Collecting and analysing data at high pile-up with ATLAS and CMS.

Detector designs, reconstruction performance, and analysis strategies

N. Styles, for the ATLAS and CMS Collaborations,
Rencontres De Moriond,
18/03/15

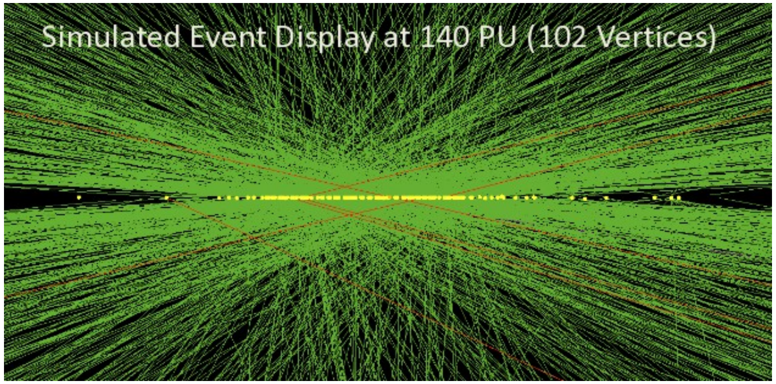
HELMHOLTZ GEMEINSCHAFT

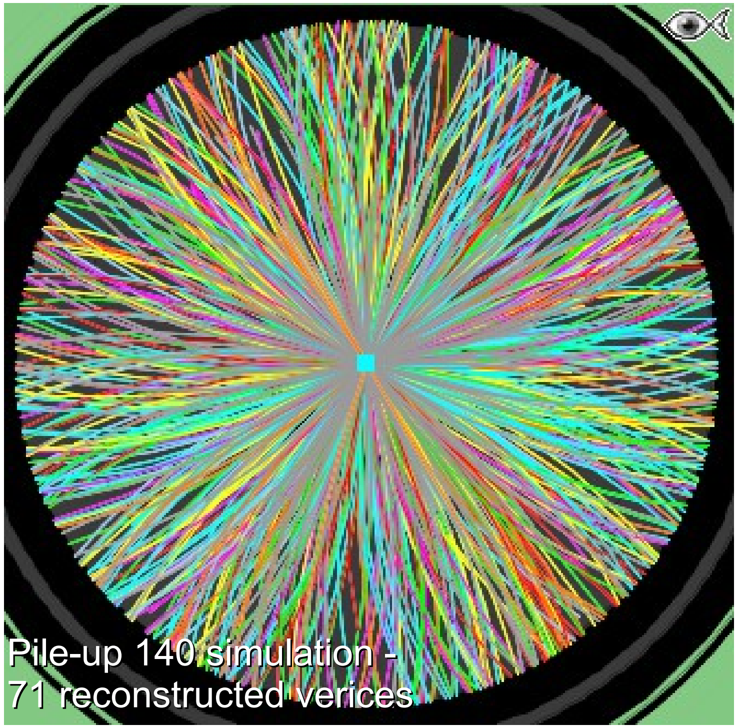
DESY

Introduction

- High-Luminosity LHC (HL-LHC), planned to begin operation in 2025
  - Comprehensive program of accelerator upgrades
  - "Phase 2" LHC Upgrade
  - Peak instantaneous luminosity 5 - 7 $\times 10^{34} cm^{-2}s^{-1}$
  - Integrated luminosity 250-300 fb^{-1} 14 TeV pp collisions per year, aiming at total dataset of 3 ab^{-1}
  - Implies events with pile-up 140-200
- Will provide extremely rich physics potential
  - To make best use of this, experiments will need to find ways to cope with challenging environment
  - Upgrades to detectors, new reconstruction techniques, revised analysis strategies

See talk from Mike Lamont



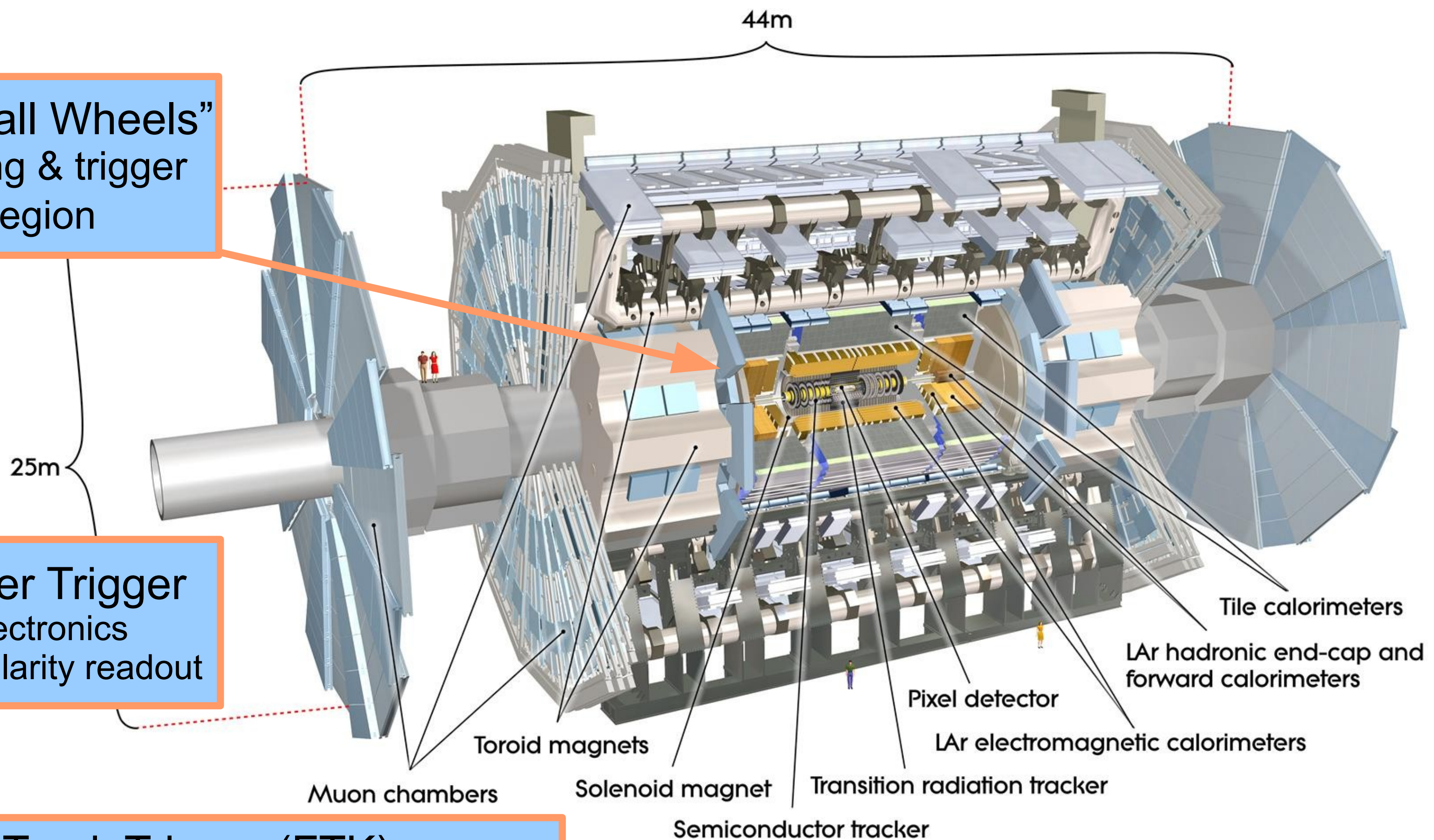


ATLAS Detector Phase 1 upgrades

- ATLAS will already undergo a series of ' Phase 1' upgrades prior to HL-LHC operation – to be completed by 2020 – which will remain in place for Phase 2

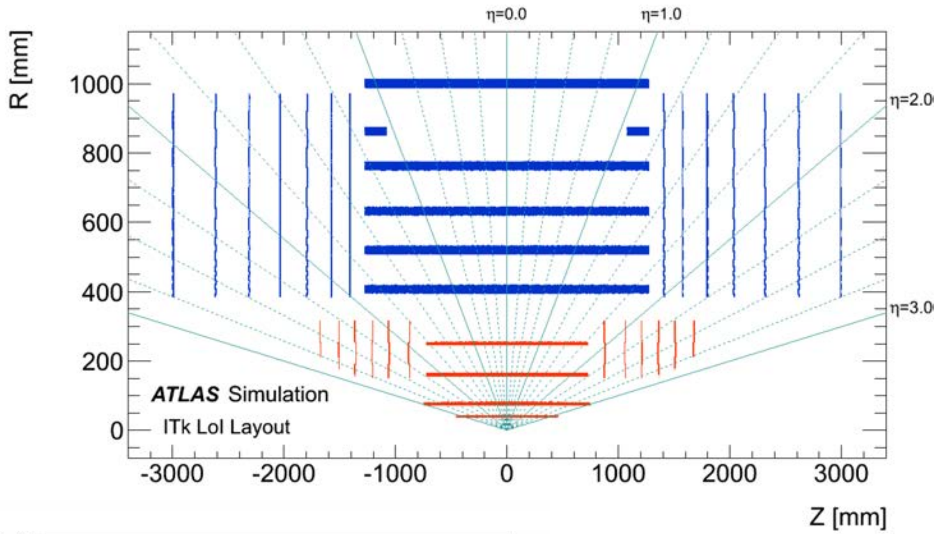
Muon "New Small Wheels"
Improved tracking & trigger in forward region

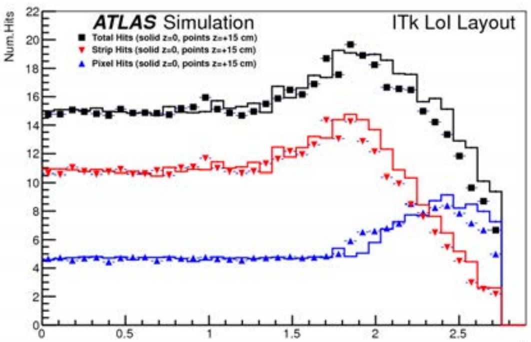
L1 Calorimeter Trigger
Upgraded electronics
Allows finer granularity readout



Fast Track Trigger (FTK)
Hardware-based track finder
Based on hit pattern matching to pre-stored patterns
Runs after L1 Trigger

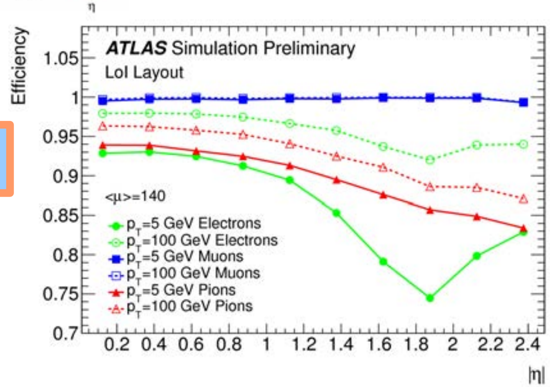
ATLAS Phase 2 Inner Tracker Upgrade - ITK





14 Si hits over majority of tracking acceptance – gives robustness against any module losses

Tracking efficiency



- For Phase 2 upgrade, ATLAS plans full replacement of Inner Tracker
  - All silicon tracker (pixels and microstrips)
  - Significantly increase granularity
  - Minimise material budget within tracking acceptance
  - Sufficient hits on track to maintain high efficiency and combat combinatorics at high pile-up
- ITK "Letter of Intent" layout has been developed
  - Used as baseline for majority of performance studies

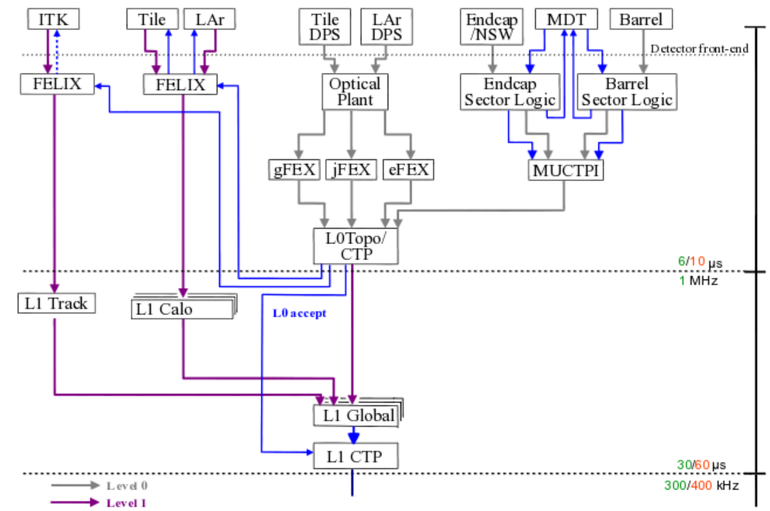
ATLAS – Upgrade to other systems

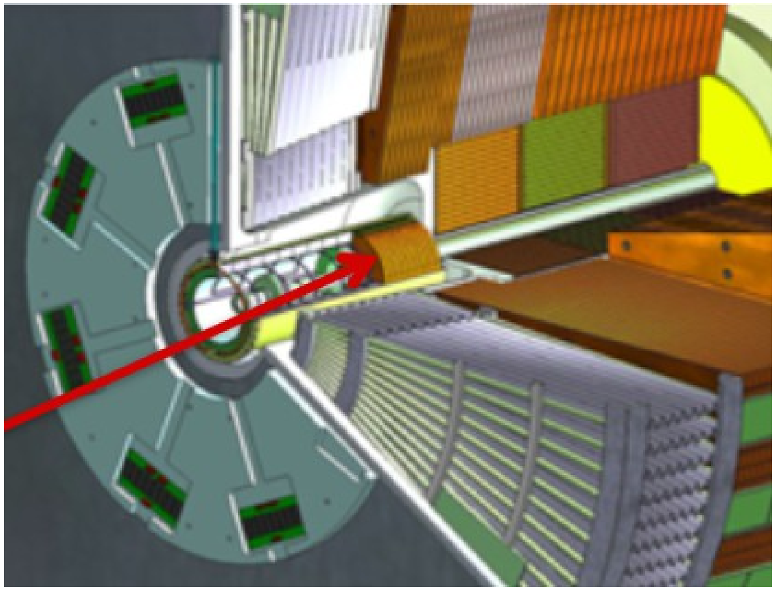
> New Trigger Architecture

- 2-Level Hardware trigger design
- Level 0: 1 MHz, 6µs latency, uses Calo + Muons
- Level 1: 300-400 kHz, 24µs latency
- L1Track: Use tracking information earlier in trigger processing – move part of HLT track reconstruction to L1
- Region-of-Interest (RoI) based approach

> Calorimeters

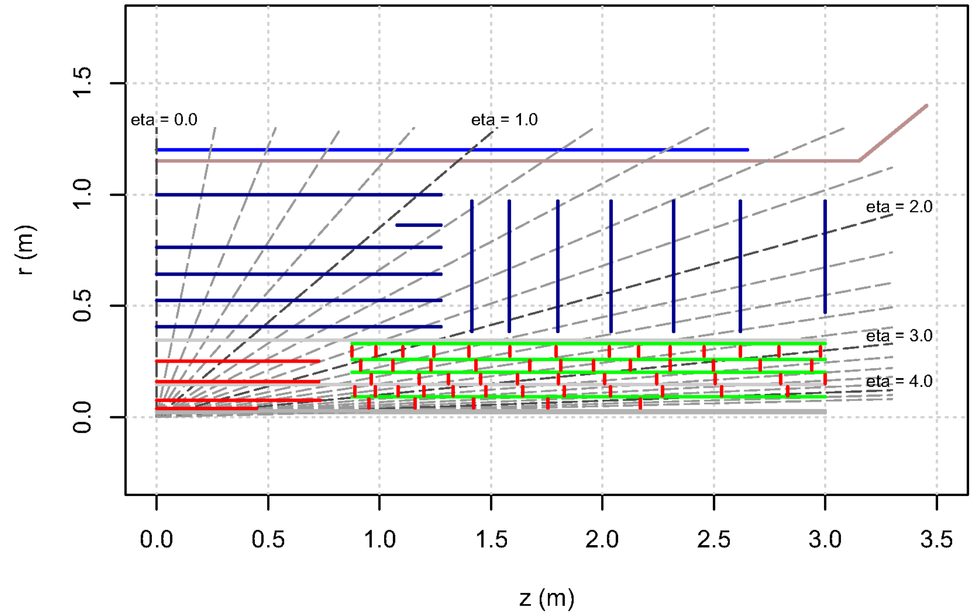
- Tile and Liquid Argon calorimeters require full electronics replacements
- Needed to cope with increased radiation levels and trigger rates
- Forward calorimeter may be fully replaced if significant degradation of current system, or higher granularity mandated by physics requirements

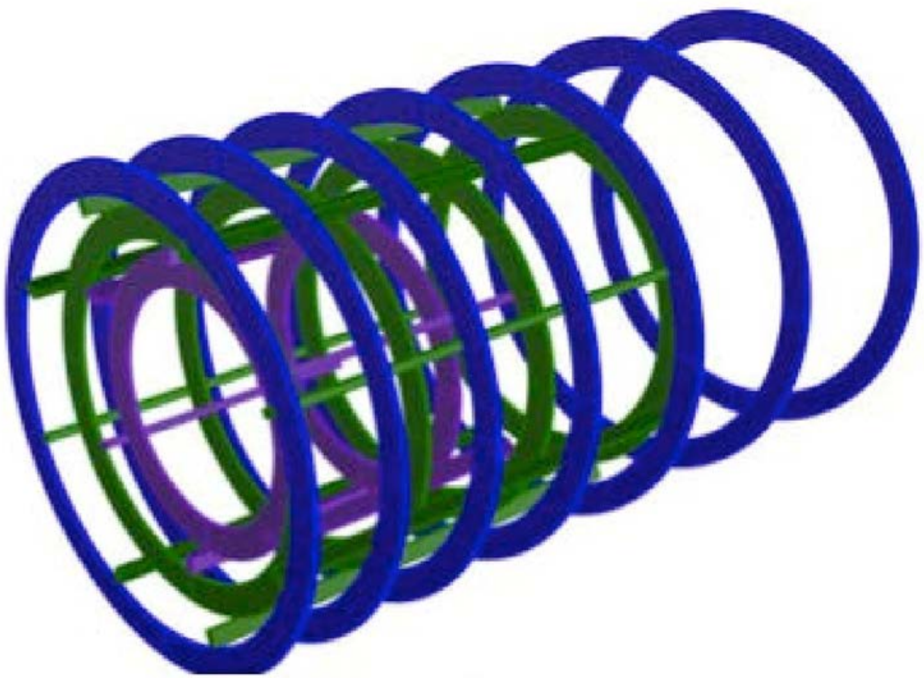




ATLAS– Layout Concepts with high-η extensions

- Potential for extending tracking coverage to |η|<4 under serious consideration
  - Tracking performance under investigation – limitations from field strength in forward region
  - Extension of pixel system proposed with "rings" in place of traditional endcap disks – offers more flexibility for placement of modules and services



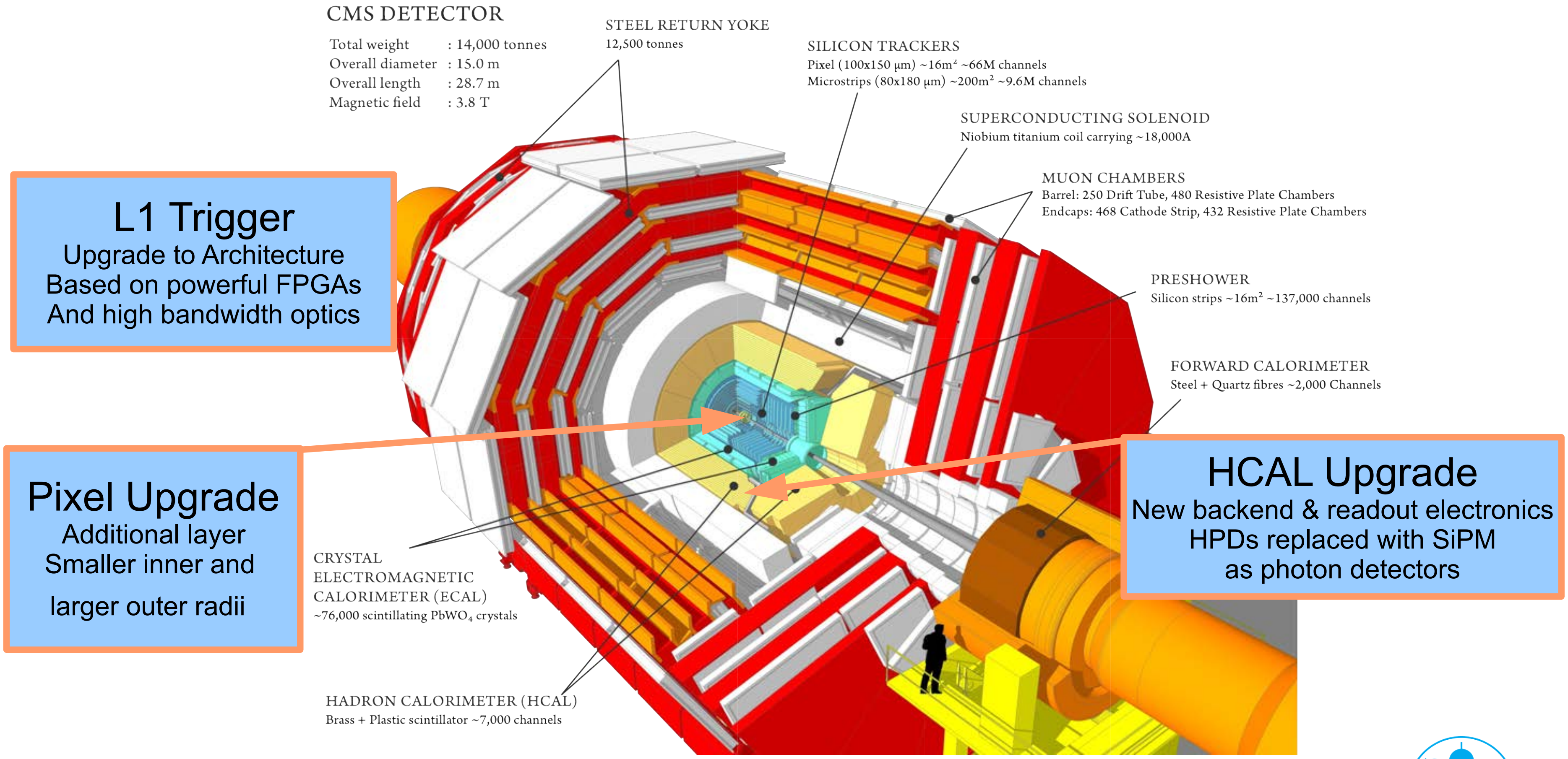


- Could be combined with modifications to other systems to maximise impact
  - Additional muon chambers
  - Increase granularity in forward calorimeter

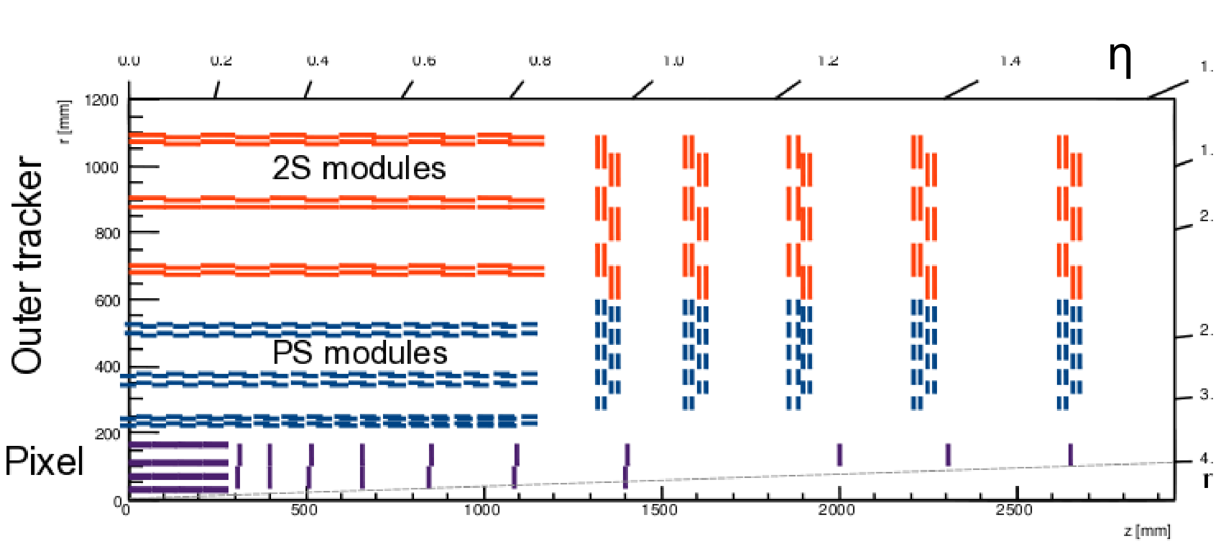
See also talk from Alex Tuna

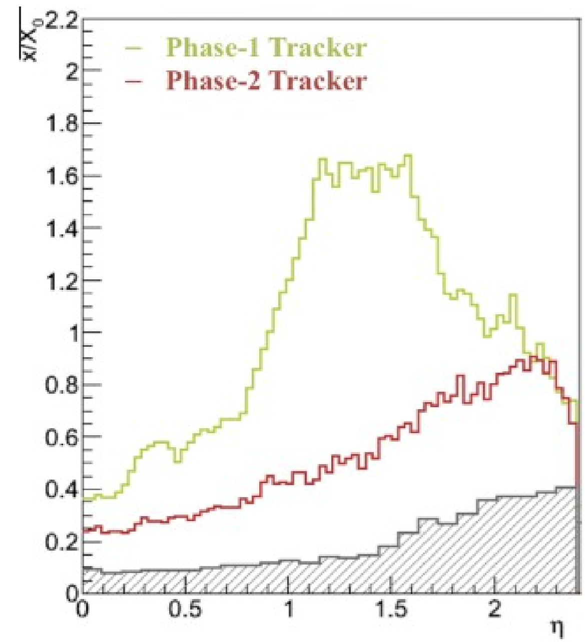
CMS Detector Phase 1 Upgrades

- CMS also plans Phase 1 Upgrades that will remain in place for Phase 2
  - Pixel system will be replaced for Phase 1, but not remain in place



CMS Phase 2 Inner Tracker Upgrade

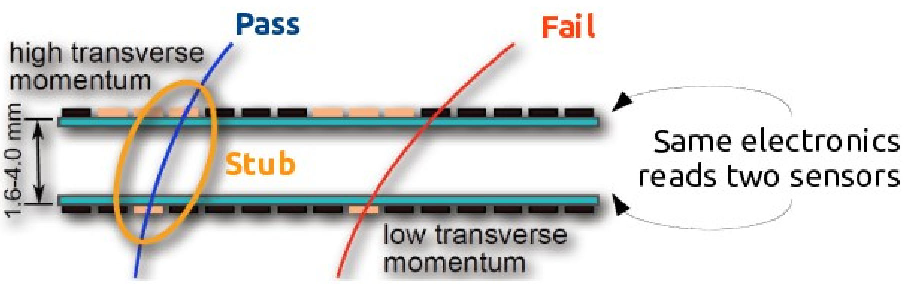


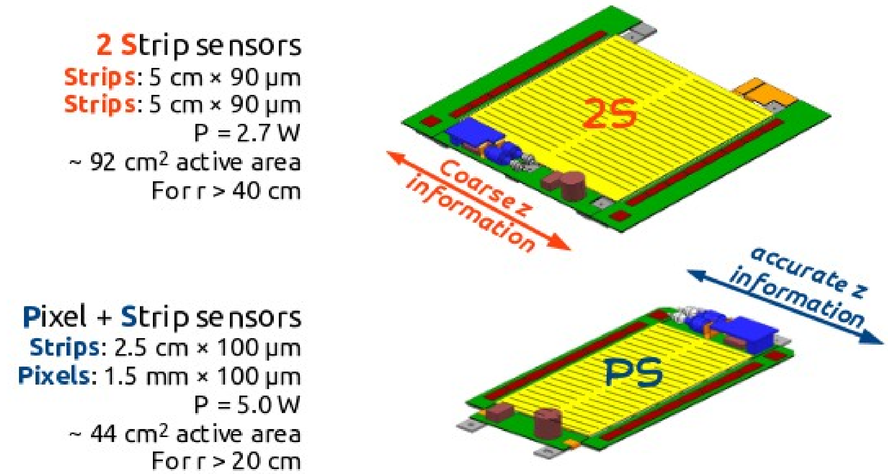


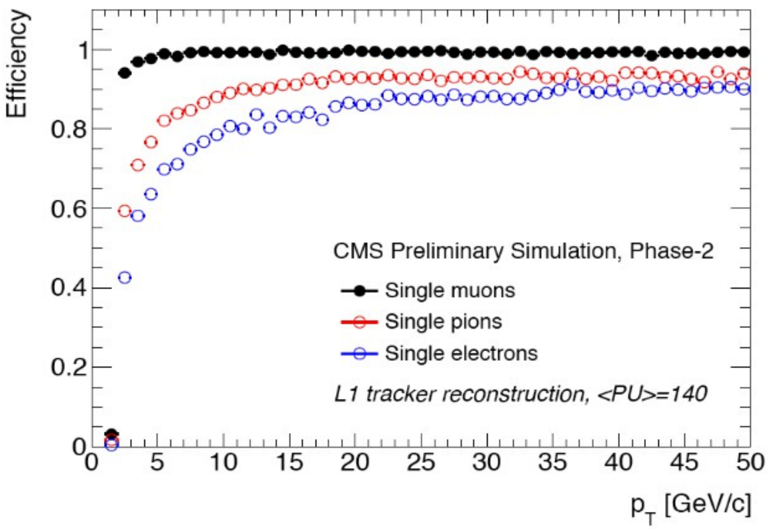
> CMS baseline design for full tracker replacement in Phase 2

- As ATLAS, emphasis on minimising material and increasing granularity, with ample hit coverage over tracking acceptance
- CMS baseline includes tracking coverage up to |η|<4
- CMS Tracker replacement designed to allow self-seeded L1 Track Trigger – different approach to allowing tracking information at earlier stage of trigger

CMS Self-Seeded Track Trigger







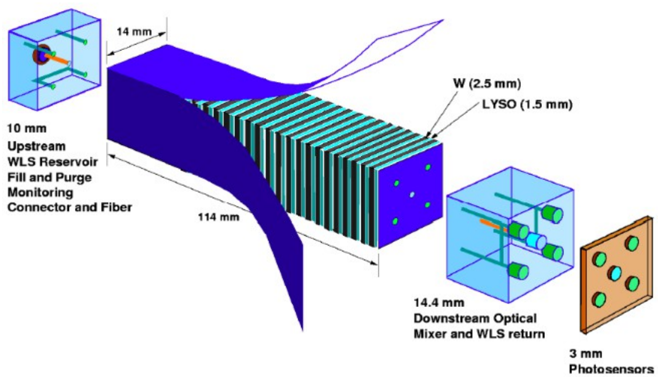
L1 Tracking performance using stub input

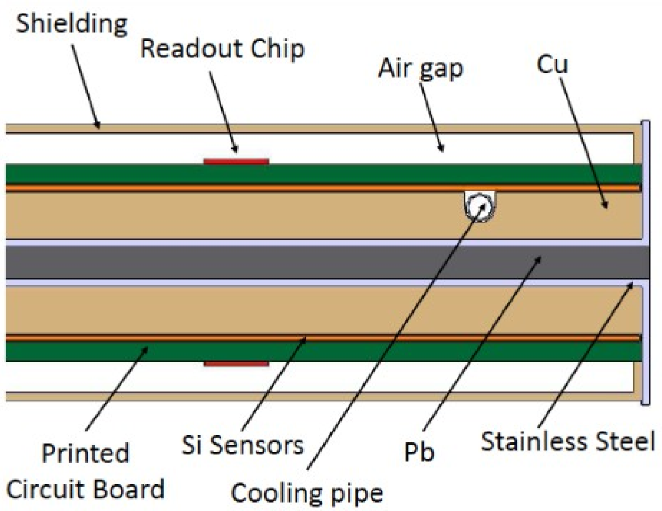
- Use lever-arm between sensor sides to trigger on high-p_T tracks
  - Different granularities used in different regions as necessary
- 2 Hardware implementations under consideration
  - Associative memory & commerical FPGAs
  - L1 tracking performance under study
  - Requires ~10 µs latency

DESY

CMS Upgrades to other systems

- Forward calorimetry will need replacement due to radiation-induced signal loss – 2 concepts under consideration
  - Compact Pb/LYSO Shashlik Forward EM Calorimeter with Scintillator-based HCAL
  - Silicon/lead/copper EM and silicon/brass HCAL, with scintillator/brass backing calorimeter

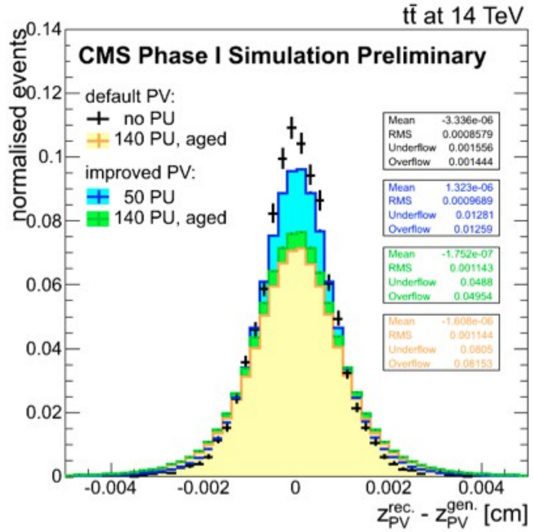


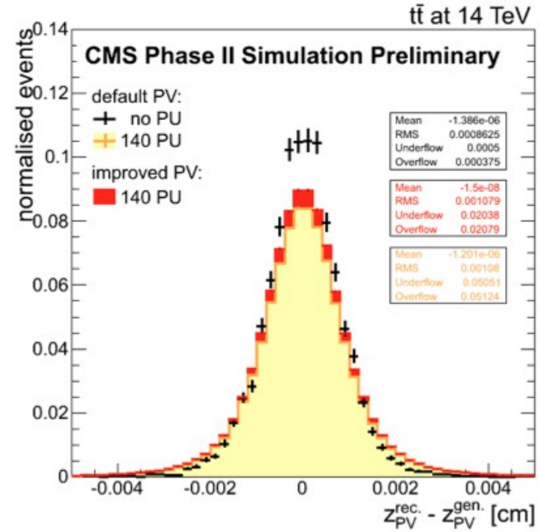


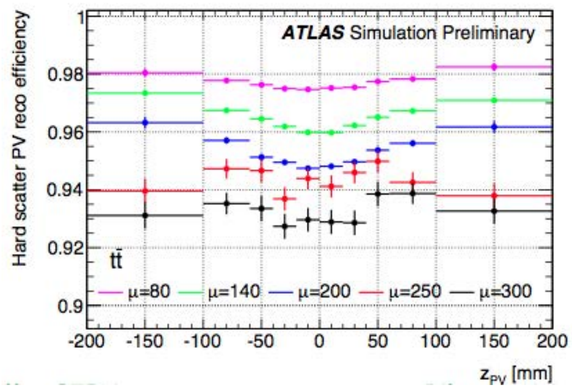
- Improvements to Muon system
  - Electronics upgrades to comply with Trigger upgrade
  - IRPCs and GEMs in forward ($1.6<|\eta|<2.4$) region – enhanced redundancy and cope with higher rates
  - Very-Forward extension to higher η with GEMs – baseline $2.0<|\eta|<3.0$ (dependent on calorimetry)

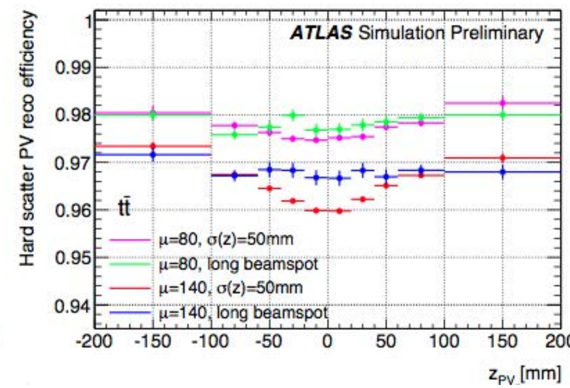
Performance of Upgraded Detectors - Vertexing

- CMS studied vertexing performance of new detector together with algorithmic improvements
  - Shows improvements with respect to 'aged' Phase I detector
  - Improvement of vertex finding efficiency from 80 % (aged detector, old algorithm) → 96 % (new detector, new algorithm)
- ATLAS studied effect of different beam profiles
  - σ =5cm gaussian, and 'long, flat' beamspot from -15cm to +15cm in z
  - Currently using “non-optimised” vertexing





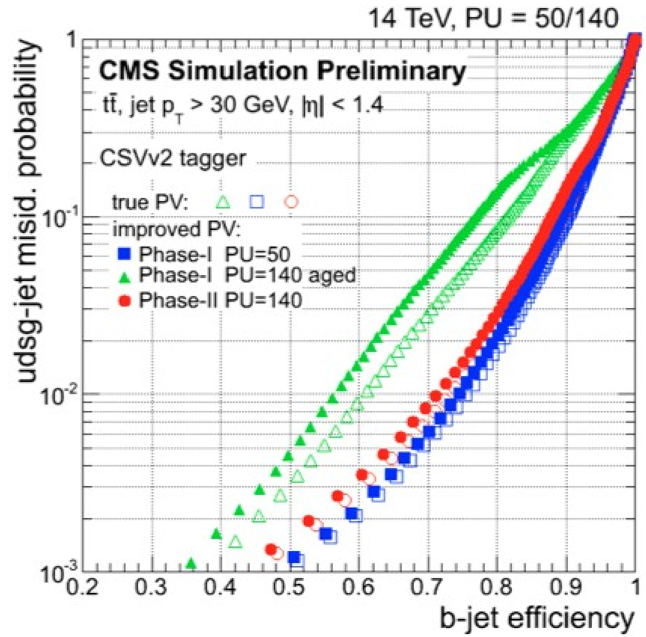


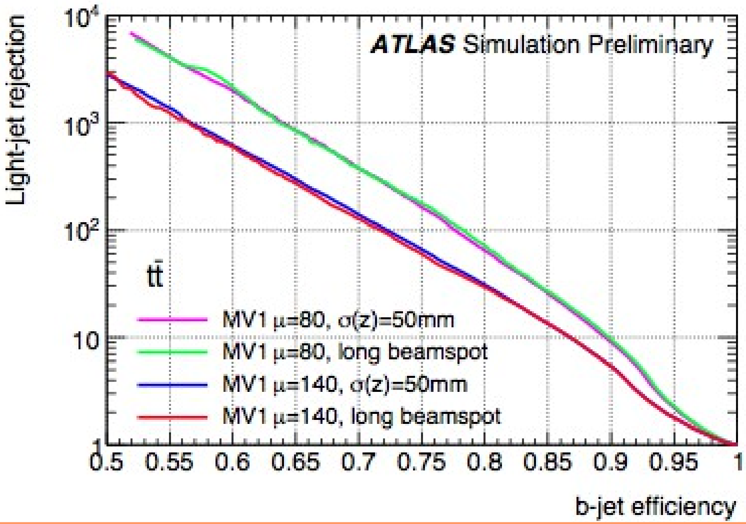


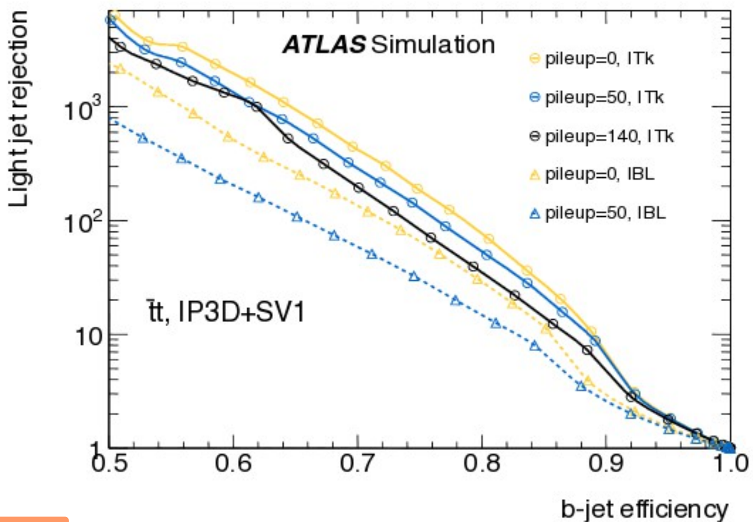
'Long, flat' beamspot requires crab cavities

Performance of Upgraded Detectors - B-tagging

- Upgraded detectors allow b-tagging performance at phase 2 very similar to that at phase 1 despite significantly increased pile-up
  - Performance helped further if correct primary vertex identification can be improved
  - If correct primary vertex identified, performance independent of beam profile



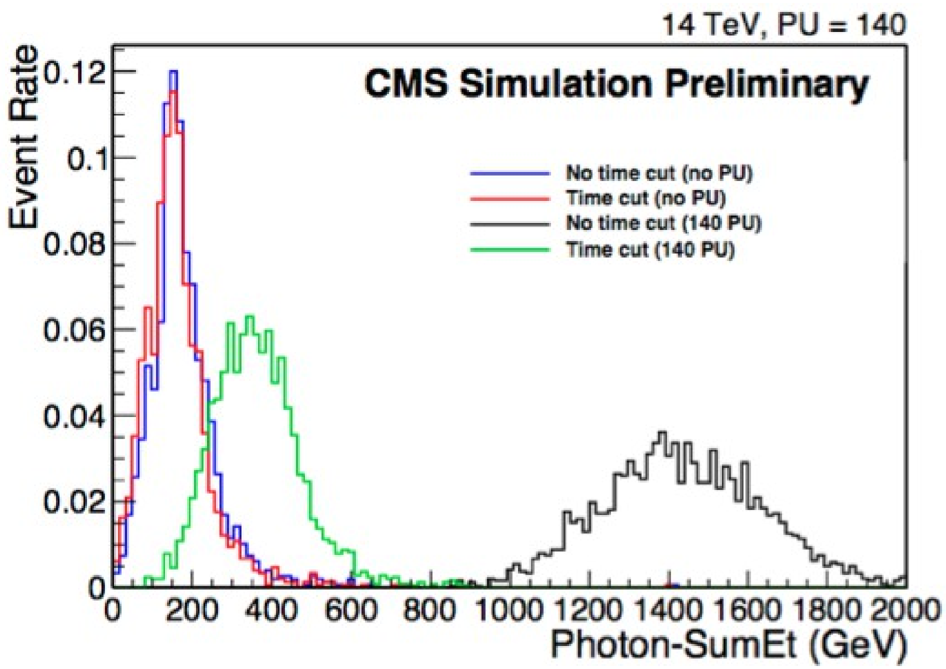


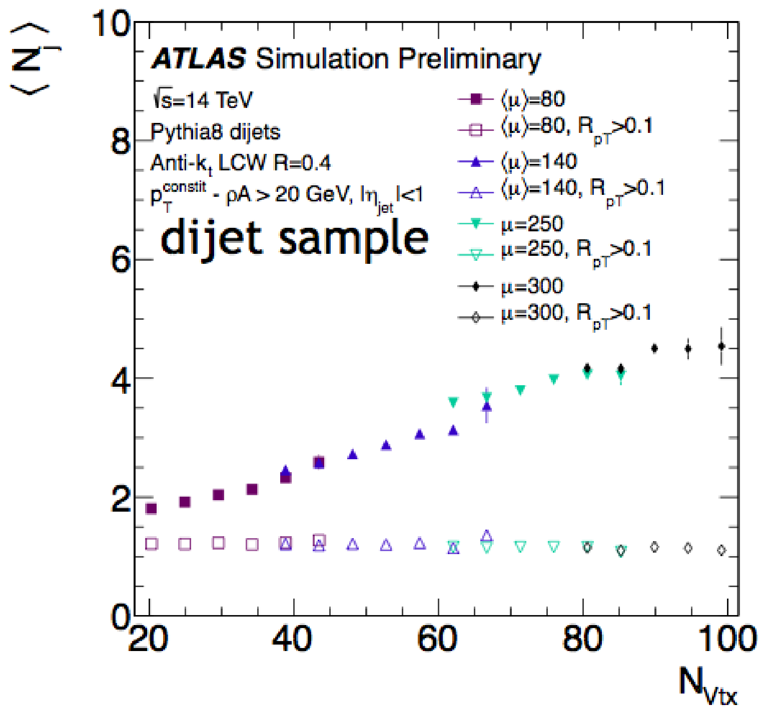


ATLAS plots assuming correct PV identified

Pile-up Mitigation Techniques

- Mitigation of pile-up effects and rejection of pile-up objects will be crucial to achieving optimum physics reach
  - Timing information has proved promising as a way to mitigate pile-up effects in reconstruction – dedicated timing layer could provide both charged particle and photon timing
  - Applying cuts on variables related to charged fraction helps reduce number of pile-up jets, as does requiring track-jet matching criteria



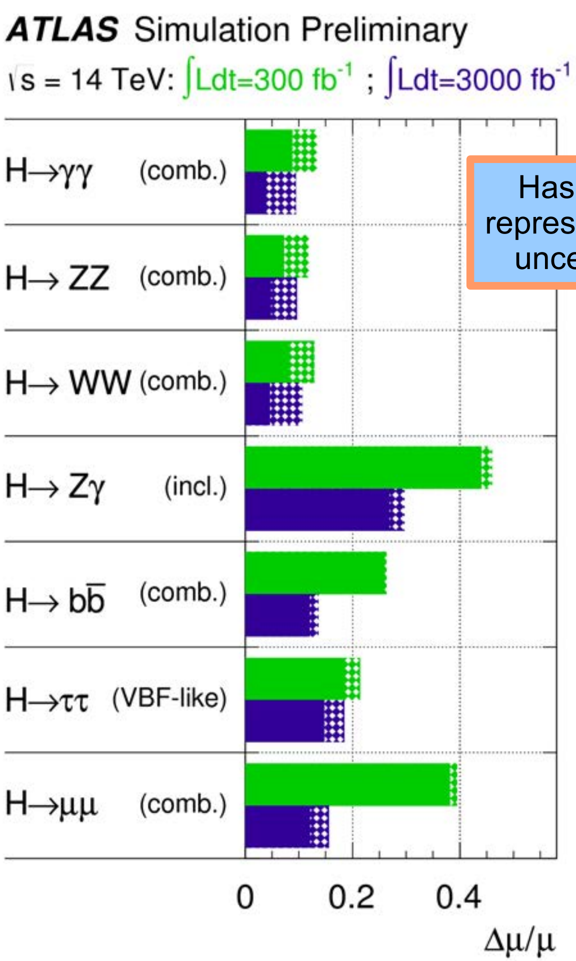


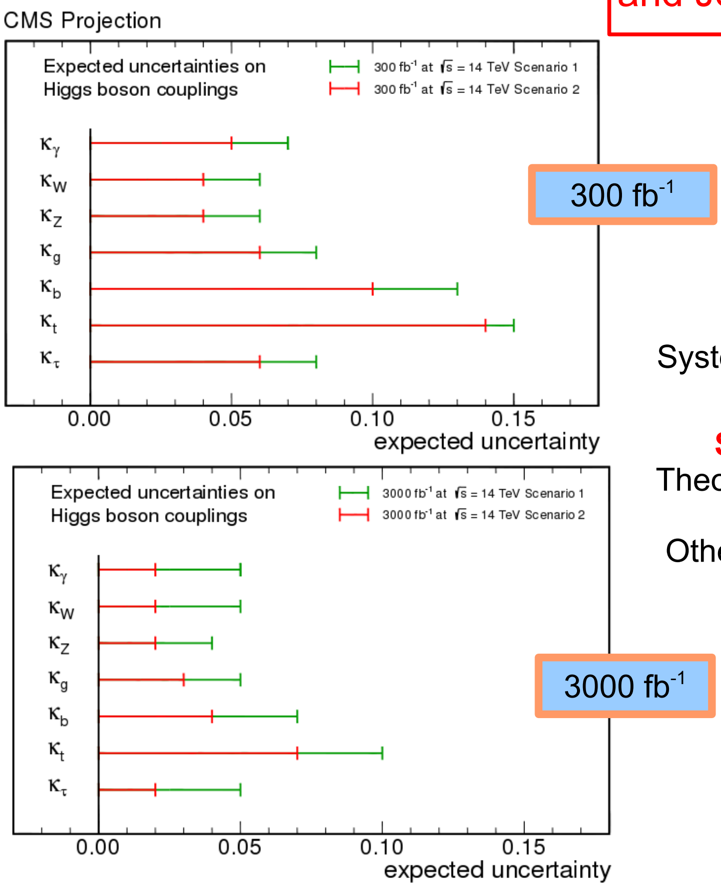
Assuming new ECAL detector element with 50ps timing resolution

Higgs Measurement Potential at HL-LHC

- HL-LHC will function as a “Higgs Factory”
  - Will greatly increase precision of coupling and signal strength measurements – particularly if theory uncertainties also improve significantly
  - New measurements will become possible

See also talks from Giacinto Piacquadio and Josh Bendavid



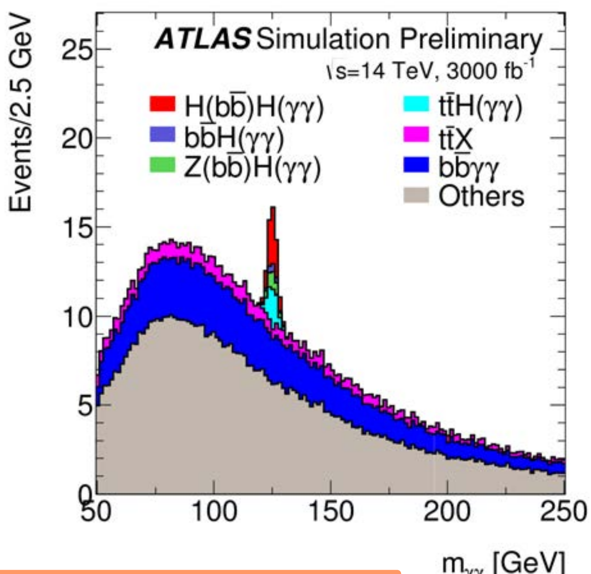


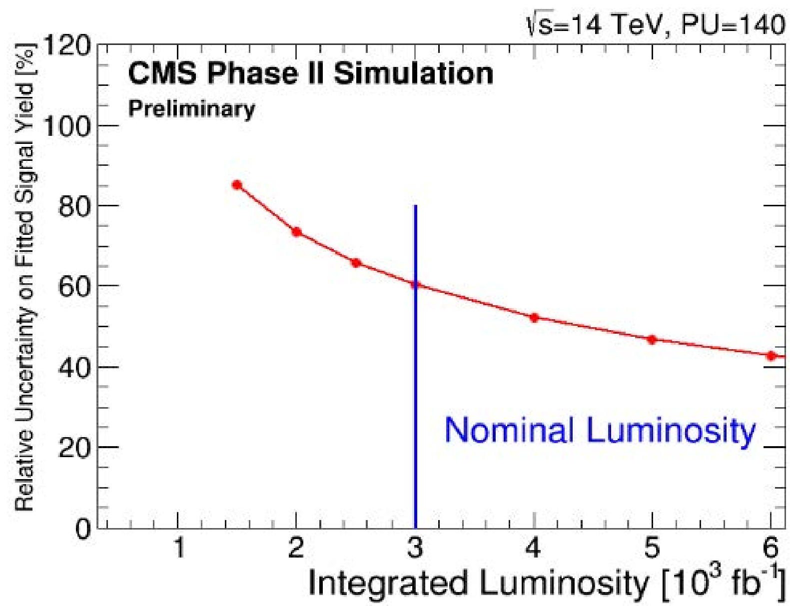
Scenario 1:
Systematics as Run1

Scenario 2:
Theory uncertainties x 0.5
Other uncertainties x √∫L

Higgs Pair Production

- Measurement of Higgs Pair Production necessary for determining Higgs Self-Coupling
  - Very small cross section means HL-LHC is great opportunity for this
  - Destructive interference between diagrams with/without self-coupling contribution
  - $HH \rightarrow bb\gamma\gamma$ one of the most promising channels
  - Eventual measurement will utilise combination of results across channels and experiments – CMS and ATLAS discussing analyses to understand differences and explore potential improvements

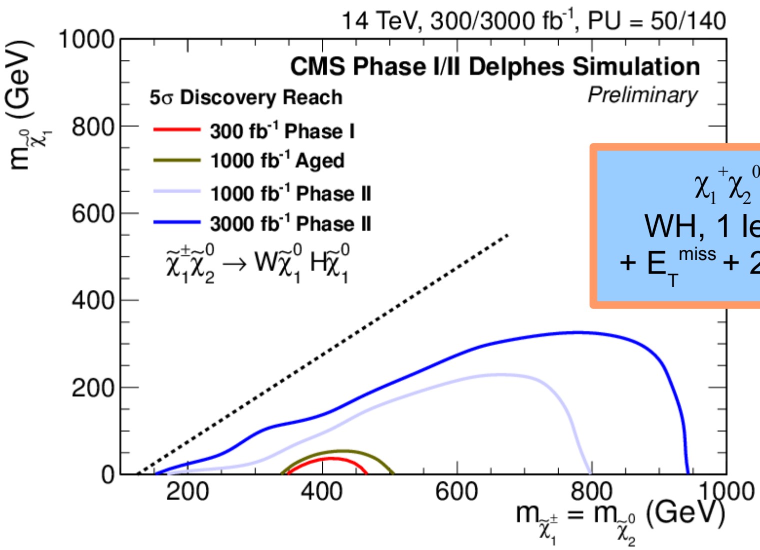




See also talk from Paolo Meridiani

ATLAS projects $S/\sqrt{B}$ 1.3 with 3 ab^{-1}

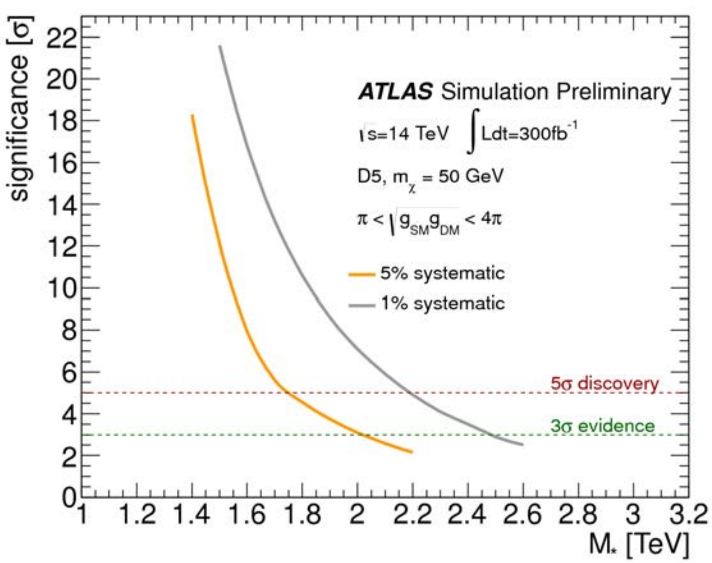
HL-LHC BSM Potential

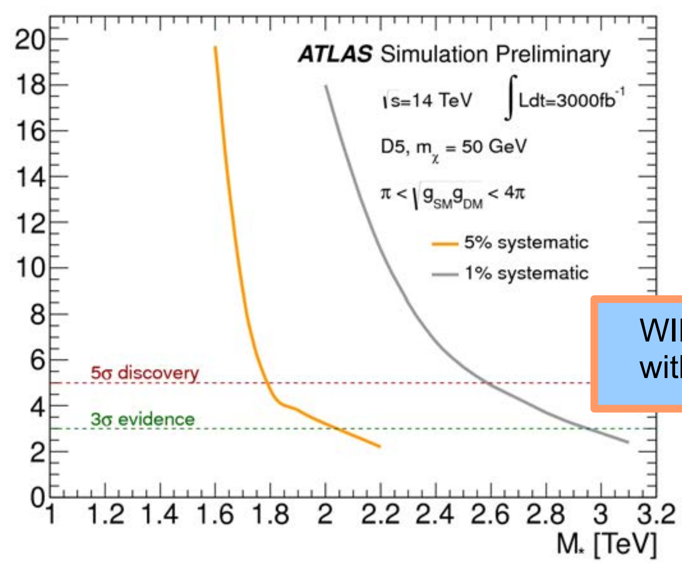


$\chi_1^+\chi_2^0$:
WH, 1 lepton
+ E_T^{miss} + 2 b tags

> HL-LHC & Detector Upgrades offer great potential for BSM searches

- Mass reach >doubled in EW $\chi_1^+\chi_2^0$ WH search
- "Mono-X" Dark Matter search - 5σ discovery up to suppression scale M* of 2.6 TeV (with optimistic systematics)





WIMP Dark Matter
with Jets and large E_T^{miss}

Results assume EFT is valid approach

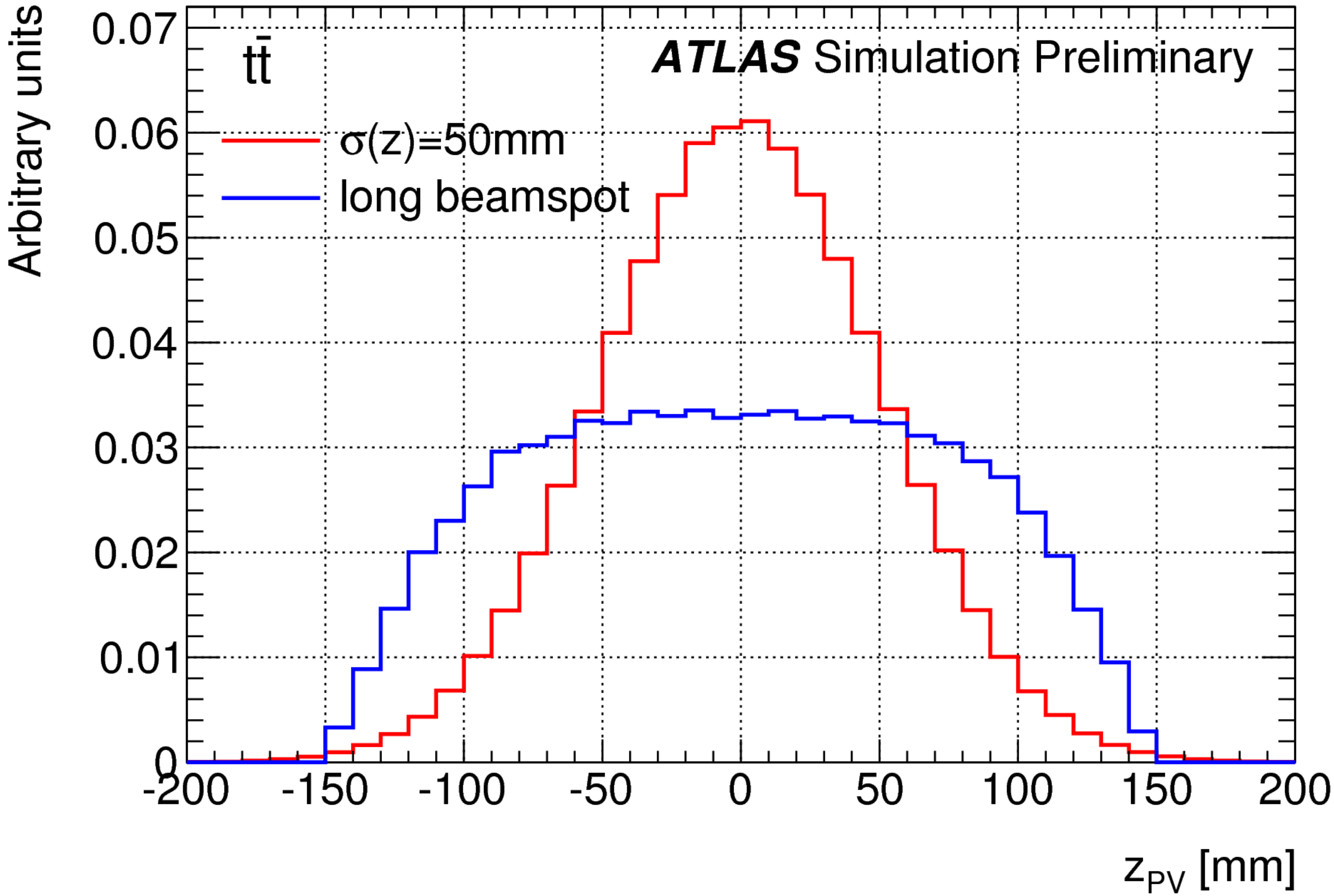
DESY

Summary

- High Luminosity upgrade of the LHC offers huge potential to further explore the High Energy Physics landscape
  - 3 ab^{-1} dataset at 14 TeV allows large gains in precision, discovery potential, and makes a number of important, low cross-section measurements possible
  - CMS Upgrade Studies: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP
  - ATLAS Upgrade Studies: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies
- Challenges presented by high pile-up will necessitate extensive detector upgrades
  - Highly promising ATLAS & CMS baselines being further developed and improved
- Techniques under development for reconstruction and analysis of data from new detectors under new conditions
  - Performance & physics reach projections may improve further with future develpments and optimsations

Back-up Slides

Beamspot Profiles



Higgs Sytematics

Scenario	Status 2014	Deduced size of uncertainty to increase total uncertainty by $\lesssim 10\%$ for 300 fb^{-1}			by $\lesssim 10\%$ for 3000 fb^{-1}				
Theory uncertainty (%)	[10–12]	κ_{gZ}	λ_{gZ}	$\lambda_{\gamma Z}$	κ_{gZ}	$\lambda_{\gamma Z}$	λ_{gZ}	$\lambda_{\tau Z}$	λ_{tg}
$gg \to H$									
PDF	8	2	-	-	1.3	-	-	-	-
incl. QCD scale (MHOU)	7	2	-	-	1.1	-	-	-	-
p_T shape and 0j $\to$ 1j mig.	10–20	-	3.5–7	-	-	1.5–3	-	-	-
1j $\to$ 2j mig.	13–28	-	-	6.5–14	-	3.3–7	-	-	-
1j $\to$ VBF 2j mig.	18–58	-	-	-	-	-	6–19	-	-
VBF 2j $\to$ VBF 3j mig.	12–38	-	-	-	-	-	-	6–19	-
VBF									
PDF	3.3	-	-	-	-	-	2.8	-	-
$t\bar{t}H$									
PDF	9	-	-	-	-	-	-	-	3
incl. QCD scale (MHOU)	8	-	-	-	-	-	-	-	2

ATL-PHYS-PUB-2014-016