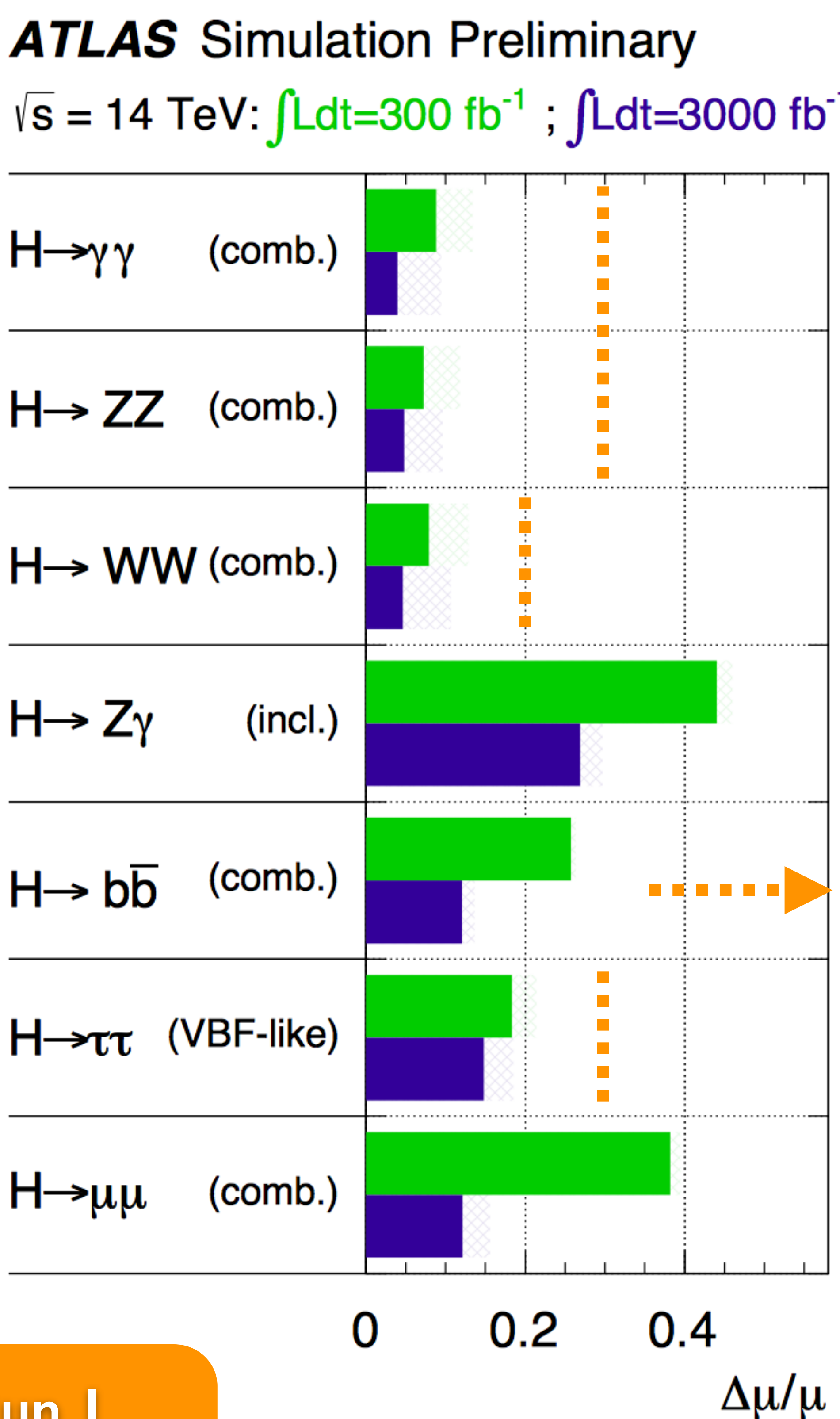
- The ATLAS Collaboration foresees 2 upgrade phases to adapt to the challenges of the LHC and to fully exploit the physics opportunities offered by the exploration of a the TeV scale
- The Phase I upgrade will enable the experiment to benefit from the 300 fb^{-1} collected with peak instantaneous luminosities 3x the design one
  - corresponding to 55-80 pp collisions per bunch crossings or “pile-up” events (<μ>)
- The Phase II upgrade is designed to support the full physics program at peak instantaneous luminosities of $7x10^{34}$ $cm^{-2}s^{-1}$ and for a total integrated luminosity 3000 fb^{-1} by 2035
  - corresponding to pile-up values up to 200



Physics Motivation: EWK Symmetry Breaking

- The Run 3 and HL-LHC combined will produced over 100 million SM Higgs bosons in total
  - access to rare decays like H in μμ and H in ZϒY
  - assessment of the top Yukawa coupling via ttH production
- The large sample will also allow to probe for the CP structure of Higgs and the self-interaction

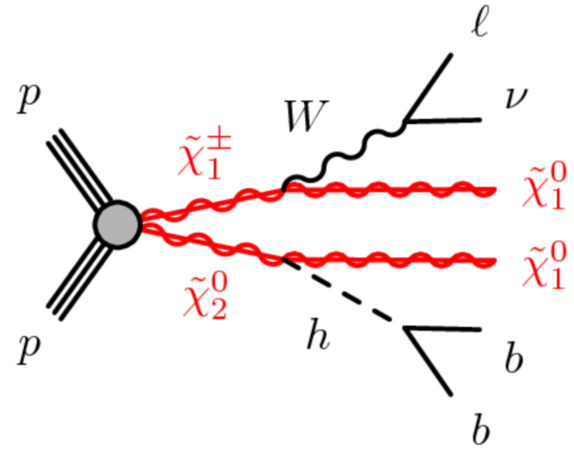
Dedicated talk on Higgs Prospects by A. Nisati on Thursday

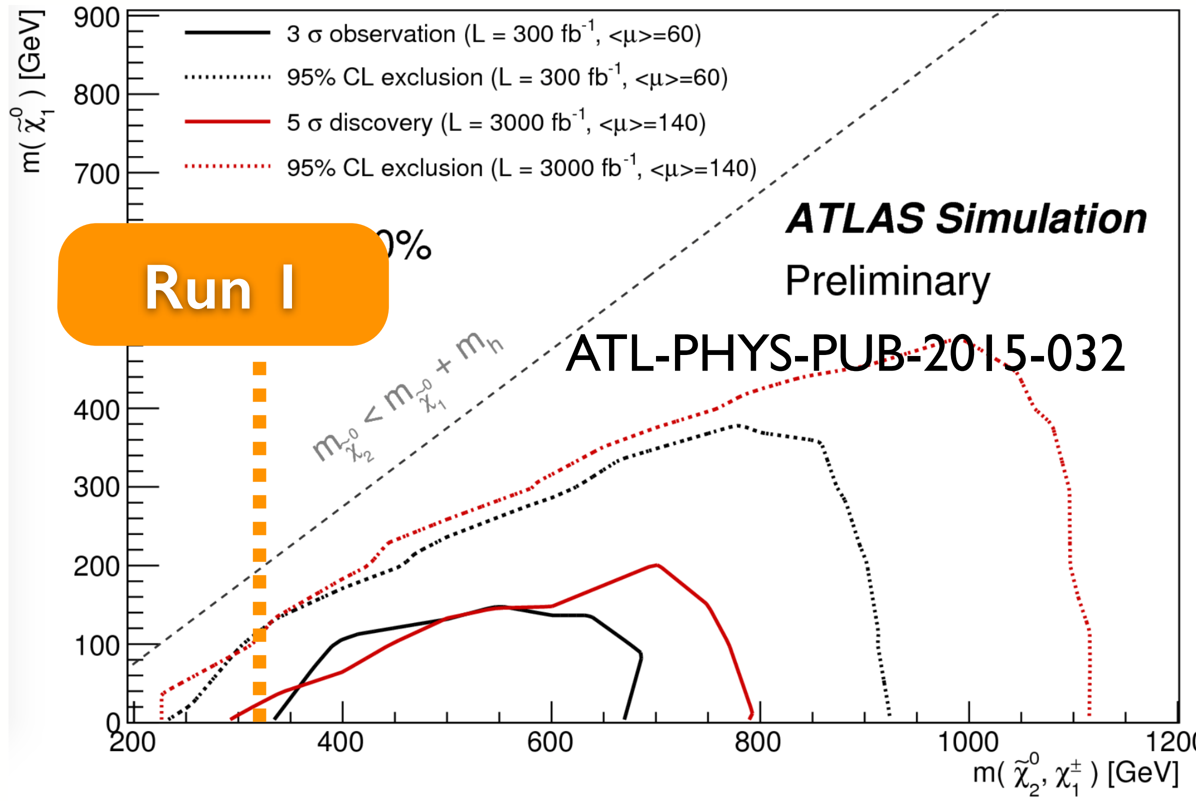


Run I

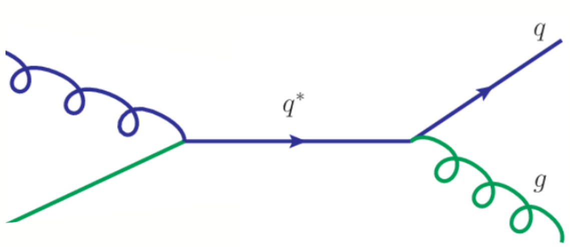
Physics Motivation: Searches for BSM

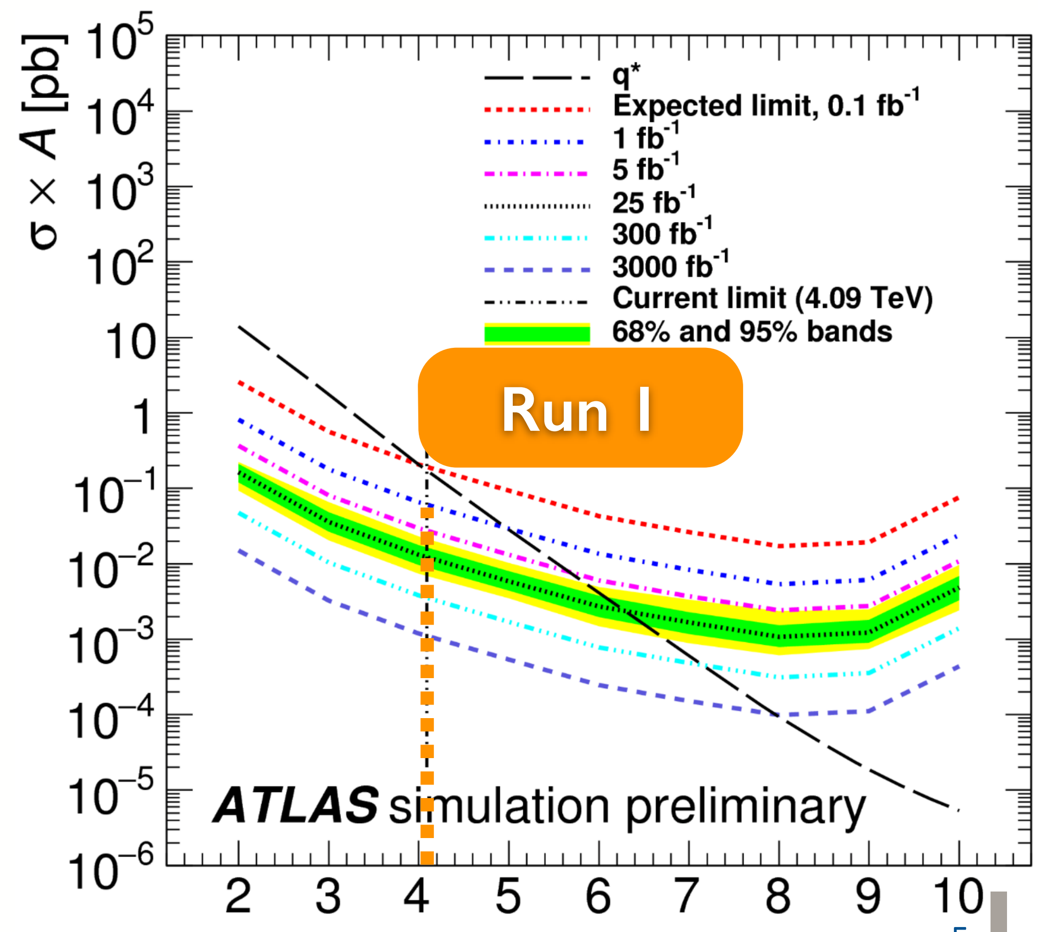
- The discovery potential at 14 TeV is greatly enhanced at Run 3 and HL-LHC
  - latest results from searches for EWK-inos and excited quarks





Dedicated talk on Higgs Prospects by J. Richman on Thursday





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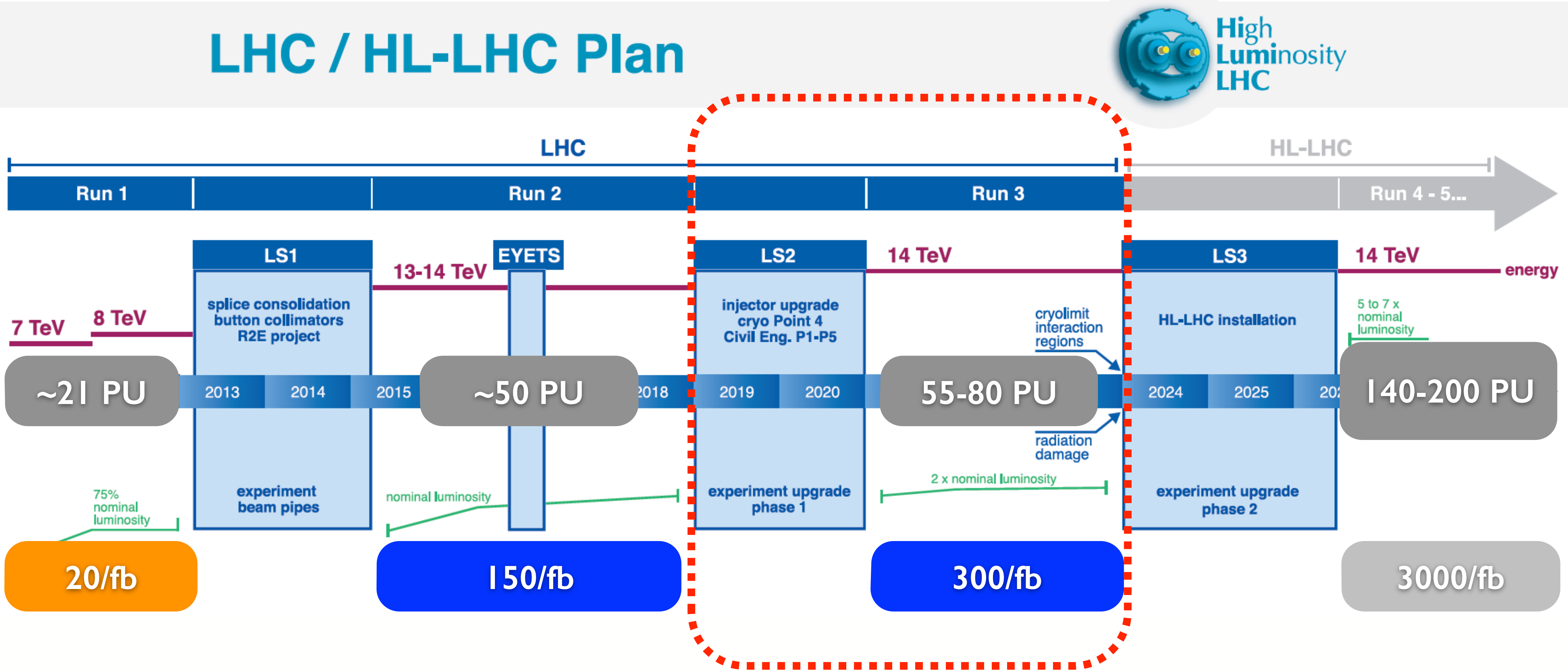
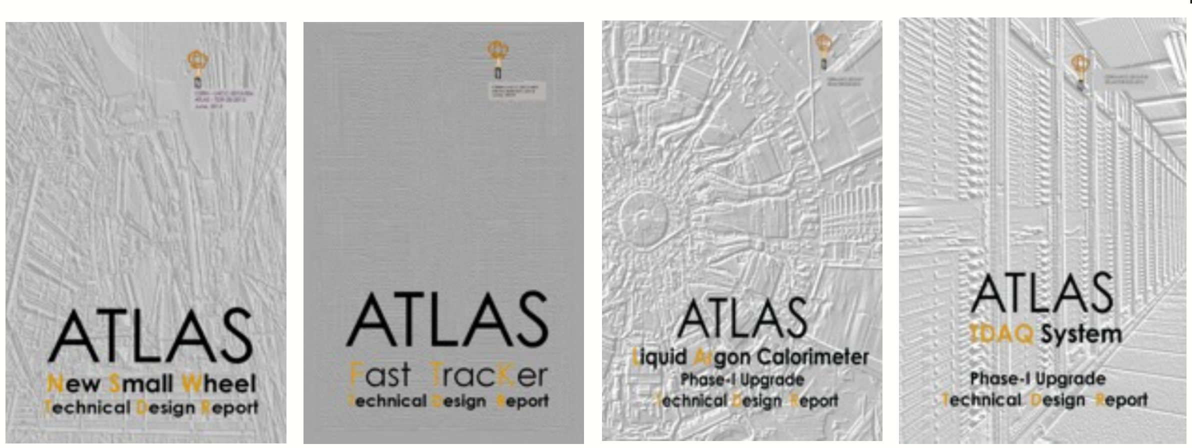
Phase I ATLAS Upgrade



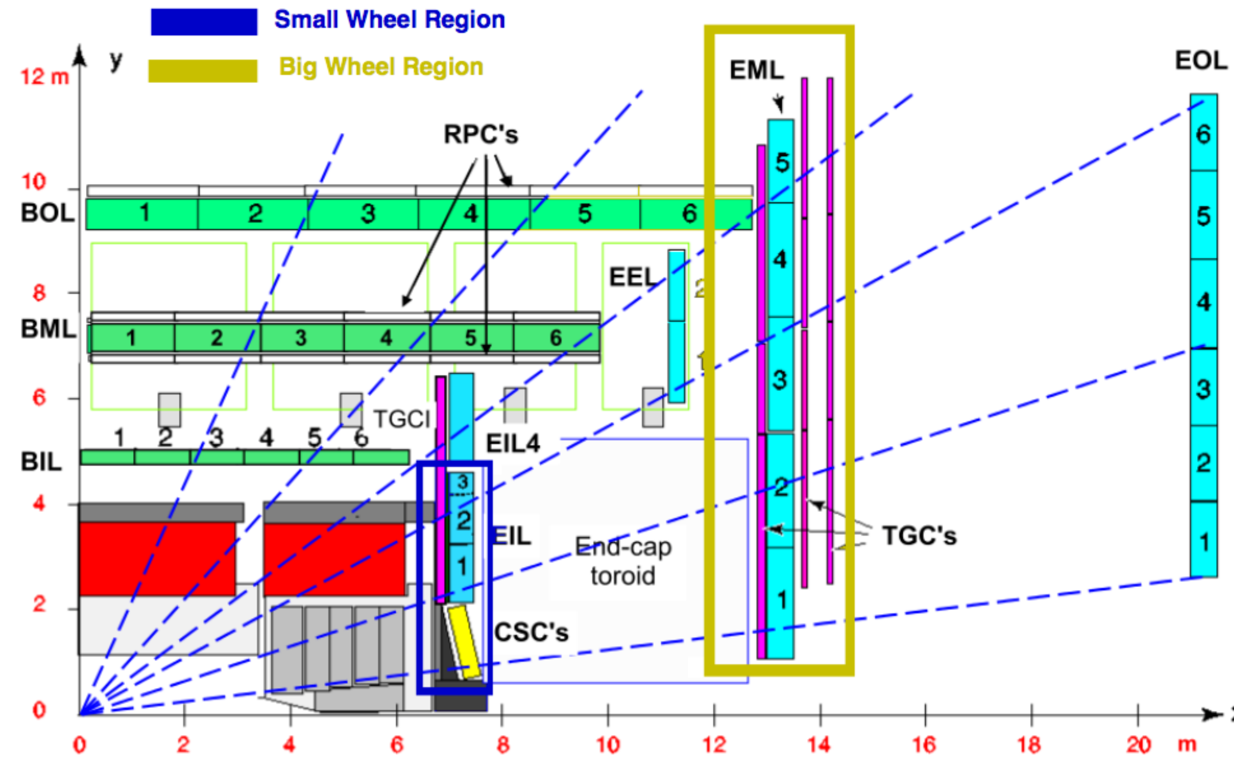
Most of the phase-I upgrades are meant to provide better trigger capabilities in order to maintain the same acceptance at higher pileup



The four main Phase-I Technical Design Reports (TDRs) are approved by the LHCC and Research Board, including scrutiny by the Upgrade Cost Group (UCG).

Overview of the New Small Wheel Upgrade

- In the Run1-2, muon end-cap triggers are based on TGC
  - ~90% of the L1 muon triggers in the EC are fakes
- Raising the pT threshold would lead to significant loss of acceptance
- A substantial degradation of tracking efficiency and resolution is expected at high luminosity
  - background rates exceeding 15 kHz/cm^2 at high luminosity



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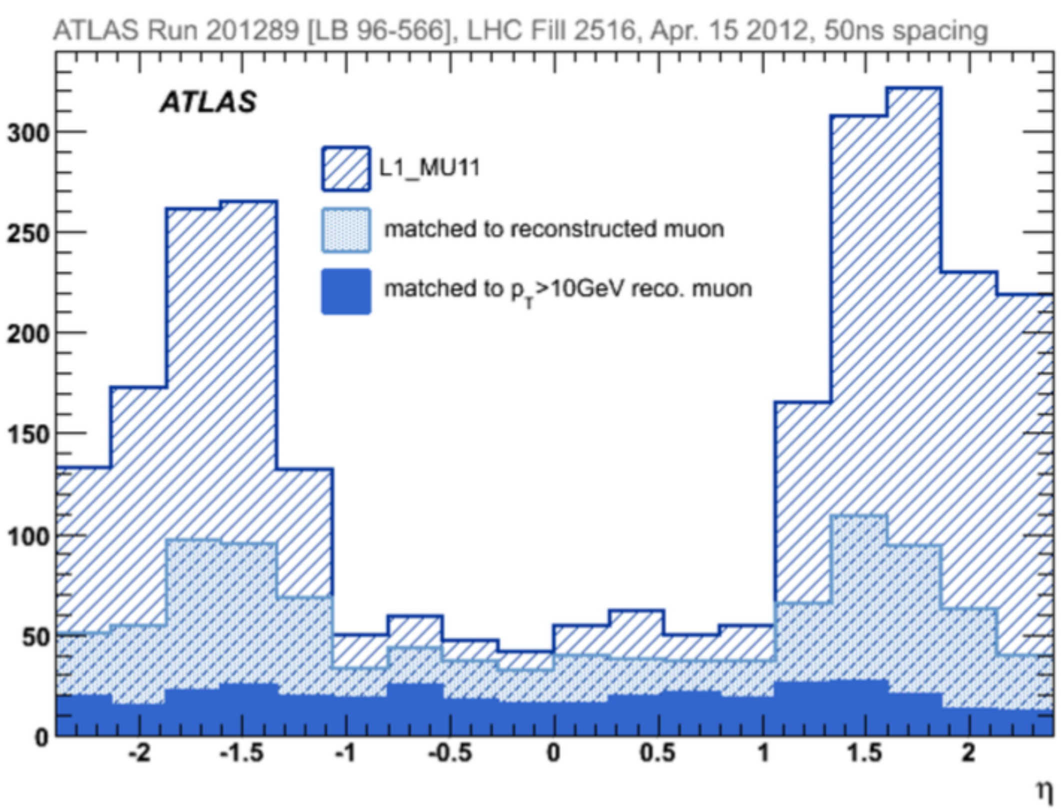
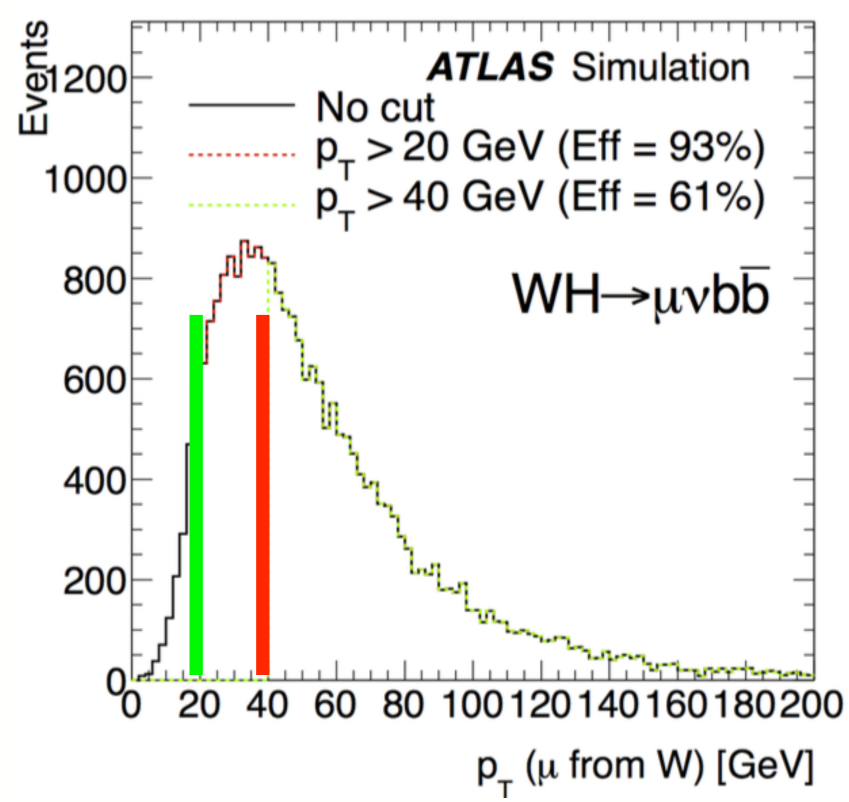
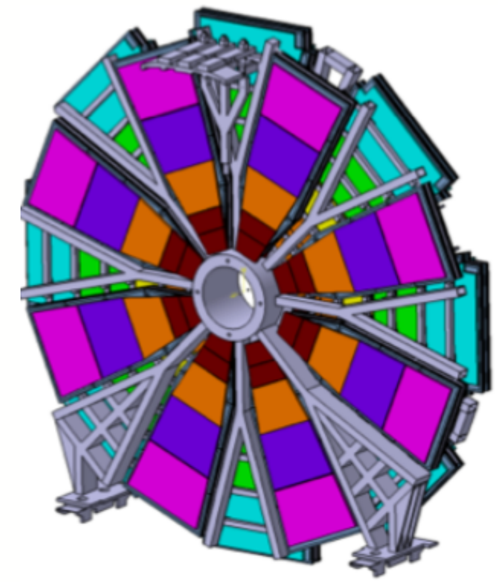


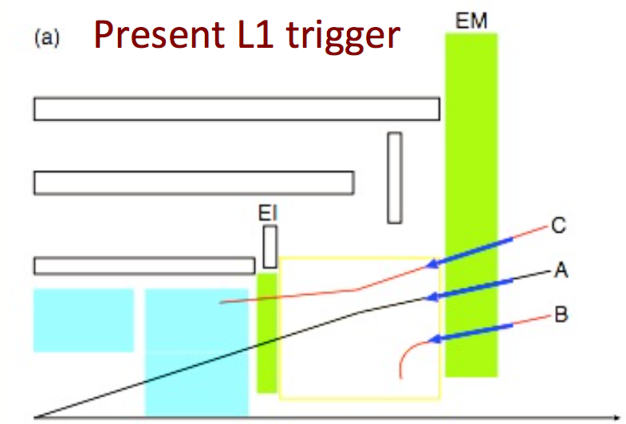


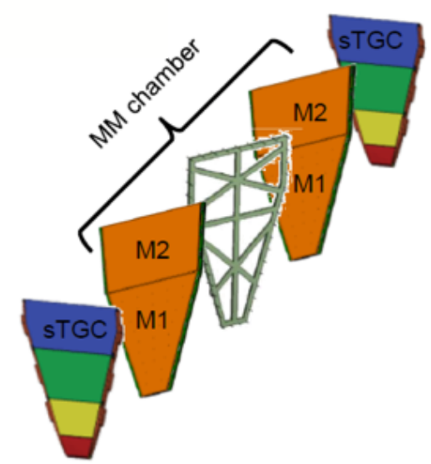
An upgrade of the New Small Wheel is proposed (1.3<|η|<2.7)

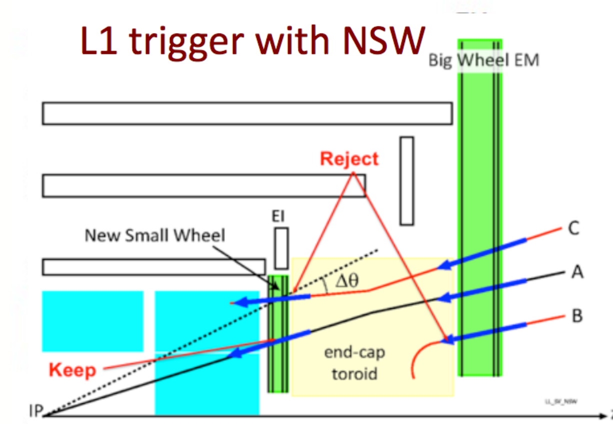
NSW Detector Technology & Performance

- Two (redundant) chamber technologies are adopted
  - TGC (sTGC): primary trigger
    - Single bunch crossing identification capability
      - segment available within 1us, current delay of the Big Wheel
    - Track vectors with <1 mrad angle resolution
    - Space resolution < 100 μm independent of incident angle
  - MicroMega (MM): primary tracker
    - Exceptional precision tracking capabilities
      - position resolution <50 μm or 100 μm per plane
    - High granularity leading to good track separation and to a match to the current system
    - High rate capability due to small gas amplification and small space charge effect









L1MU threshold (GeV)	Level-1 rate (kHz)
$p_T > 20$	60 ± 11
$p_T > 40$	29 ± 5
$p_T > 20$ barrel only	7 ± 1
$p_T > 20$ with NSW	22 ± 3
$p_T > 20$ with NSW and EIL4	17 ± 2

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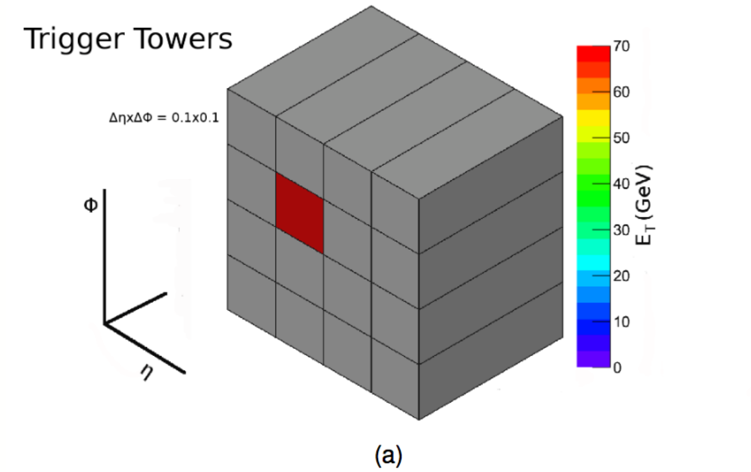
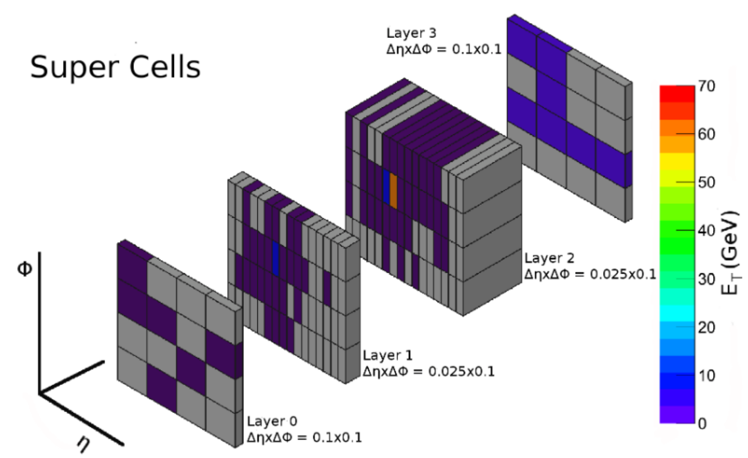
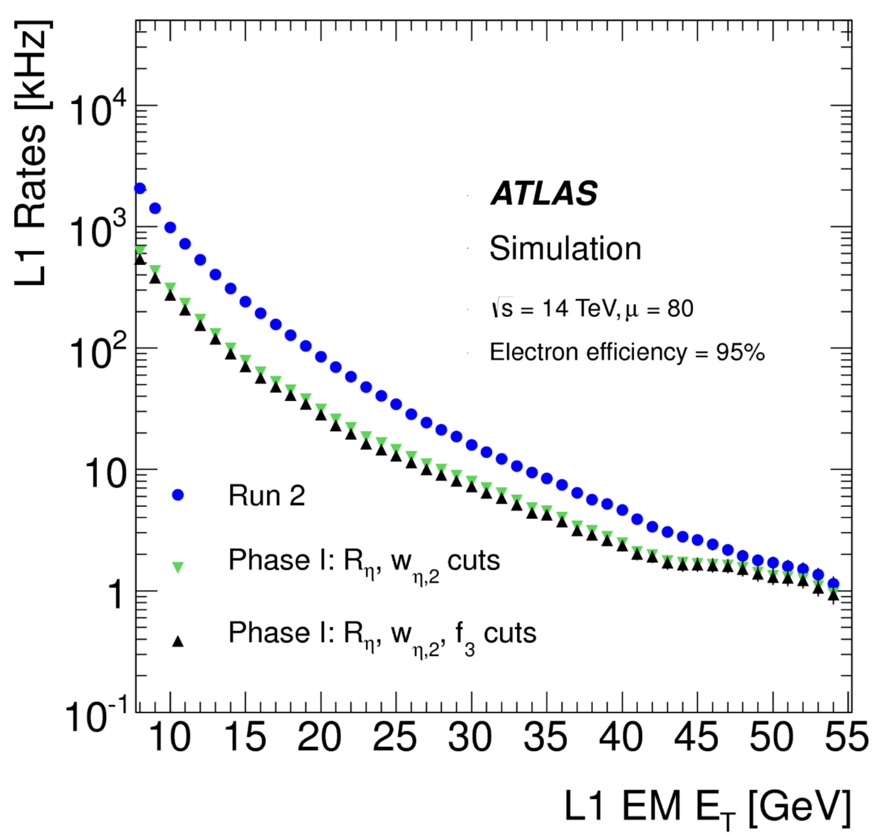
Overview of the L1 Calo Trigger Upgrade

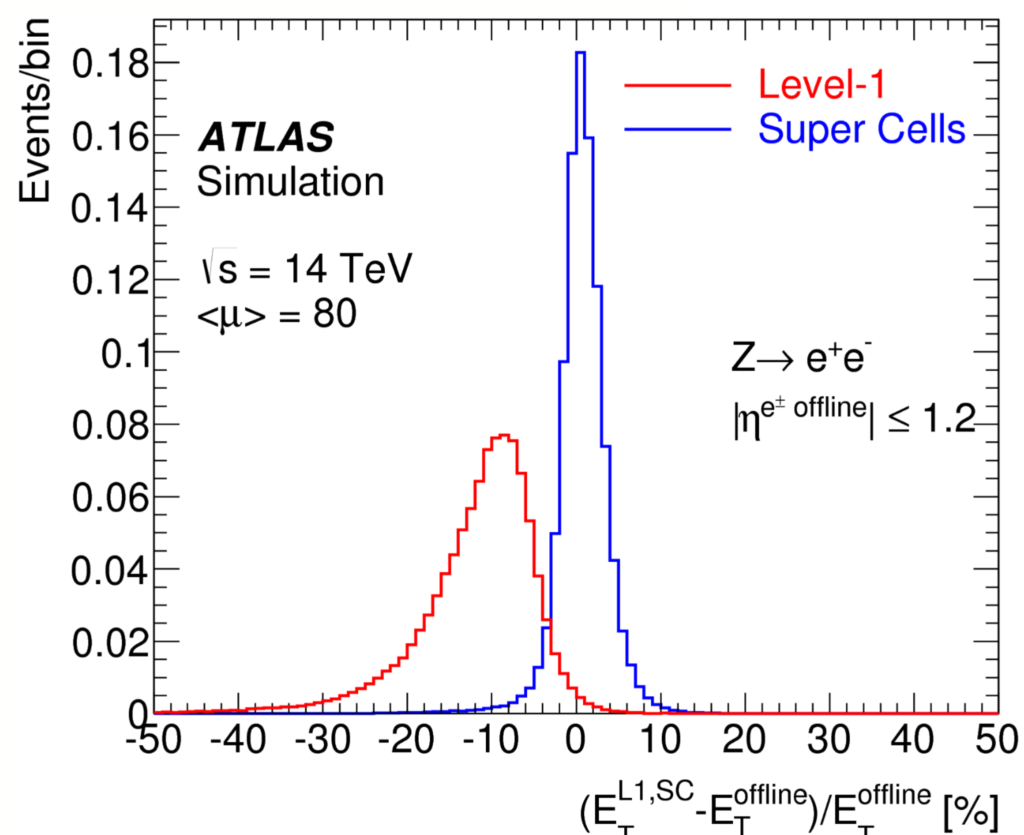
- Current L1 Calo is based on $\Delta\eta x \Delta\varphi = 0.1x0.1$ trigger towers
  - needed for photons, electrons, jets, Etmiss
  - used to compute object energy and isolation
  - expecting rates ~270 kHz @ $3x10^{34}/cm^2s$ >> total L1 rate of 100kHz (for Run 1 thresholds)



- The "SuperCell" upgrade will
  - make high granularity and longitudinal shower information available at L1 (retain transverse energy in each layer instead of summing)
  - will also improve substantially the energy resolution (12 bits in place of 8 of the towers)







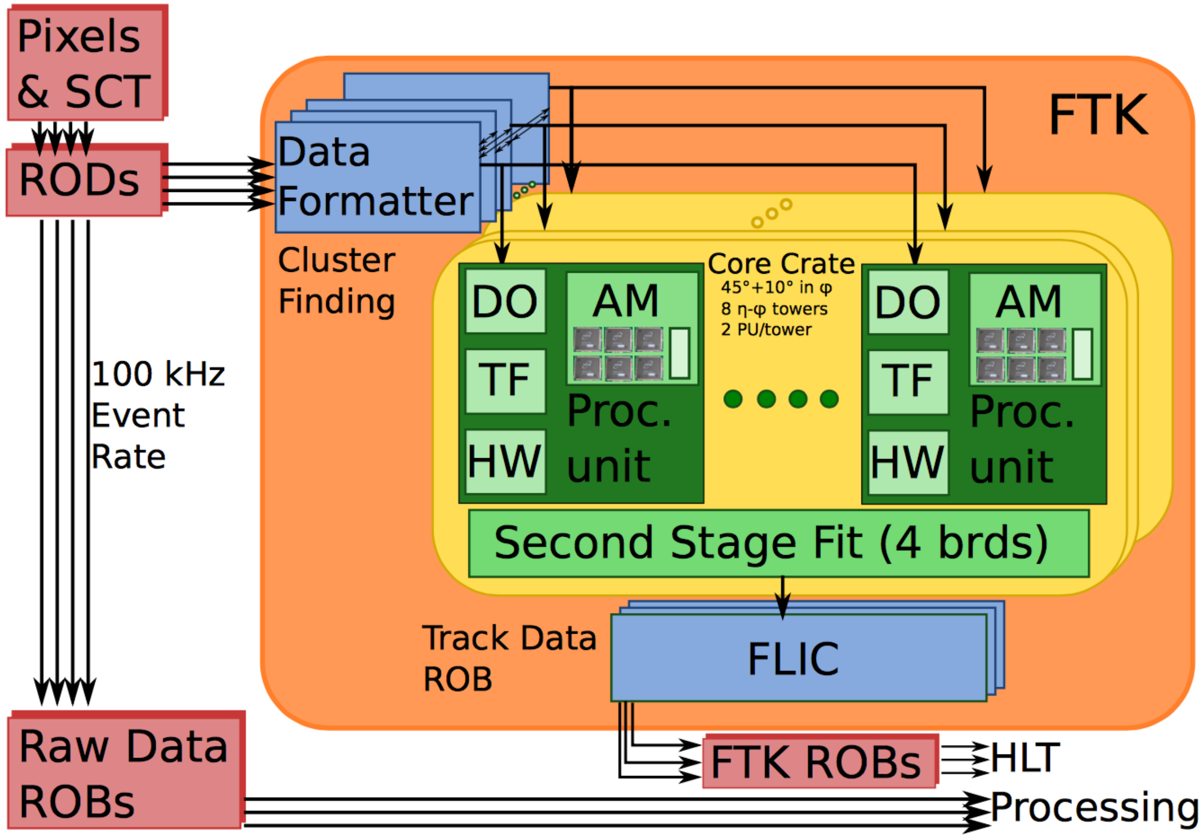
CERN-LHCC-2013-017

Overview of the Fast Tracker Trigger Upgrade

- Tracking information is critical for distinguishing which events triggered by the L1 should be kept
- Current approach based on Region of Interest (ROI) identified by the L1 trigger has limitations
  - there is a limit to either the number or size of ROIs processed by the HLT
  - global event information, such as the location of the hard interaction vertex are very important in challenging environment at high pile-up

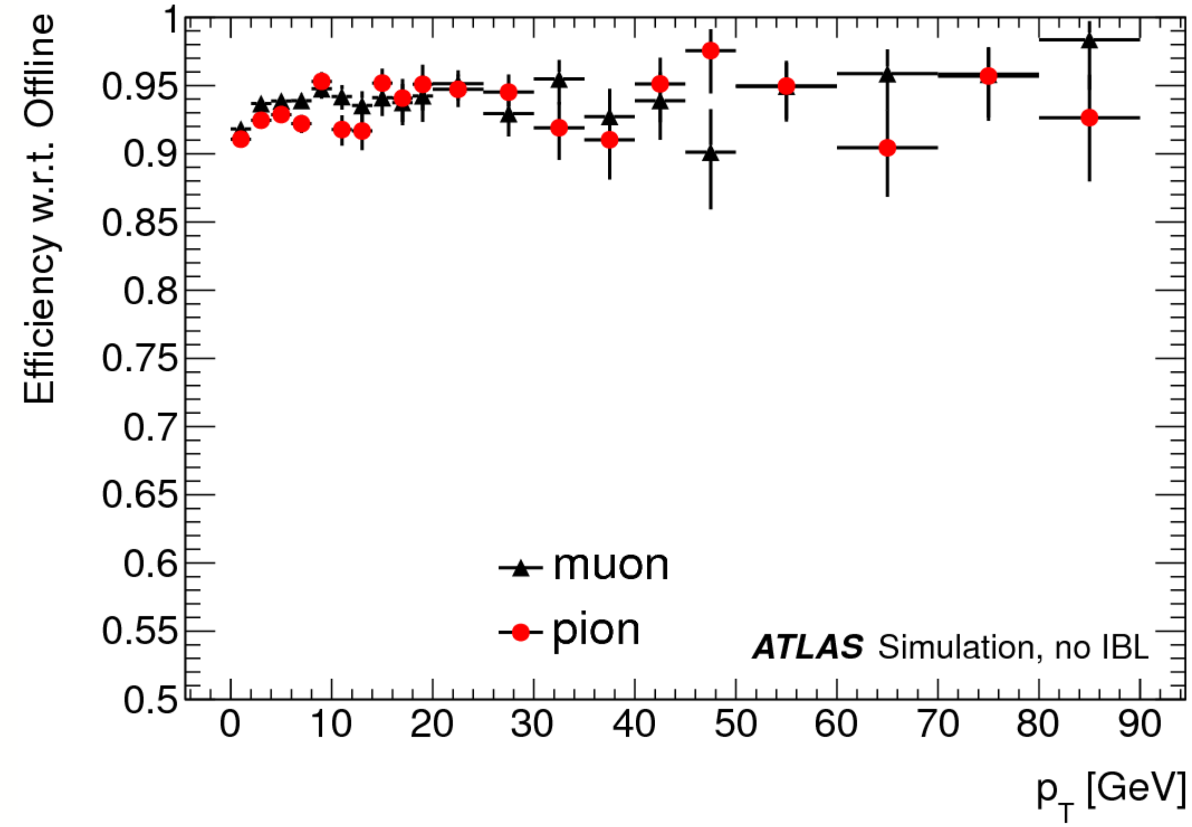
- A dedicated, hardware-based track finder (FTK) is proposed to provide *global* tracking information after Level-1 to enable the Level-2 trigger to have early access to tracking information

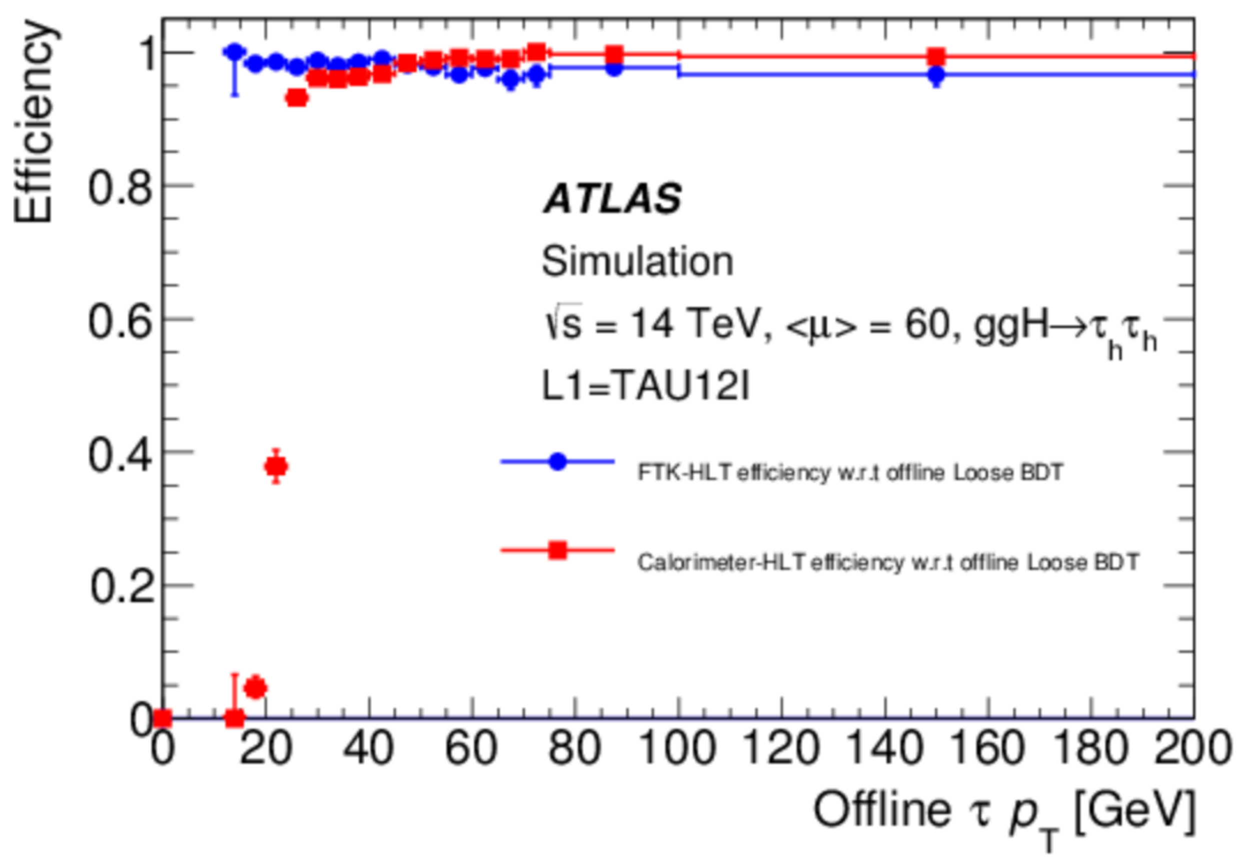
- FTK operates in two stages:
  - Stage 1
    - pattern matching performed in custom-designed chips using Associate Memory (AM)
      - information from 8 /12 silicon layers only used for track fit
  - Stage 2
    - Tracks extrapolated into the additional 4 logical silicon layers
    - Precise re-fit with all 12 layers using FPGAs
    - Determination of the Chi2 and helix parameters

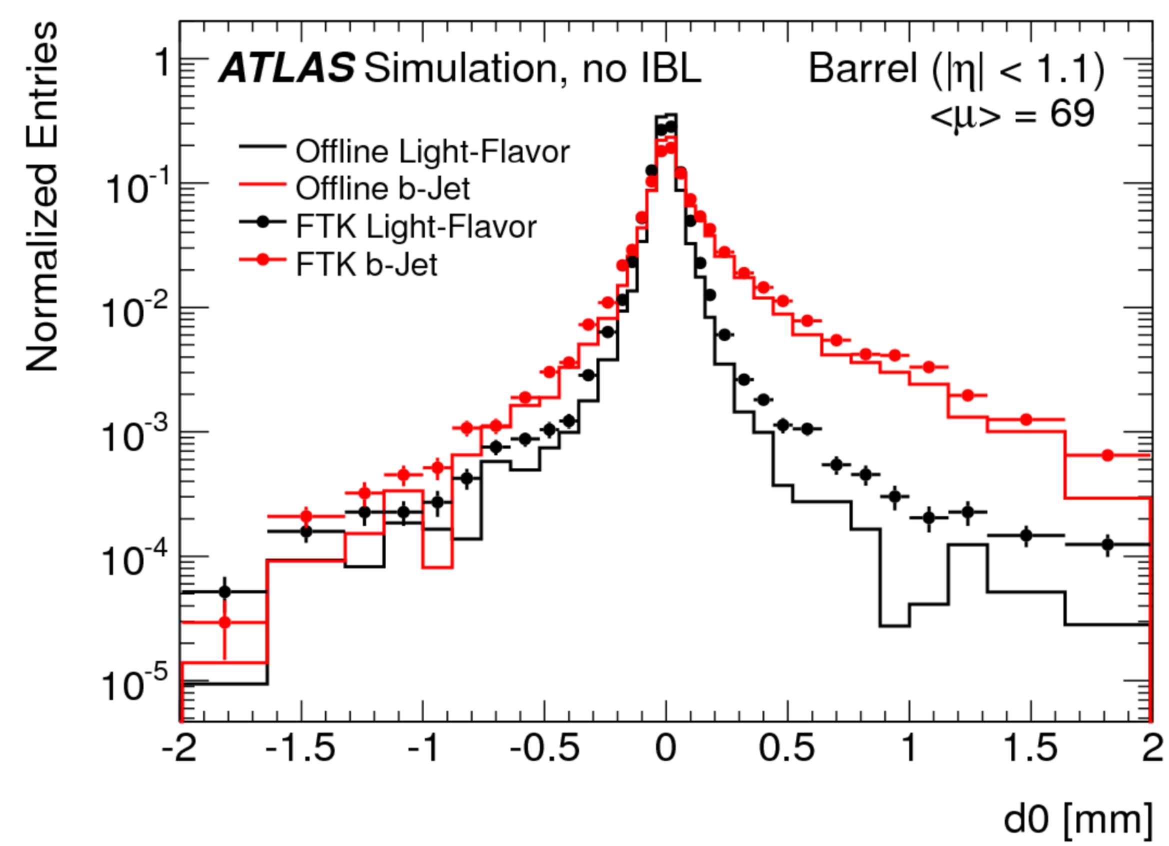


FTK Performance

- FTK is highly parallelized, detector data decomposed into independent regions (64 towers)
  - input to L2 in ~25μs (projection at <mu>=69)
- FTK online track quality and b-tagging efficiency are comparable to offline ones
- Tau trigger efficiency improves significantly
- There is a linear correspondence between the number of FTK vertices and offline vertices vs pile-up



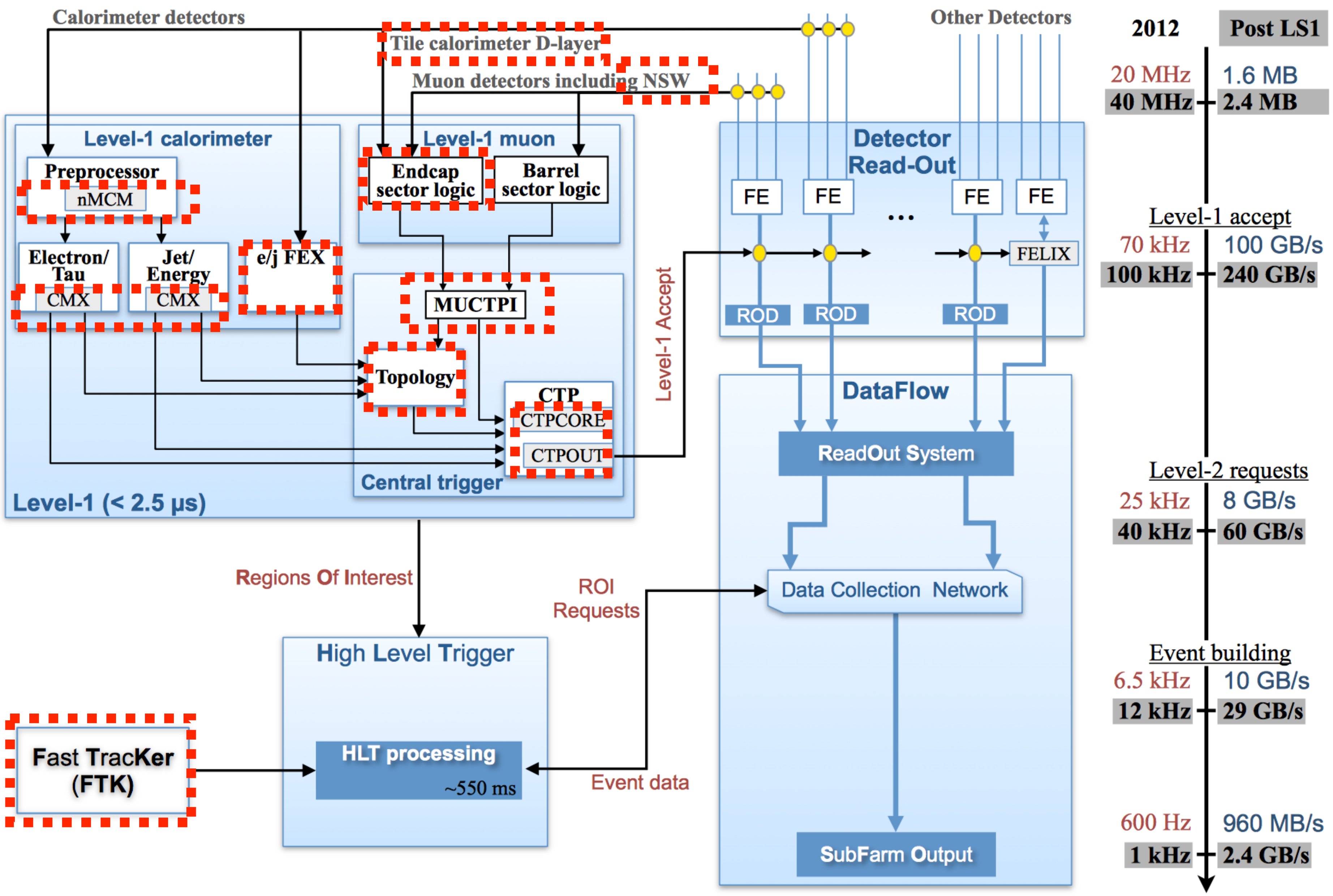




ATLAS-TDR-021

Overview of the TDAQ System

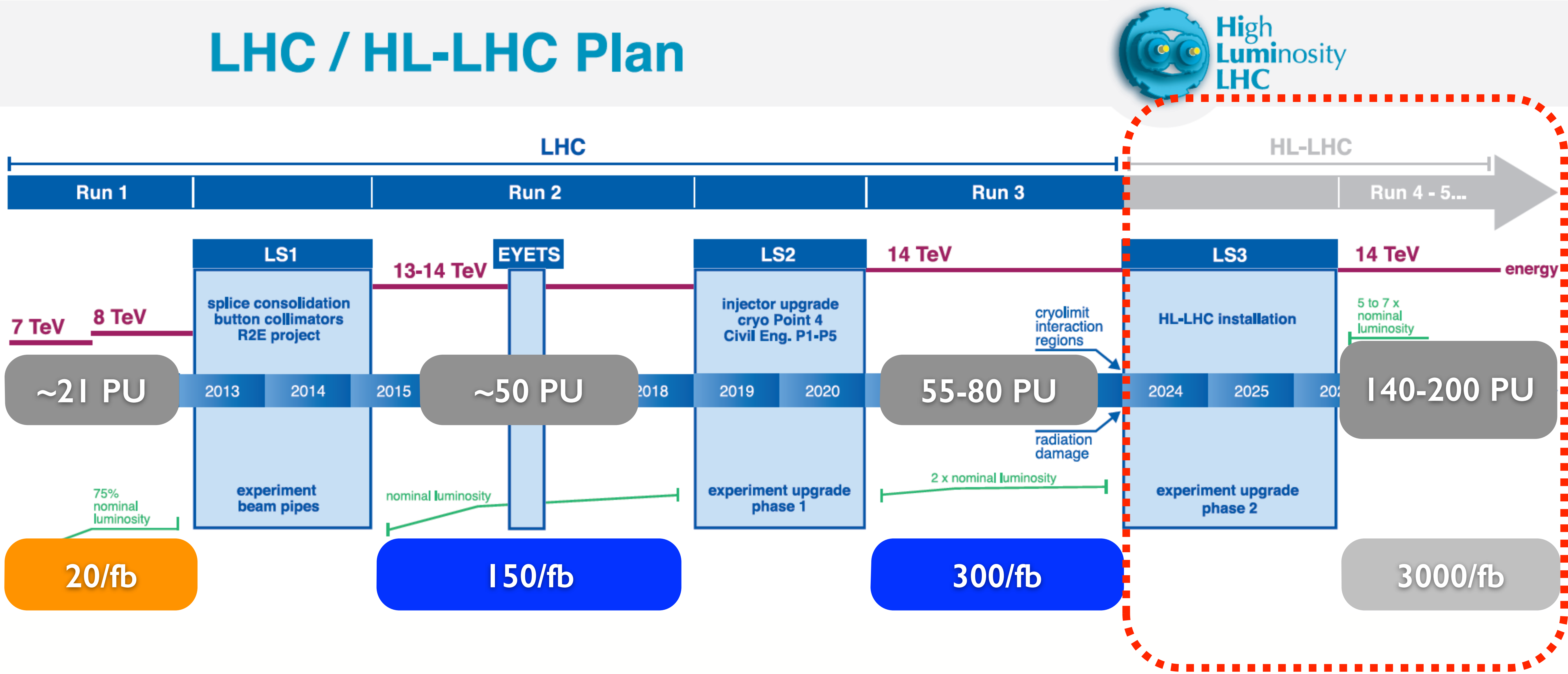
- The upgrade of the TDAQ system will allow to efficiently trigger and record data at instantaneous luminosities 3x larger than the design one while maintaining low trigger thresholds for maximum acceptance
  - All the new trigger functions have to be performed within the existing latency limit of 2.2 μs.



Red=new

ATLAS-TDR-023

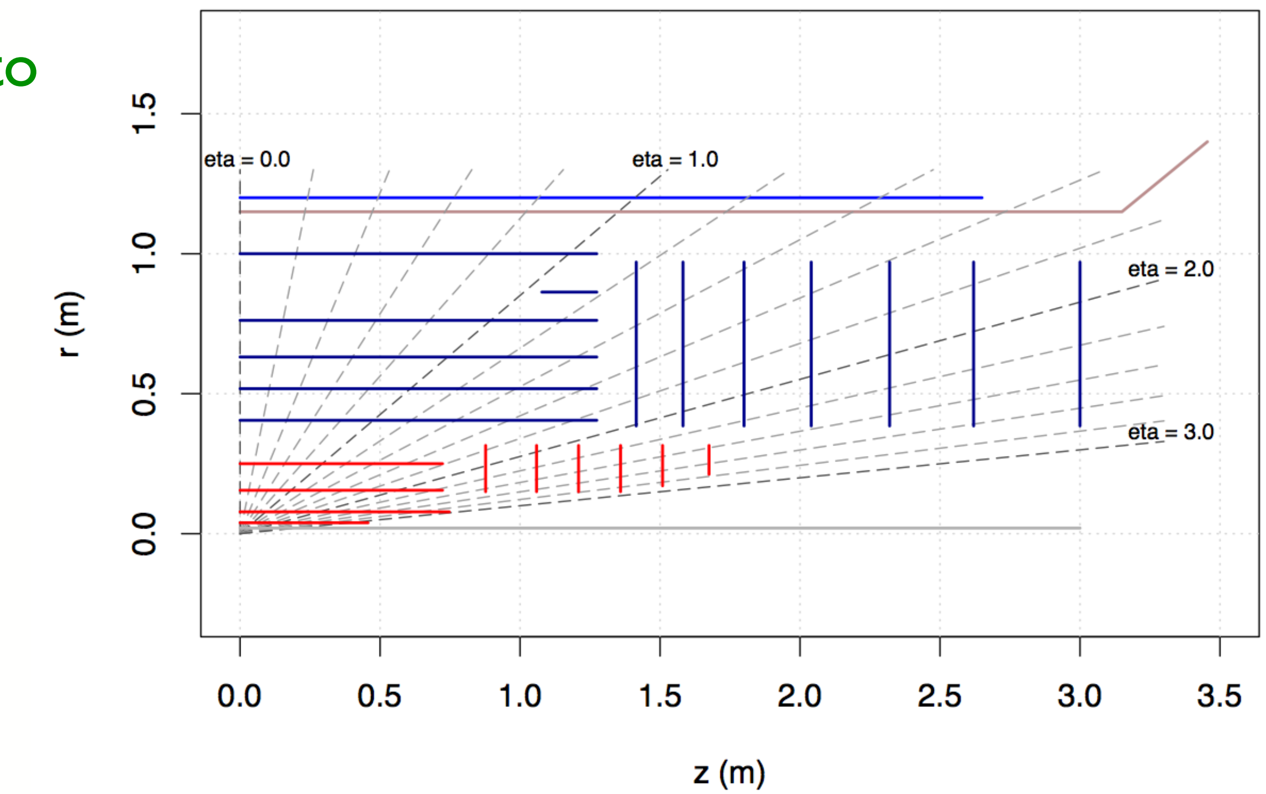
Phase II ATLAS Upgrade



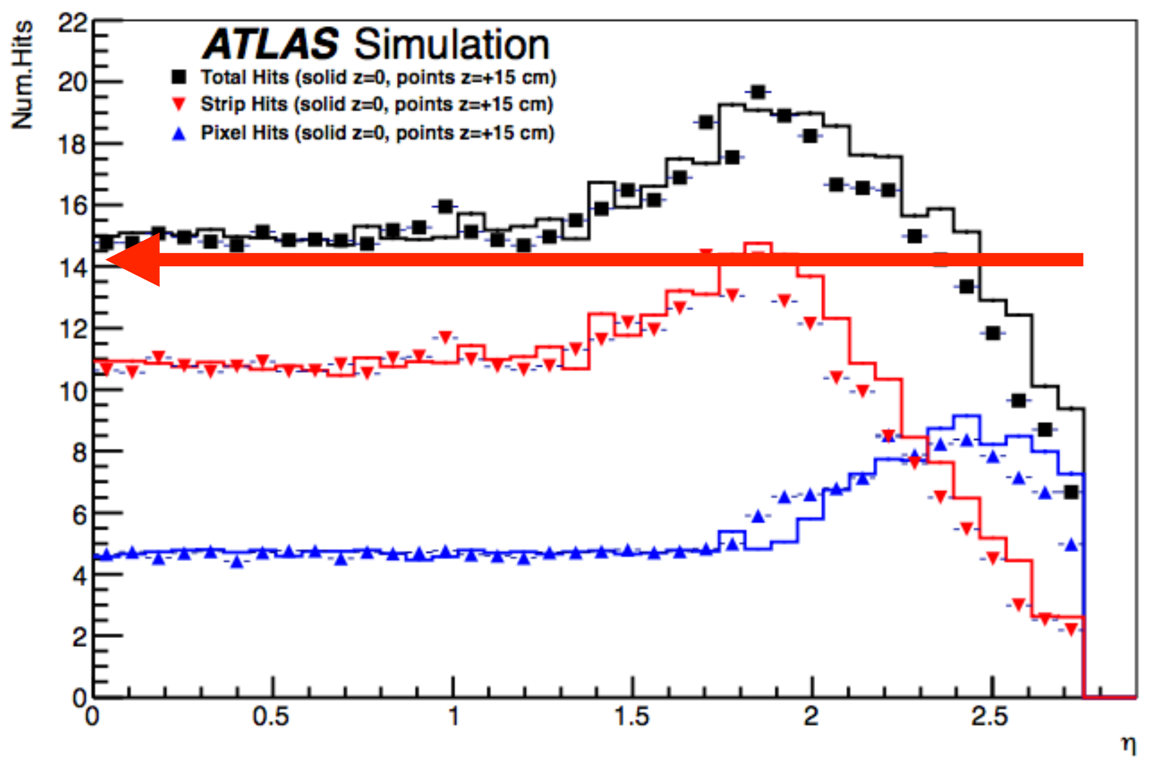
2012: 20 collisions | HL : 200 collisions

Overview of the Tracker Upgrade: ITK

- A complete replacement of the current ATLAS ID (Pixel, SCT, TRT) with all-silicon tracker is planned to cope with the increased pile-up and expected dose
- To achieve the best performance in the extremely challenging HL-LHC environment both robust tracking and reduced material are critical
- Various designs are considered (including the extension to large |η|). Letter of Intent layout comprises:
  - Strip tracker: 5 layers, stubs, 7 disks on each side
  - Pixel tracker: 4 layers, 6 disks
- At least 14 hits up to |η| = 2.5 for robustness
- Occupancy < 1% at <μ>=200 with $0.7X_0$ for |η| ≤ 2.7



Track parameter $|\eta| < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50



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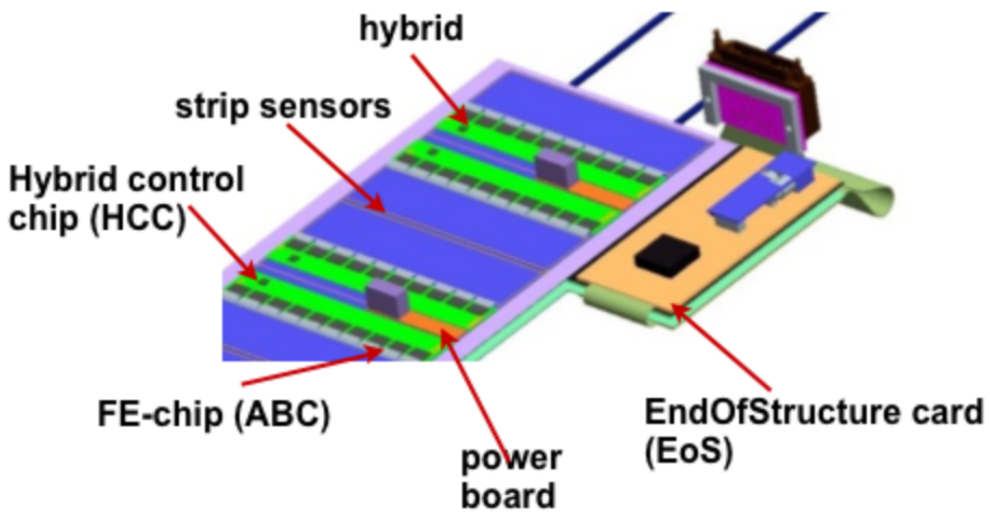
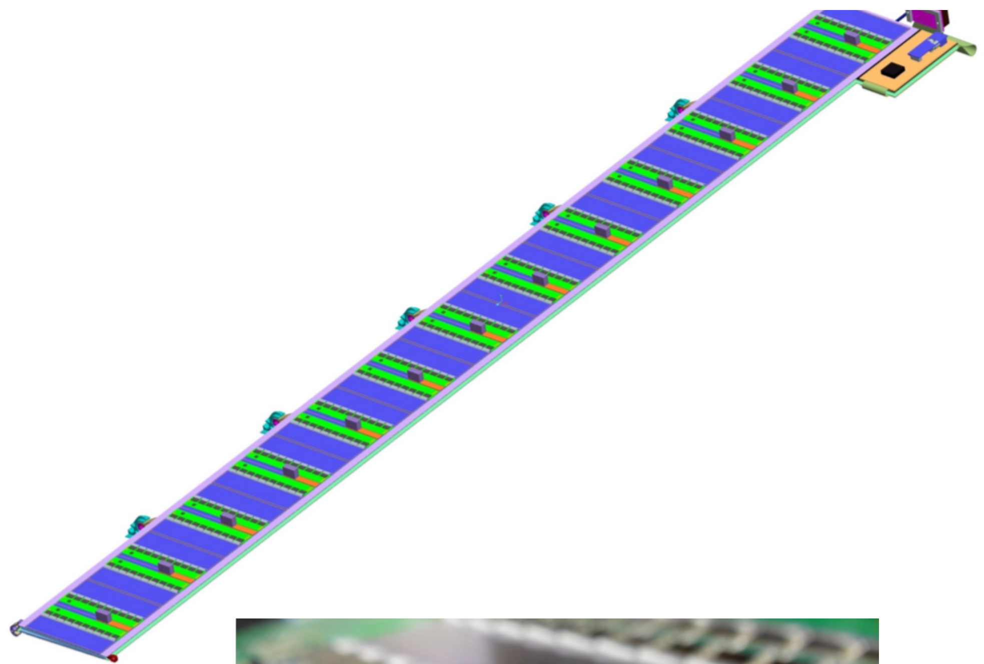
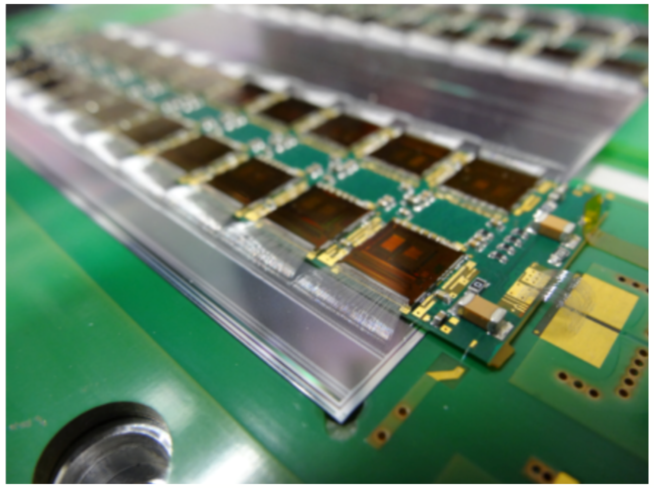
ITK: Sensors

- The pixel detector will be installed within a few cm of the beam-line where the max particle fluence will be 1.4 $x10^{16}$ cm^{-2}
  - thin sensors, pixel size 50x50 or 25x100 μm^2
  - n-in-n, n-in-p planar, 3D, diamond sensors (expected to withstand up to $2x10^{16}$ cm^{-2})
  - CMOS technology also explored for larger radius
  - must meet requirement of low mass, large bandwidth and low power consumption

- Strip detector uses n^+-in-p AC-coupled sensors
  - double-sided layers with axial strip orientation and 40 mrad stereo angle on the back side
  - short (23.28 mm) and long (47.75 mm) strips with 74.5 um pitch in the barrel
  - 6 different designs in the EC to accommodate the geometry
  - silicon modules directly bonded on a cooled carbon fiber plate

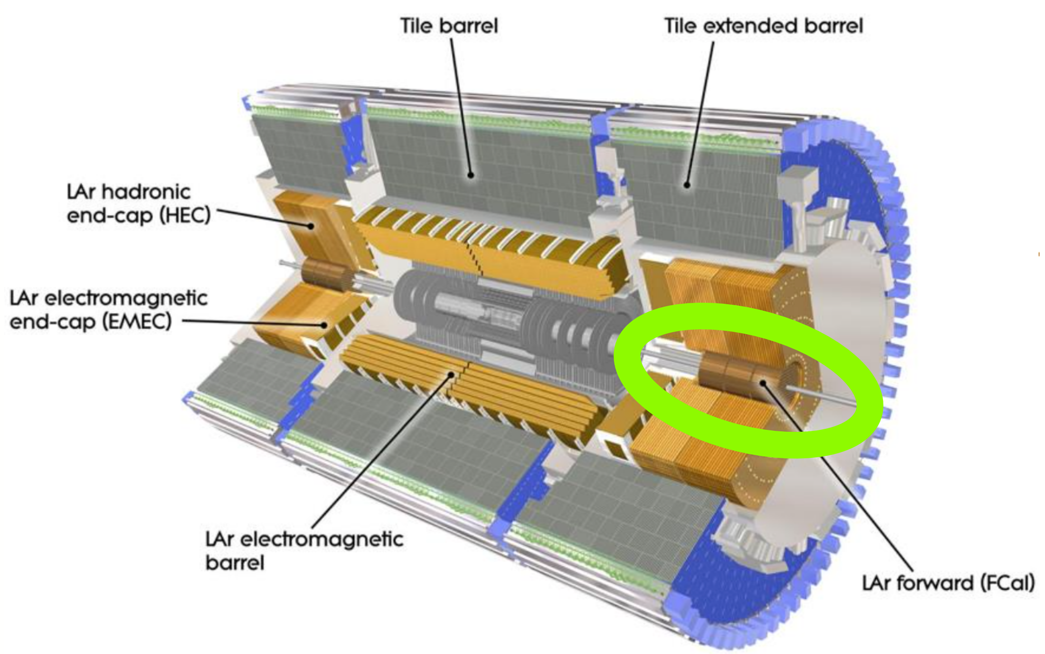




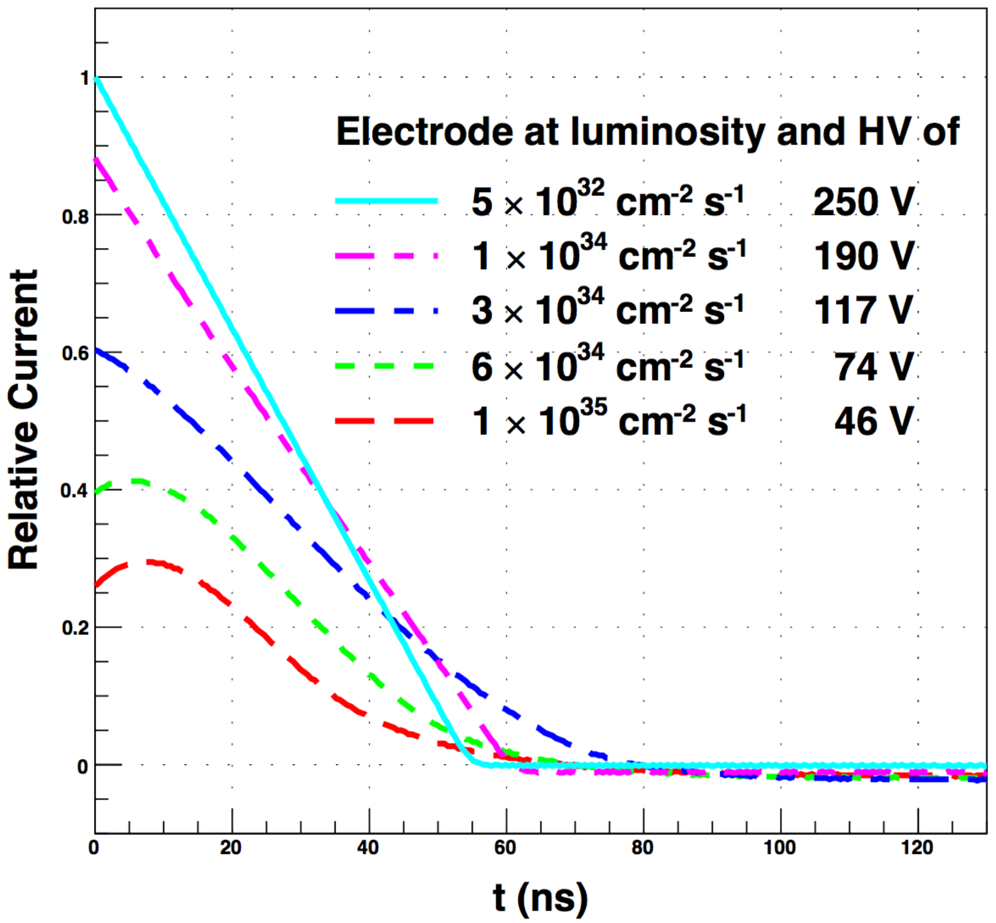


Overview of the Forward Calorimeter Upgrade

- Current Forward Calorimeter (FCAL) consists of 3 modules with FCAL1 closest to the interaction point
  - Groups of four electrodes are ganged together
  - Four such tube groups have their signals summed
  - As luminosity increases above 3×10^{34} cm^2s^{-1}, performance degrades due to space charge effects, HV drop and possibly heating up of the liquid argon.



- Two upgrade options (three when including no upgrade)
  - sFCAL
    - design similar to that FCAL but narrower LAr gaps
    - increase in the readout granularity implemented by removing the signal summing (size of most all of the readout cells reduced by a factor of four)
    - improved cooling system to avoid Ar bubble formation
  - additional miniFCAL in front of the FCAL
    - 3 technologies are explored: diamond, silicon, and liquid argon (planned to use copper as absorber)



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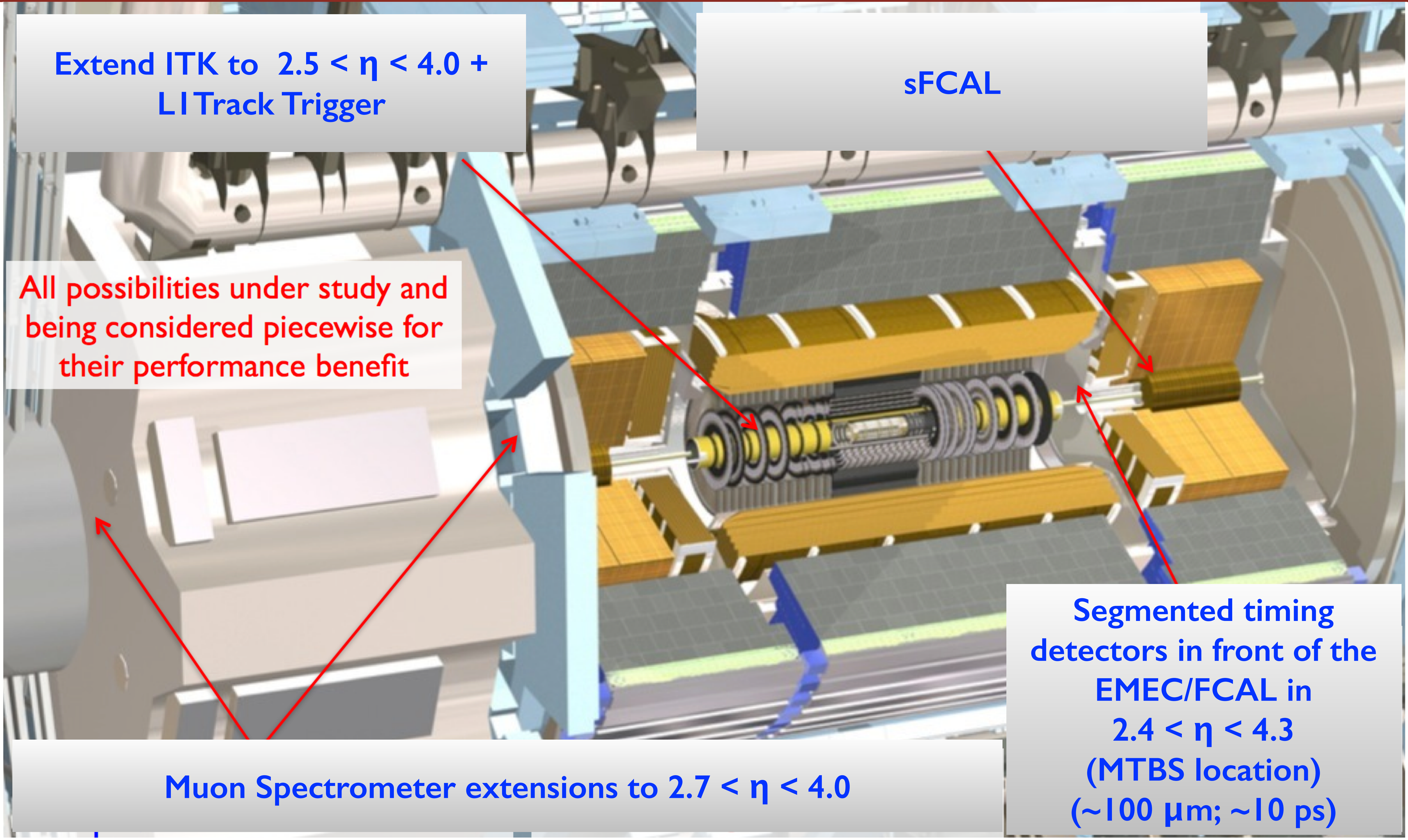
TRIUMF

Extension of ATLAS to large Pseudorapidity



Extend ITK to $2.5 < \eta < 4.0$ +
L1 Track Trigger

sFCAL

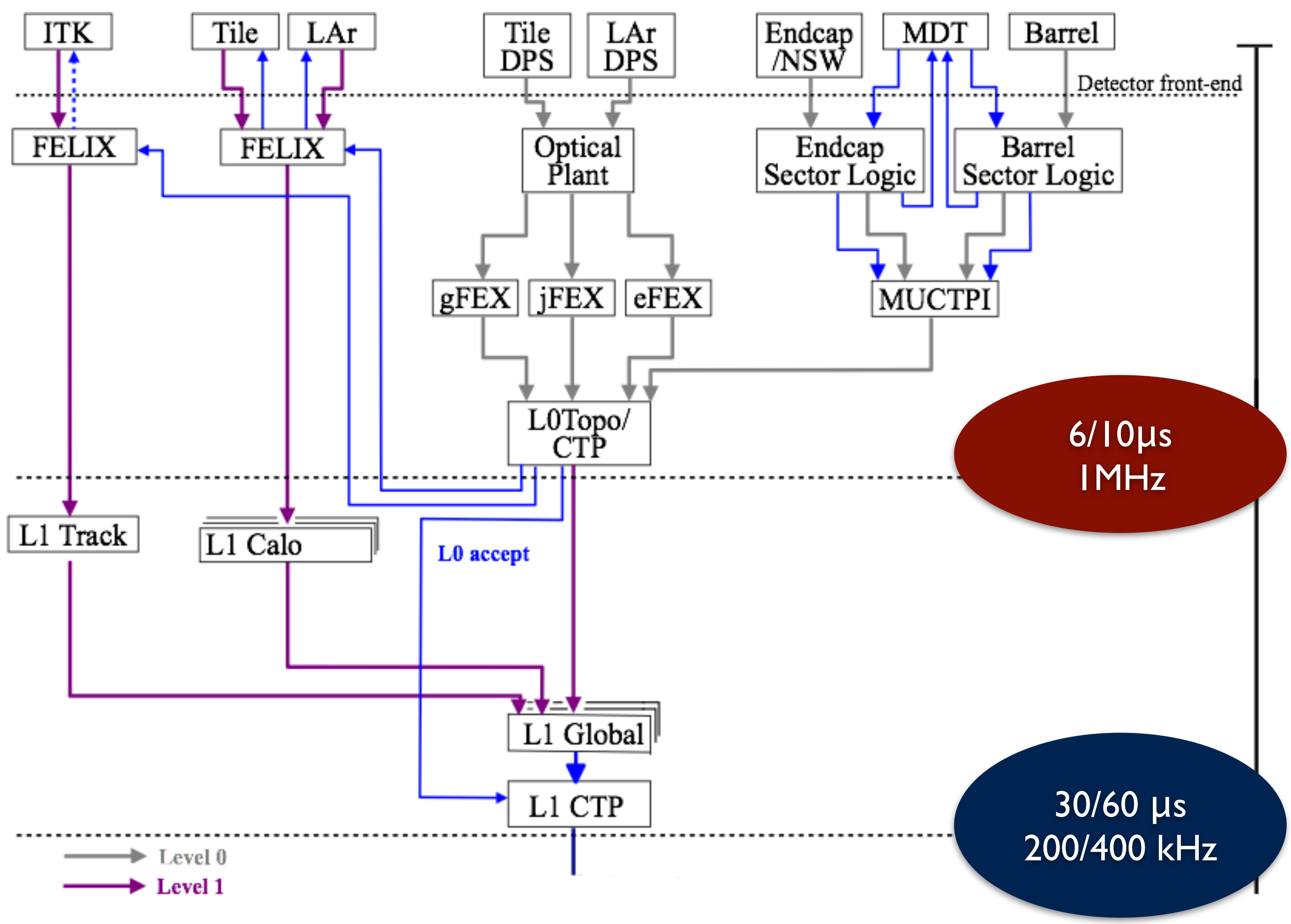
All possibilities under study and being considered piecewise for their performance benefit

Segmented timing detectors in front of the EMEC/FCAL in $2.4 < \eta < 4.3$ (MTBS location) (~100 µm; ~10 ps)

Muon Spectrometer extensions to $2.7 < \eta < 4.0$

Overview of the TDAQ Upgrade

- To maintain low thresholds, a new trigger system is proposed with a 2-step first level hardware trigger:
  - **1st step, Level-0**: calorimeter and muon information defines the regions of interest (benefits from the Phase I Level-1 upgrades)
    - precision muon chambers most likely included
  - **2nd step, Level-1**: **regional tracking information**, regional full calorimeter granularity, refined muon selection using muon precision tracking chambers
- Offline-like algorithms will be used at the High-Level Trigger (software) with a readout rate of 5-10 kHz



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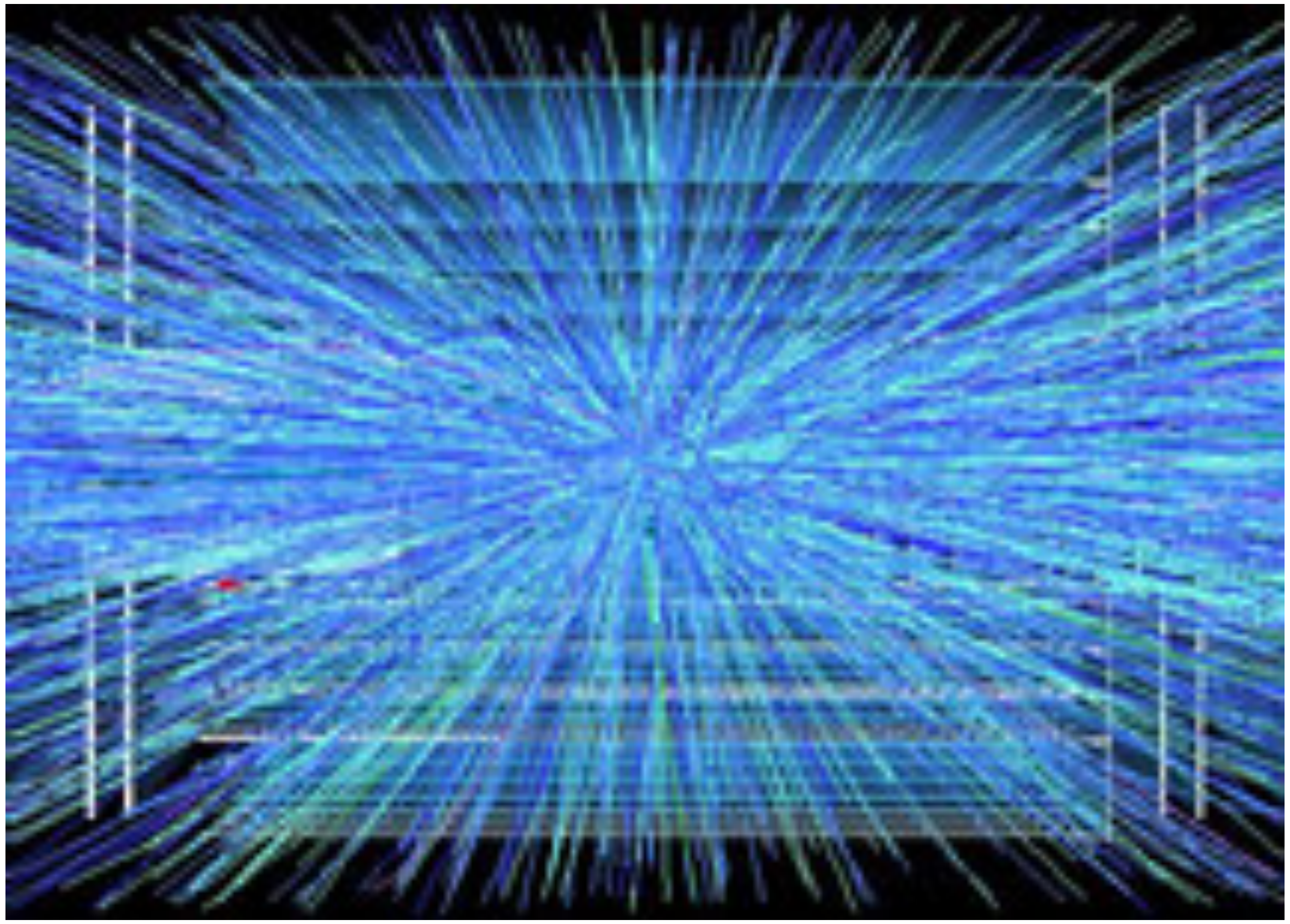
Performance of ATLAS at HL-LHC

- **Performance are assessed using full simulation**
  - Run 2 detector and <μ>=50, 300/fb
  - New tracker (ITK) in Run 1 Calorimeter and Muon system, with varying <μ> and beam configuration



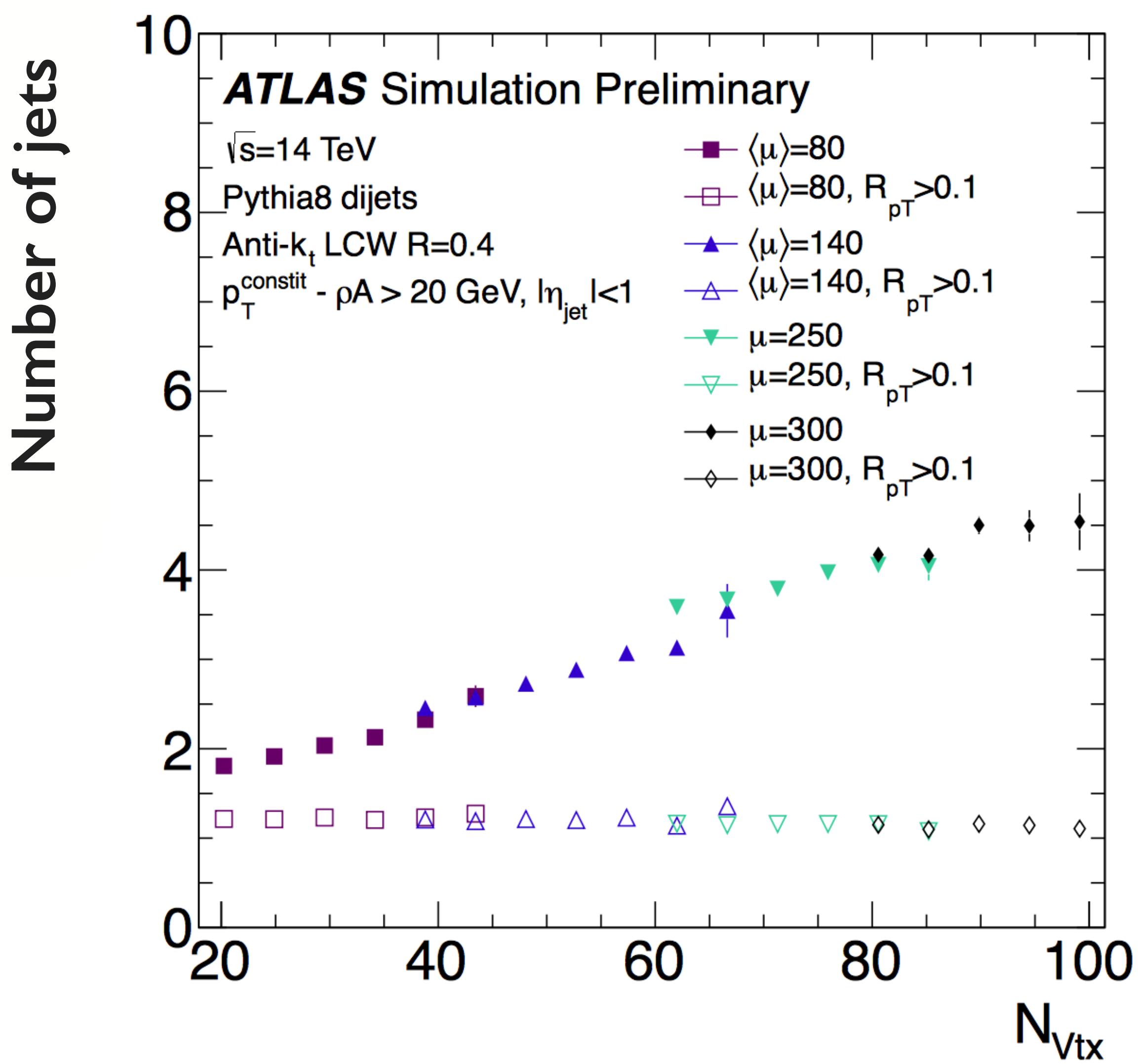
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies#LoIs_TDRs_and_other_notes

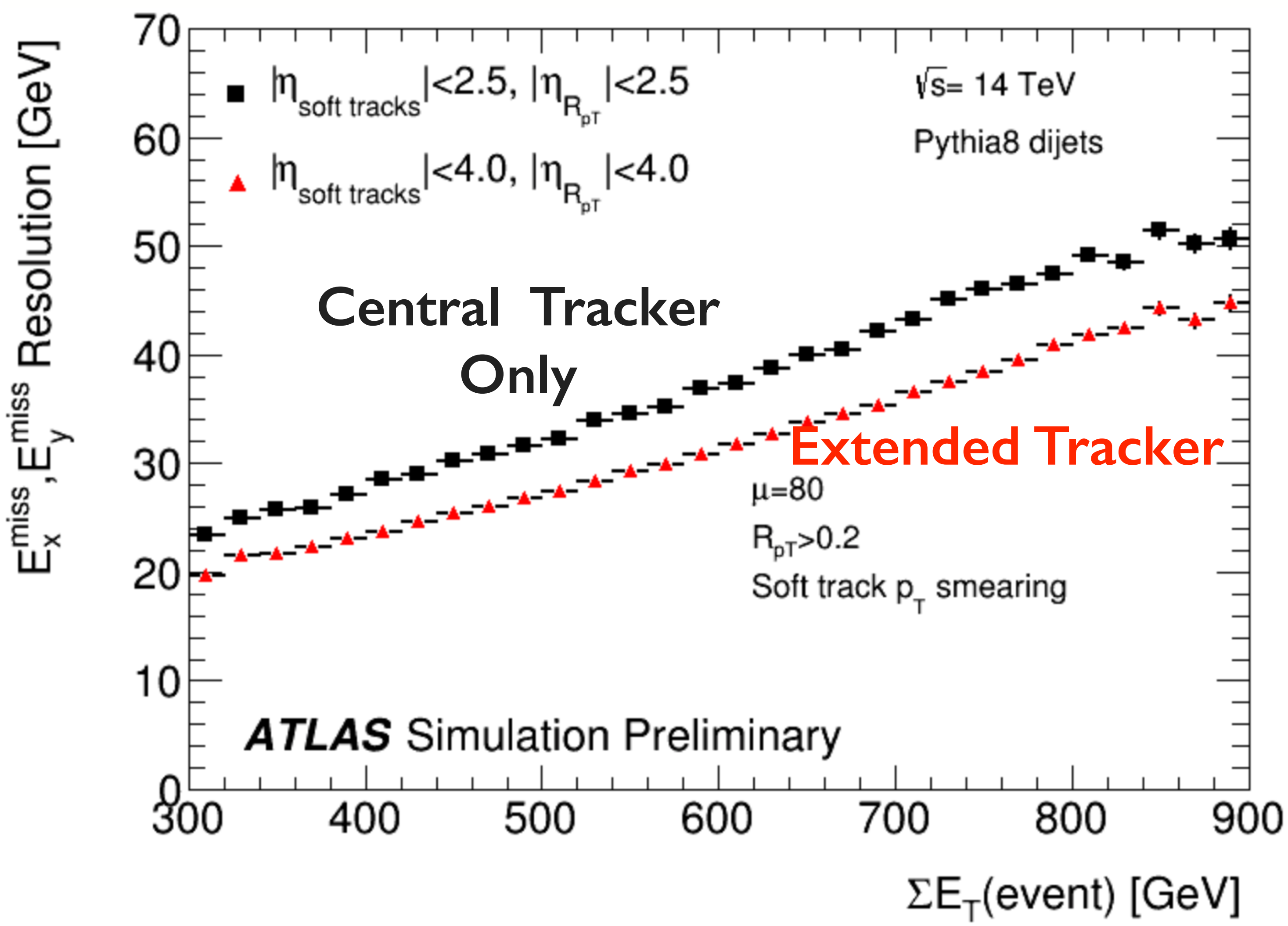
Pile-Up Rejection

- Pile up jets can be discriminated from the hard scatter jets using the jet charged fraction
- Suppression of pile-up jets improves the Etmiss resolution
  - suppression of jets from pile improves if tracker is extended to large eta

$$R_{pT} = \frac{\sum_k p_T^{\mathrm{trk}_k}(\mathrm{PV}_0)}{p_T^{jet}}$$

$$\sigma(E_{x,y}^{miss}) = s + k\sqrt{\Sigma E_T}$$





PileupSuppressionECFA2014

LargeEtaECFA2014

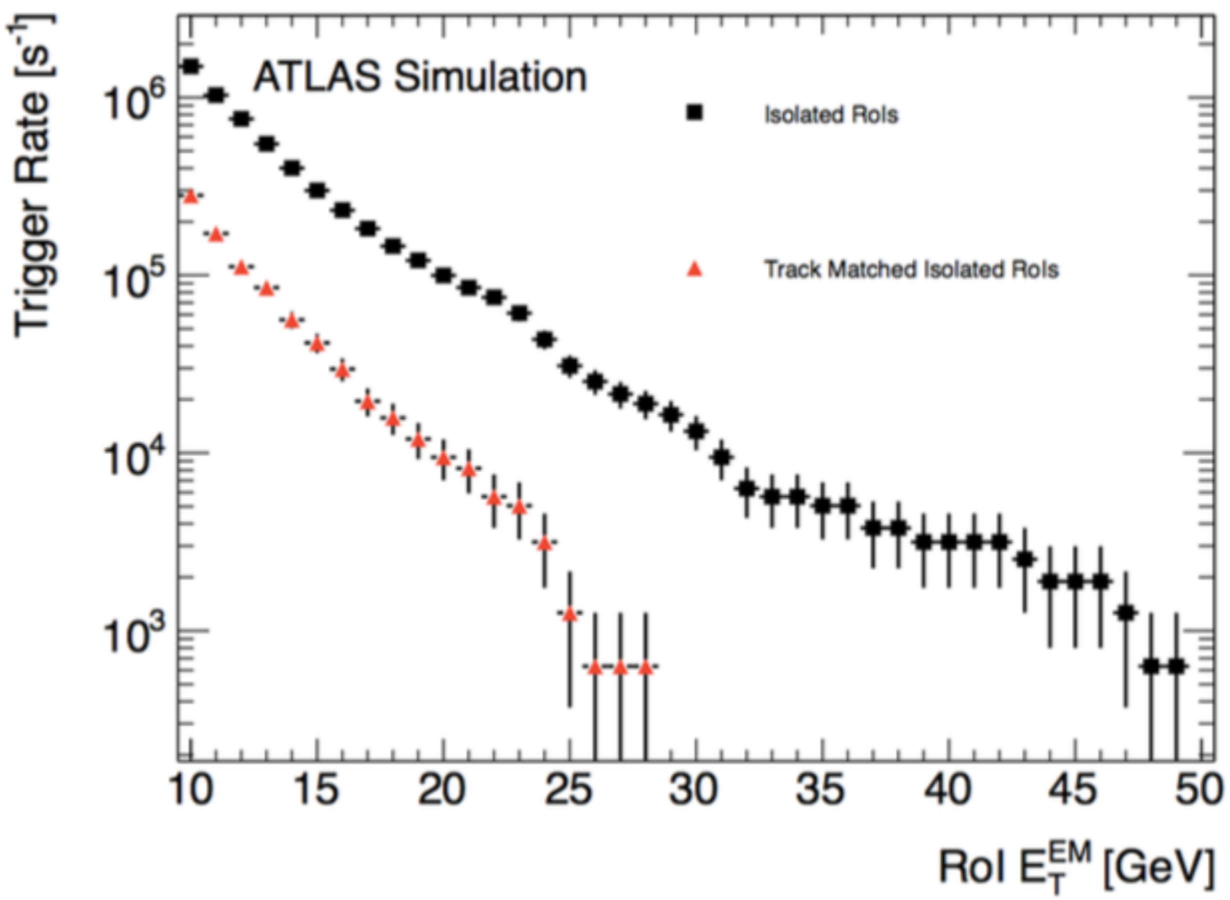
Summary and Conclusions

- To meet the challenges of the accelerator and exploit the large dataset to be collected during Run 3 and the HL-LHC, the ATLAS Collaboration has developed a comprehensive upgrade program
  - The Phase 1 upgrade will focus on the trigger system, to allow ATLAS to run at 3x design instantaneous luminosity while maintaining low trigger thresholds
    - New Small Wheel
    - L1 Calo Trigger
    - Fast Track Trigger
  - The Phase 2 upgrade is critical to run ATLAS up 7x design instantaneous luminosity and efficiently collect 3000/fb by 2035
    - Full-silicon based tracker (ITK)
    - sFCAL or miniFCAL
    - TDAQ (including L1Track)
- A combination of new detector components and improved algorithms provides the necessary pileup mitigation and guarantees good performance even under the challenging HL conditions

Additional Material

L1Track Upgrade

- Tracking at L1 is critical electron, taus, jet triggers as the instantaneous luminosity increases
- The baseline design for the proposed L1Track uses an RoI based approach
  - L1Track will provide *all* tracks in a number of relatively small regions (~10% of ITK) identified at L0
- The main challenge is to fit within the trigger latency constraints
  - expected to operate at ~ 6μs latency but high level of parallelism required
- The associative memory (AM) technology used in the FTK for the pattern recognition is the prime candidate for the L1Track pattern recognition strategy.



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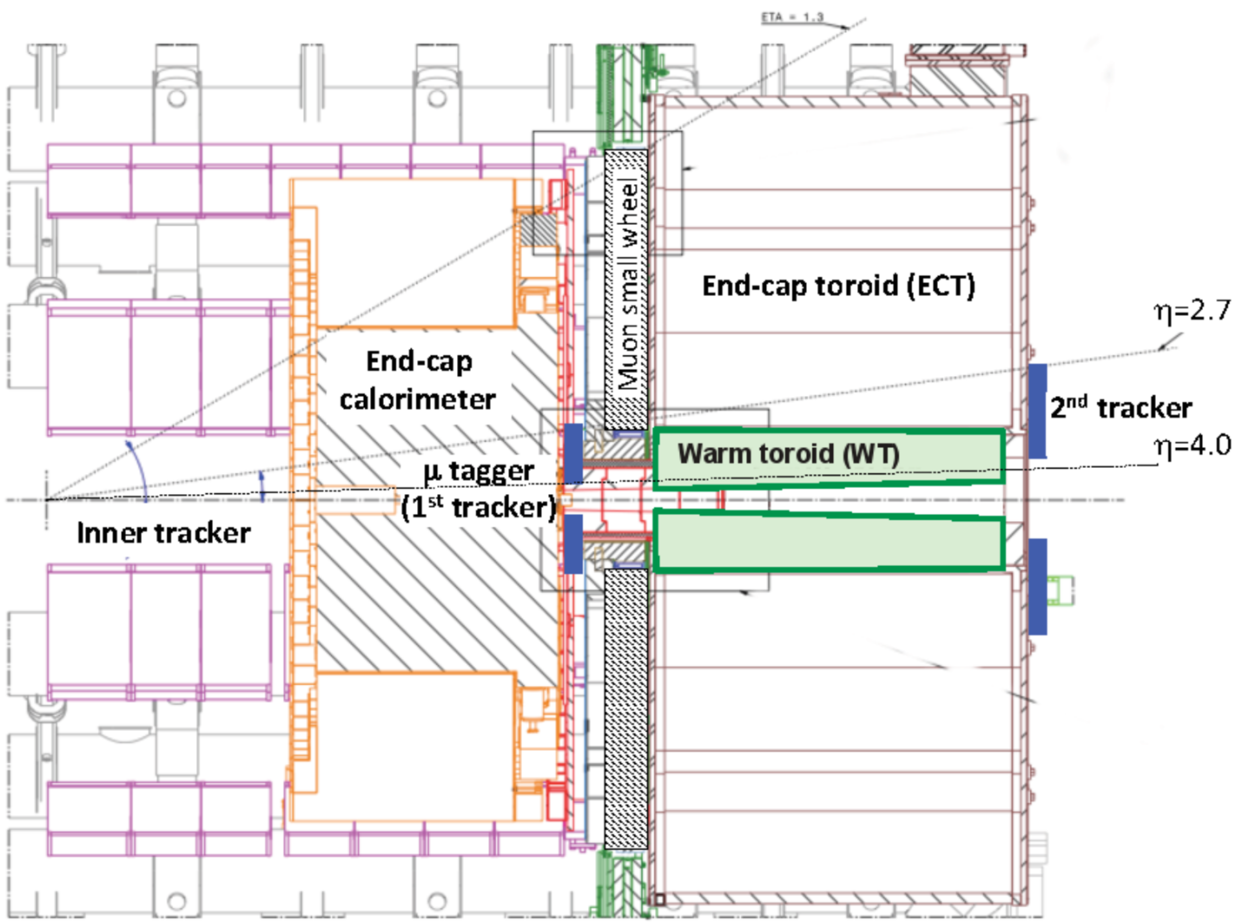
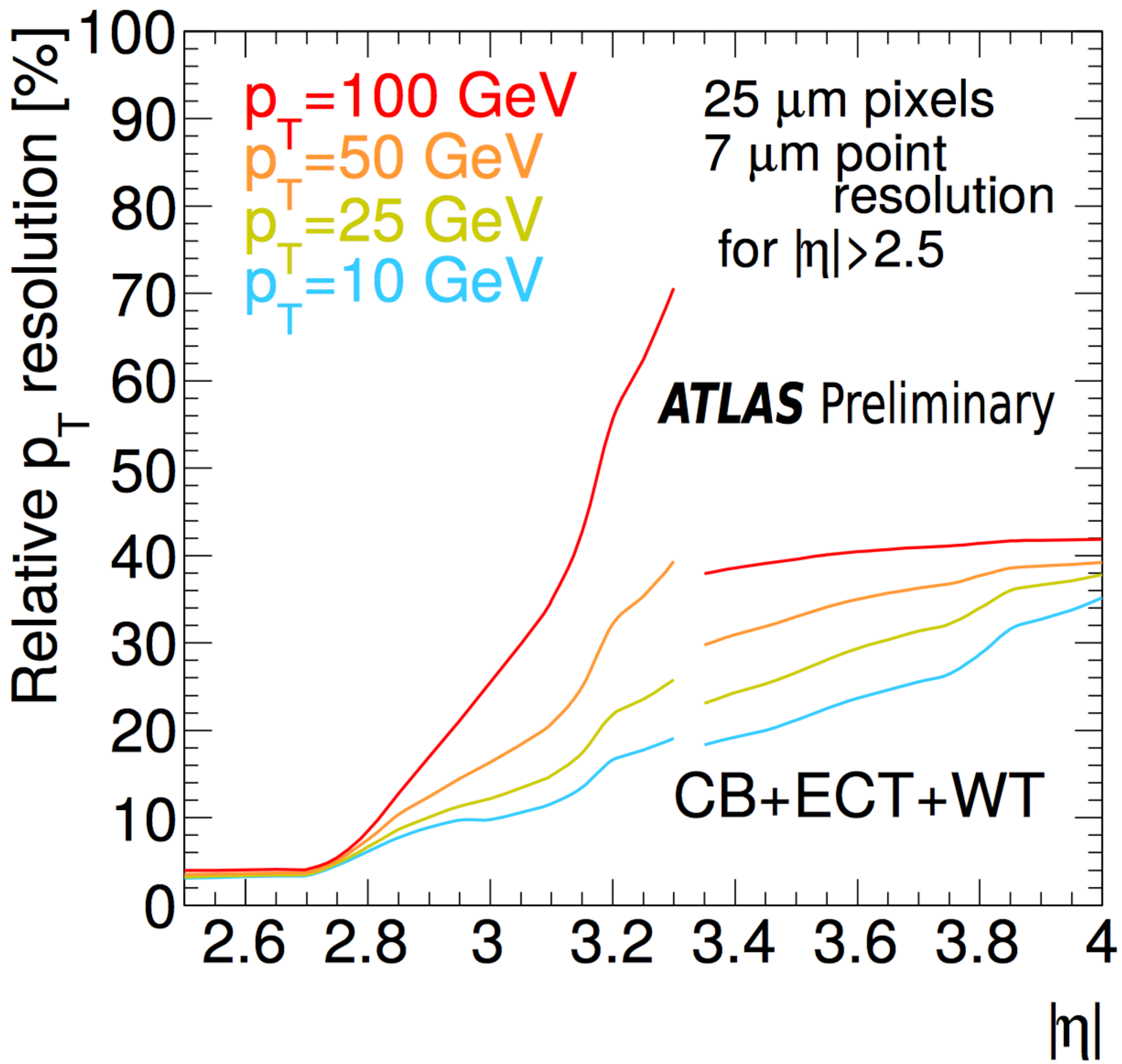
Muon Extension





https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/MUON/PublicPlots/2014/ATL-COM-PHYS-2014-1329/

L1 Calo Trigger Upgrade

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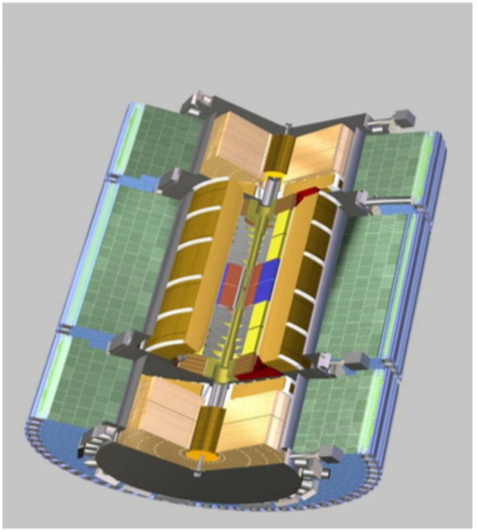

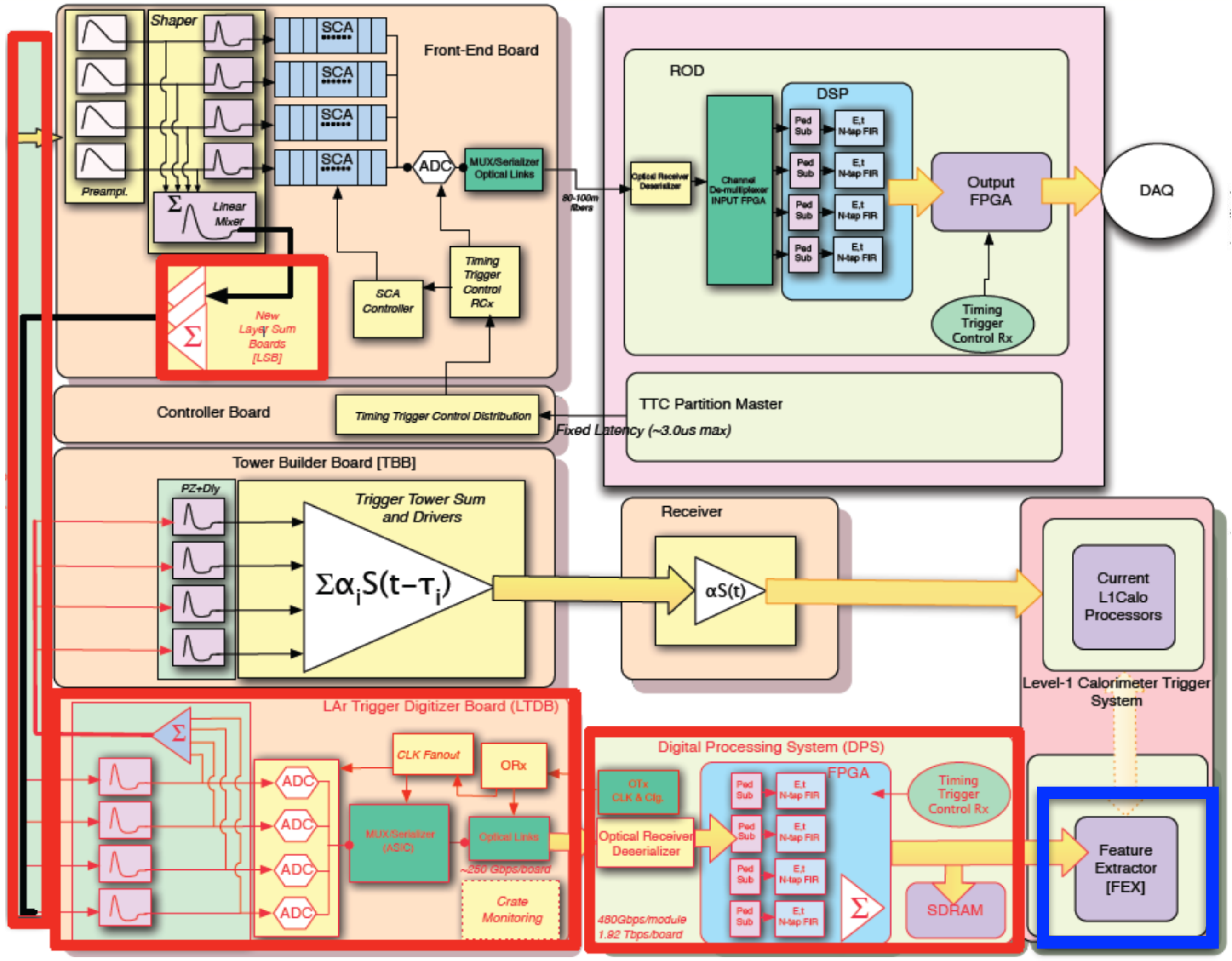

Red=new LAr system

Blue=new trigger FEX

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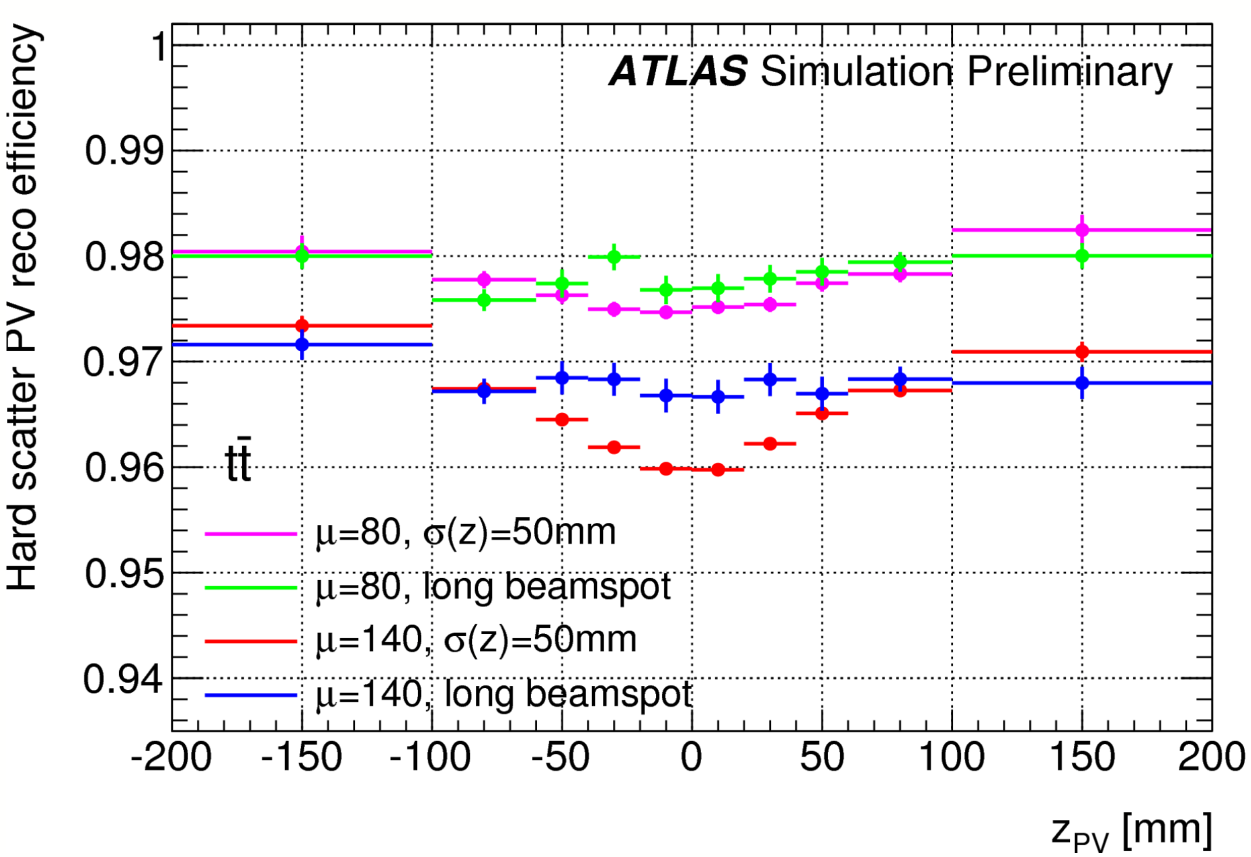
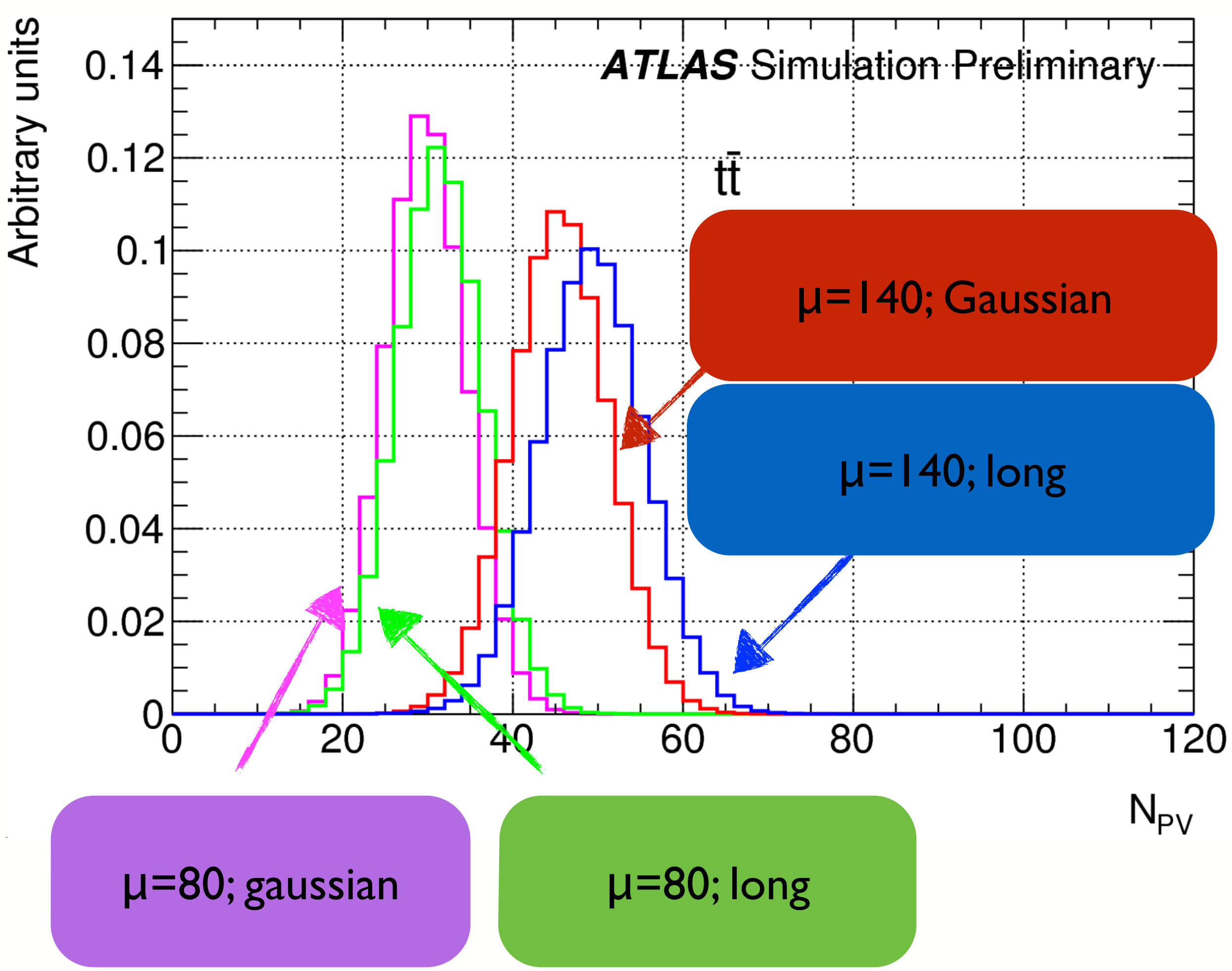
- The upgrade of the Layer Sum Board and of the Base-plane allows the LAr Trigger Digitizer Board (LTDB) to digitize information with high granularity
    - Tower Build Board kept as fully operational legacy system
- Digitized signals are processed remotely by the LAr Digital Processing System (LDPS) converting the samples to calibrated energy in real-time and sending them to the new Feature Extraction processors of the trigger system

Performance of ATLAS at HL-LHC: Vertexing

- **With an average pile-up value of 200 interactions per bunch crossing, the most critical component in object reconstruction is pile-up mitigation**
  - <μ>=200 is an average of a Poisson distribution with a sigma of about 12 events
- Primary vertex finding efficiency ~96% in tt events
  - Long-flat beam configuration might mitigate effects from pile-up

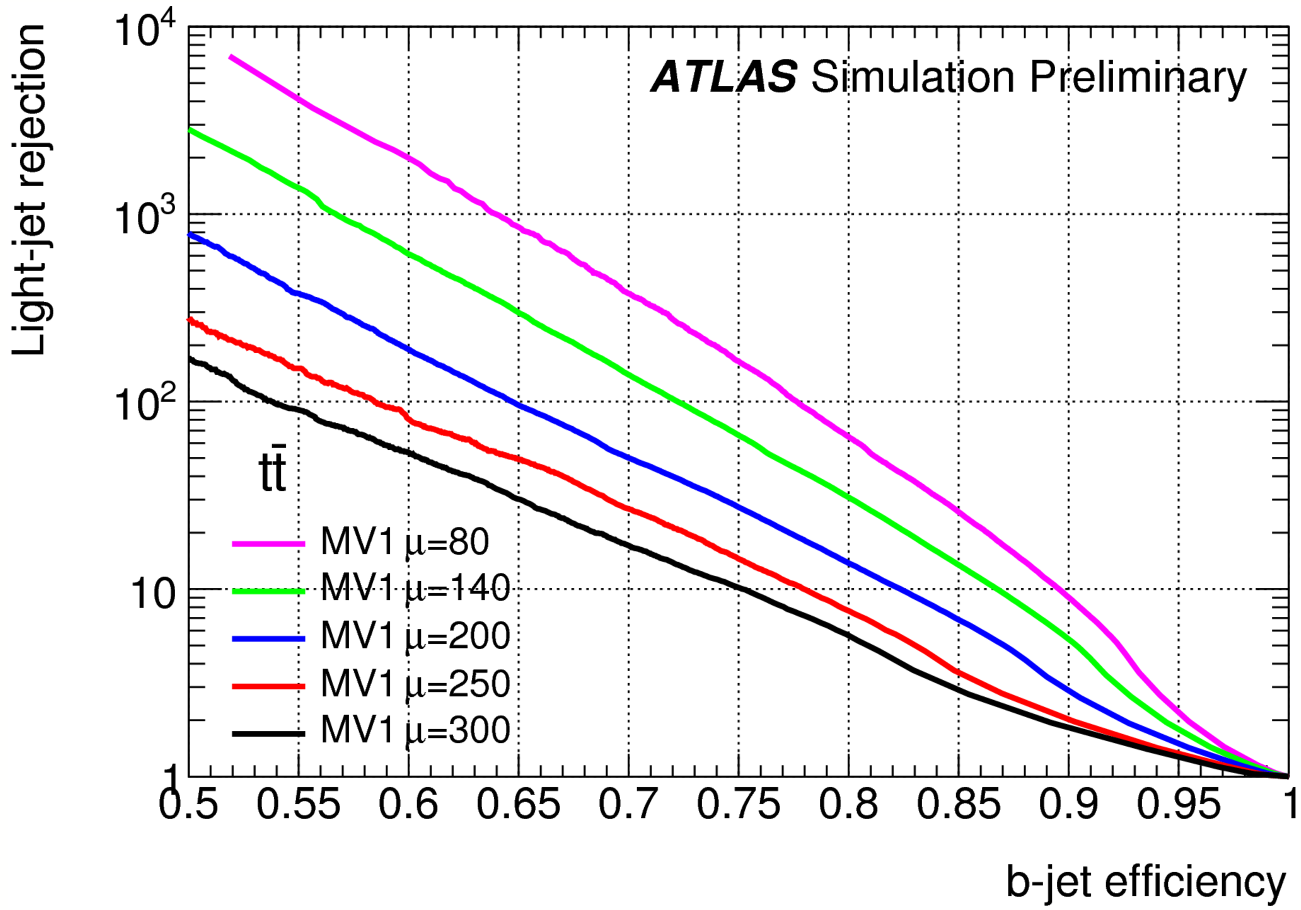


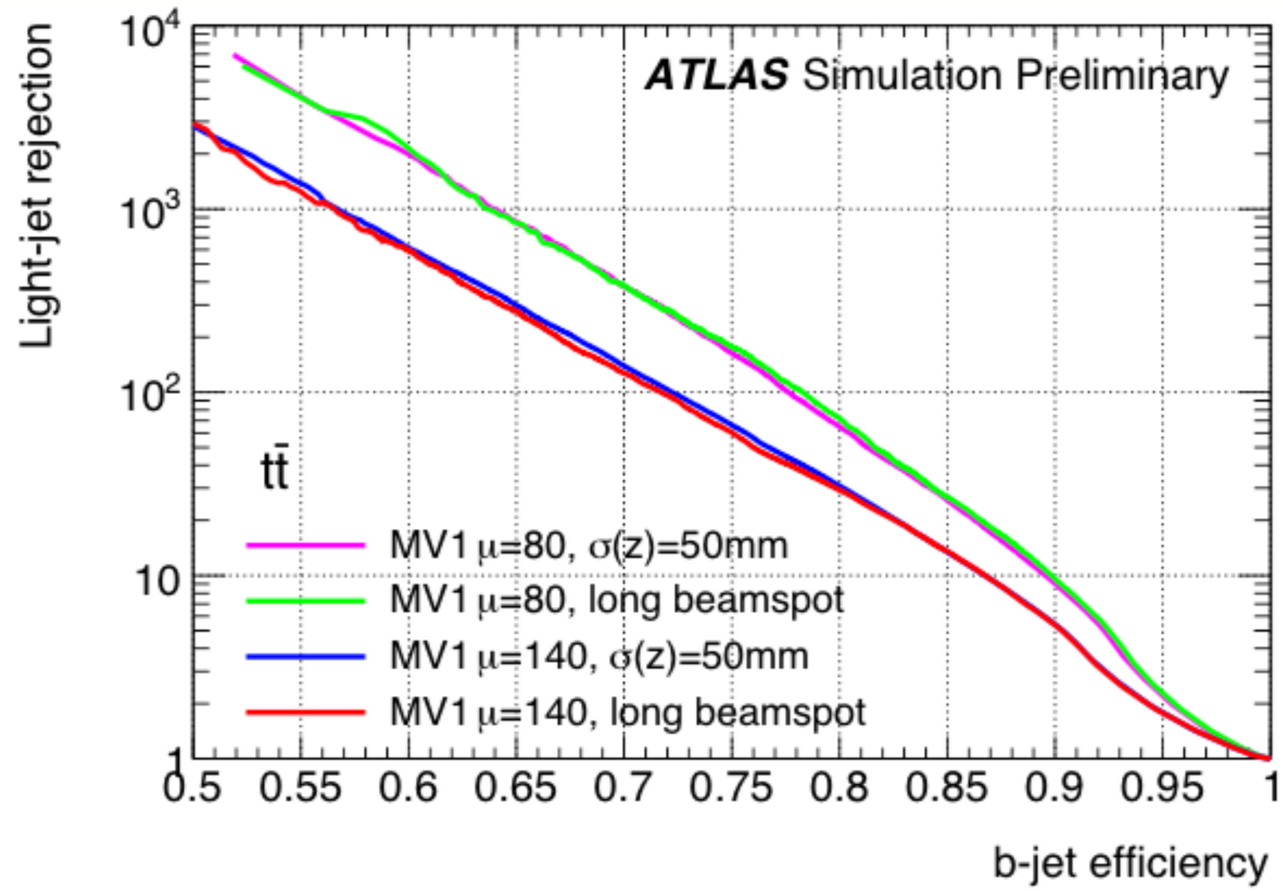


PLOT-UPGRADE-2014-003

Tagging b-jets

- High pile-up in general leads to higher mis-identification probability for fixed b-tagging probability
- Phase 2 detector recovers the b-tagging performance goals for Run 2 despite the higher pile-up
  - The benefit from the long beam spot is not significant
  - *Run 1 algorithms run out of the box, no re-optimization shown today*





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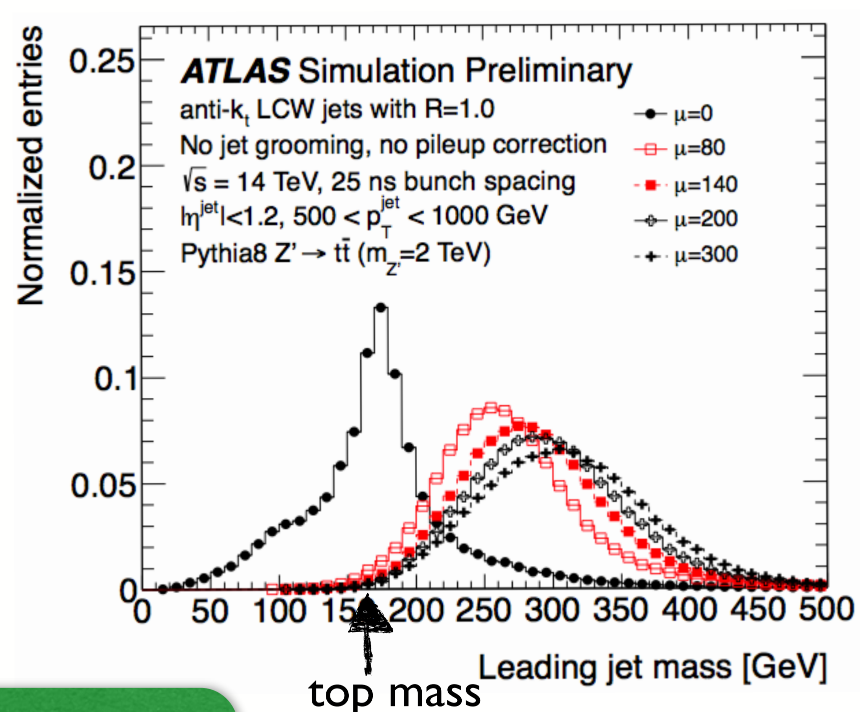
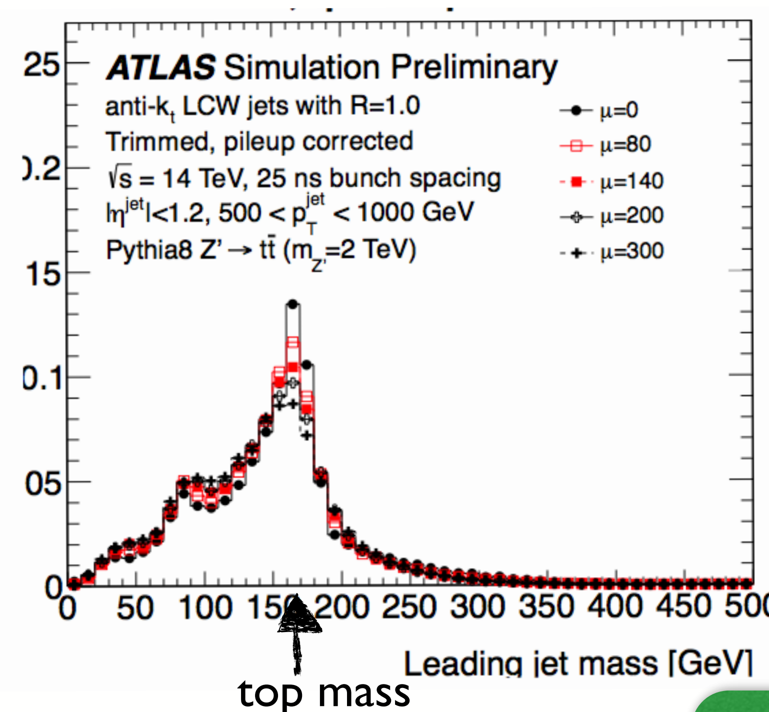
Jet Substructure

- Removal of low-pT R=0.3 subjects and pile-up corrections are applied to hard-scatter jets with R=1.0 to restore scale and improve energy resolution

Z' in tt





No pile up corrections

Pile up corrections applied

QCD