Physics motivation and detector upgrades for the new era of the ATLAS experiment

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On behalf of the ATLAS Collaboration

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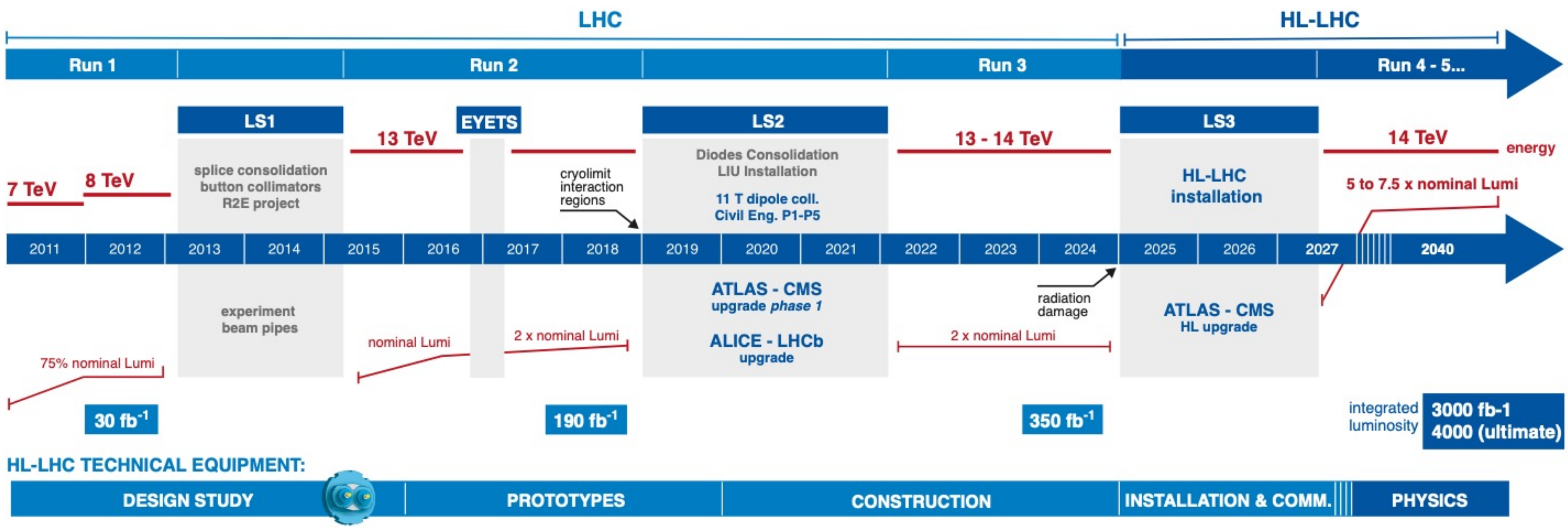
Luminosity and Energy Increases at LHC



- Long Shutdown 2 (Phase-1 upgrade) preparing for Run 3
  - Luminosity leveling at 2 x $10^{34}/cm^2/s$, possible increase to $\sqrt{s}$=13.5 or 14 TeV
  - Expecting accumulation of 300 fb^{-1} during Run 3 pp campaign
- Long Shutdown 3 (Phase-2 upgrade) to prepare for HL-LHC
  - The HL-LHC era with lumi of 7.5 x $10^{34}/cm^2/s$ at $\sqrt{s}$=14 TeV
  - Large data samples and major experimental challenges

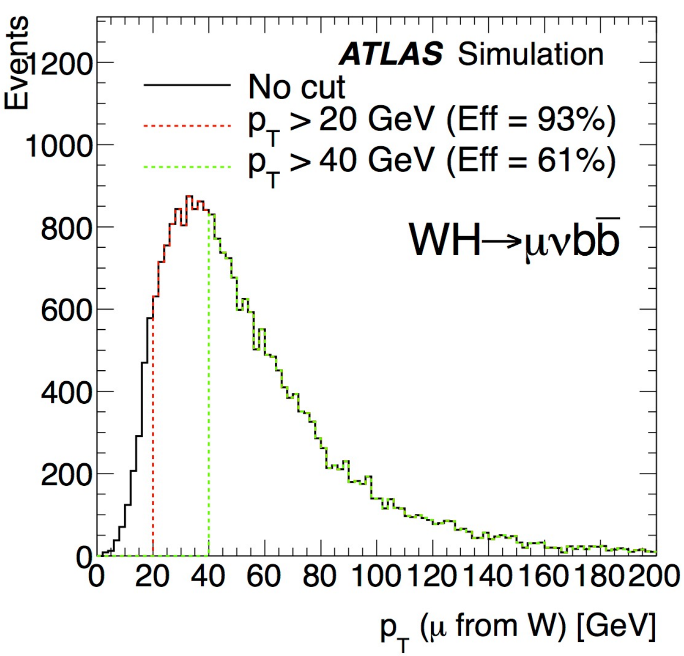
ATLAS Run-3 and HL-LHC Physics Program

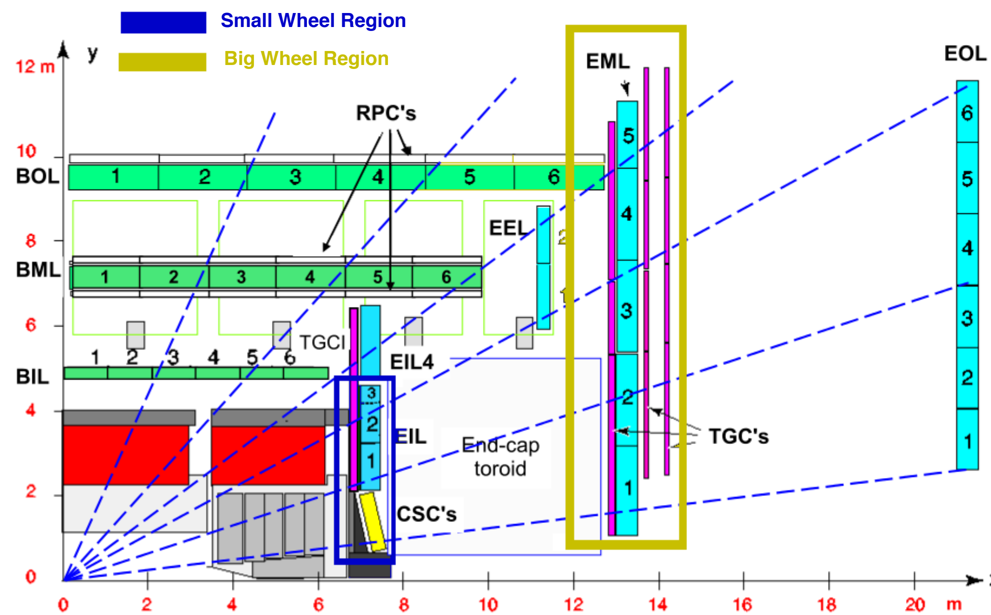
- Very broad program covering all areas of hadron collider physics
- Many studies performed for TDRs and European Strategy input
  - Measurement of **Higgs** boson properties: couplings, mass, width
  - Precision **electroweak** measurements: vector boson scattering, W mass, weak mixing angle, triboson couplings, rare processes
  - Searches for **Beyond Standard Model** physics: SUSY, dark matter
  - **QCD** measurements: precision PDF sets, especially in forward regions
  - **Flavor physics** studies: rare b-decays, constraints on CKM
  - **High-density QCD** measurements with heavy-ion and pp collisions
  - **Forward physics** with tagging of exclusive production processes
- Studies in ATLAS benefit from full HL-LHC simulation
  - Updated detector performance and systematic uncertainties

Focus on an interesting subset of the ATLAS results in my limited time

Muon Detector Upgrades

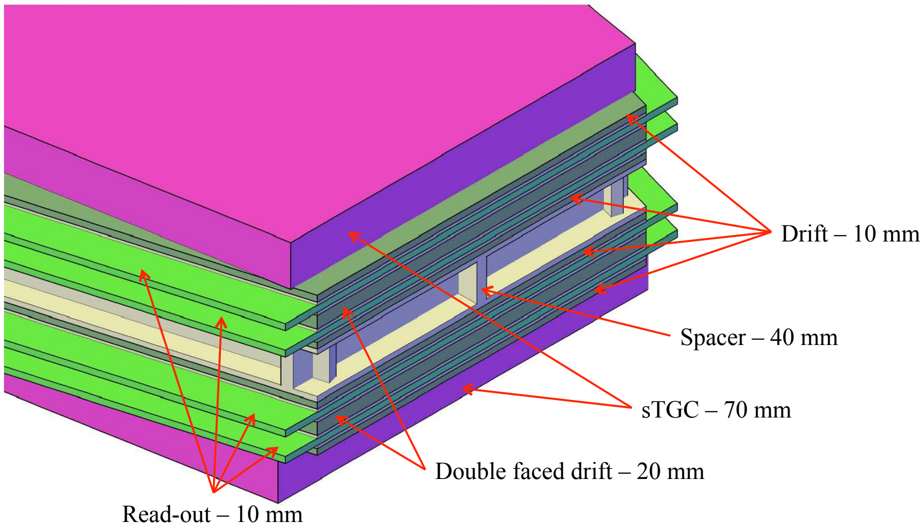
- Limited p_T resolution and high hit occupancy in current detector dictate higher L1 trigger thresholds for single muons
  - Impact on electroweak physics measurements with leptonic signatures
- Precision angle measurements in the small wheel region can sharpen the L1 trigger turn-on and restore the lower threshold
  - New Small Wheel needed with 1 mrad angular resolution measurement

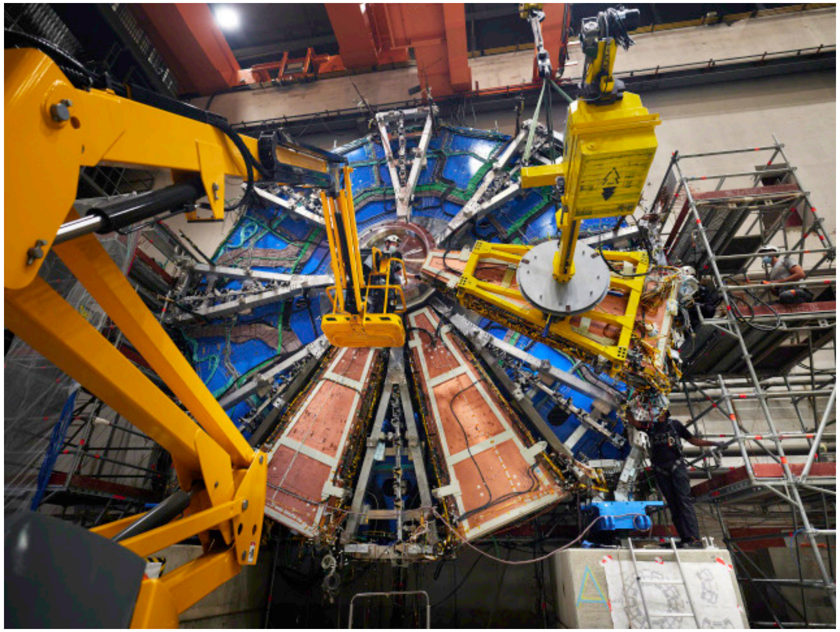




Muon New Small Wheel

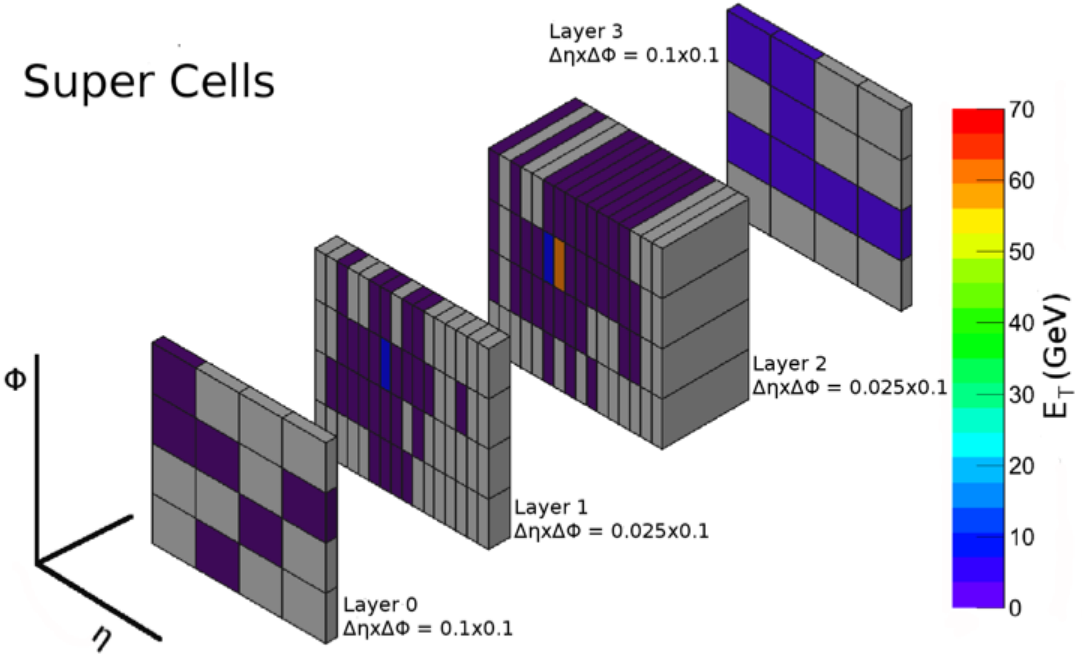
Detector sandwich: TGC-MM-MM-TGC



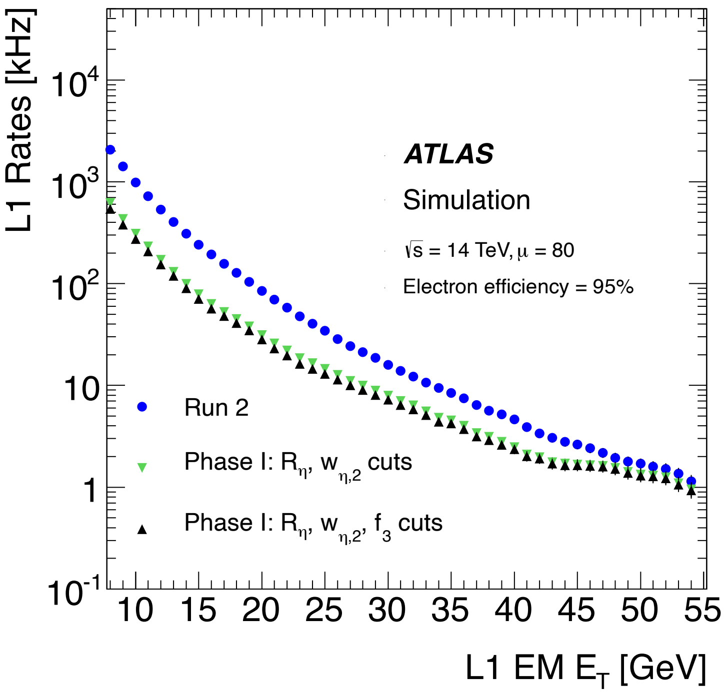


- Small-strip Thin Gap Chambers provide fast readout for trigger, while MicroMegas detectors give precision tracking resolution
  - MM spatial resolution of 100 μm based on fine strip pitch
  - Redundant system with good offline precision from sTGCs, too
  - Large-scale precision chambers require careful quality control at distributed fabrication sites
- Commissioning is underway at CERN

LAr Calorimeter and L1Calo Trigger



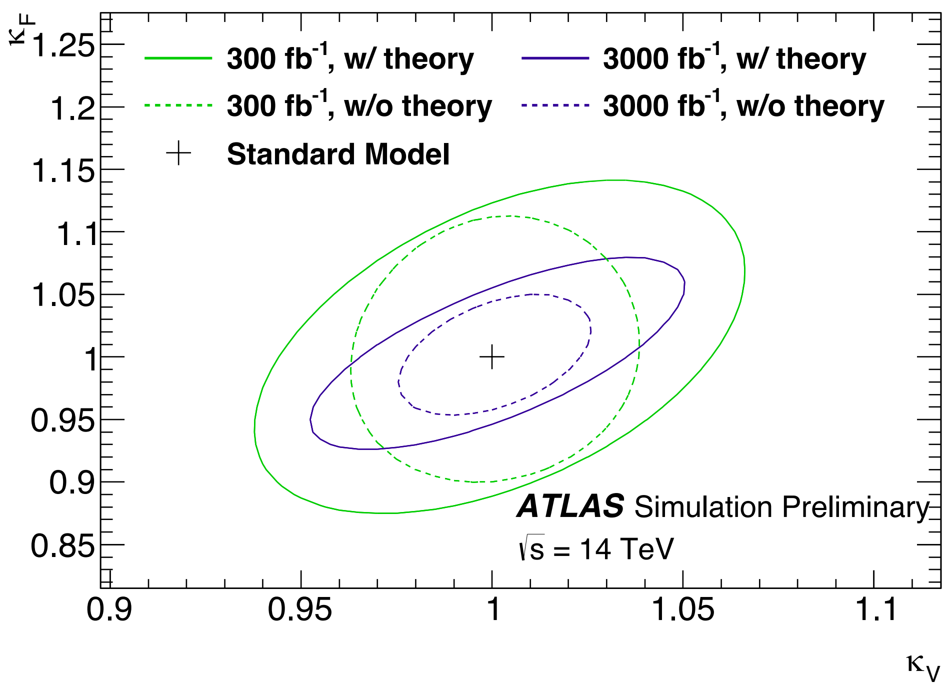
- Improve trigger energy resolution and identification efficiency for e, γ, τ leptons, and jets by increasing readout granularity
- Coarse trigger towers replaced by super cells

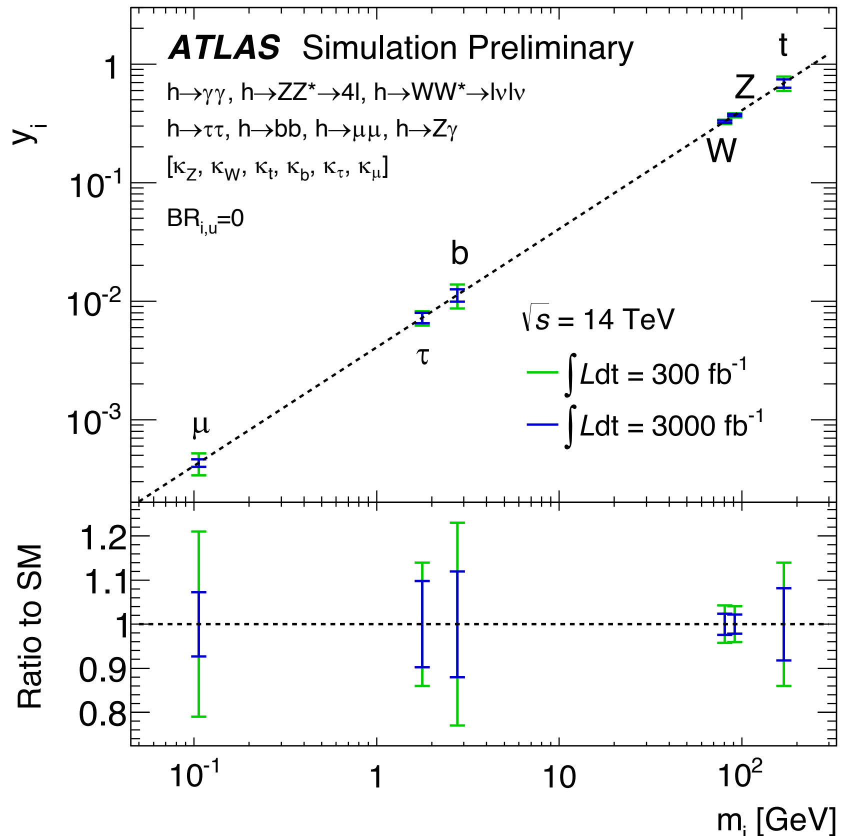


- Increased information in trigger allows for shower shape measurements
  - Improved jet rejection gives a lower trigger rate and allows ATLAS to maintain lower EM trigger thresholds in Run 3

Run-3 Higgs Boson Measurements

- Estimates of Run-3 sensitivity are based on late Run-1 results
  - Expect these to be very conservative projections, nearly surpassed already
- Lepton, photon, and missing energy trigger improvements offer improved sensitivity to the most comment event signatures



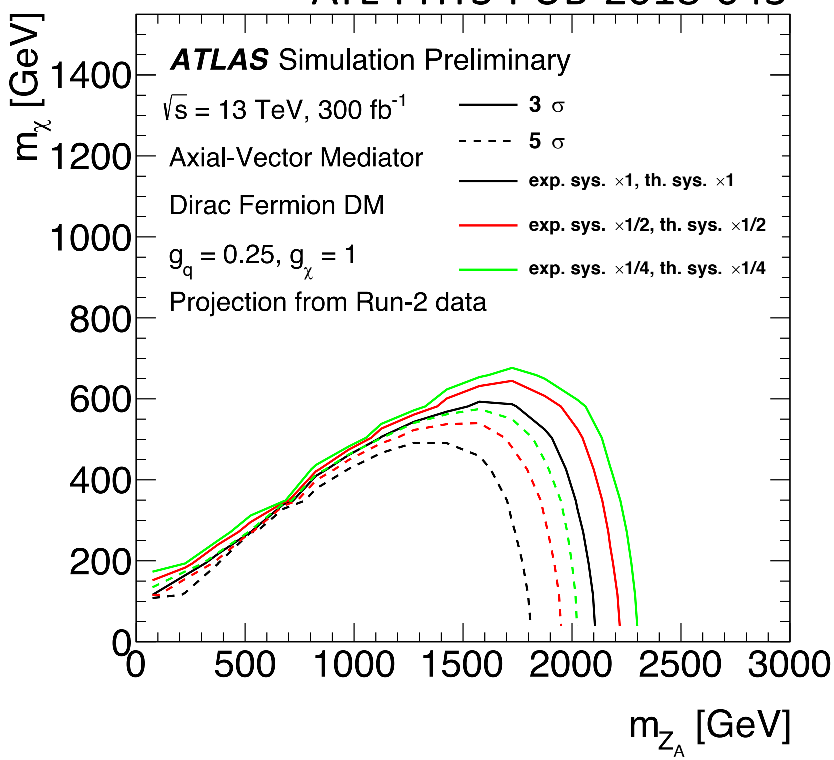


Run-3 SUSY and Exotic Searches

Monojet signature (WIMP recoil)

Jet + missing energy signature with WIMPs produced through axial-vector mediator

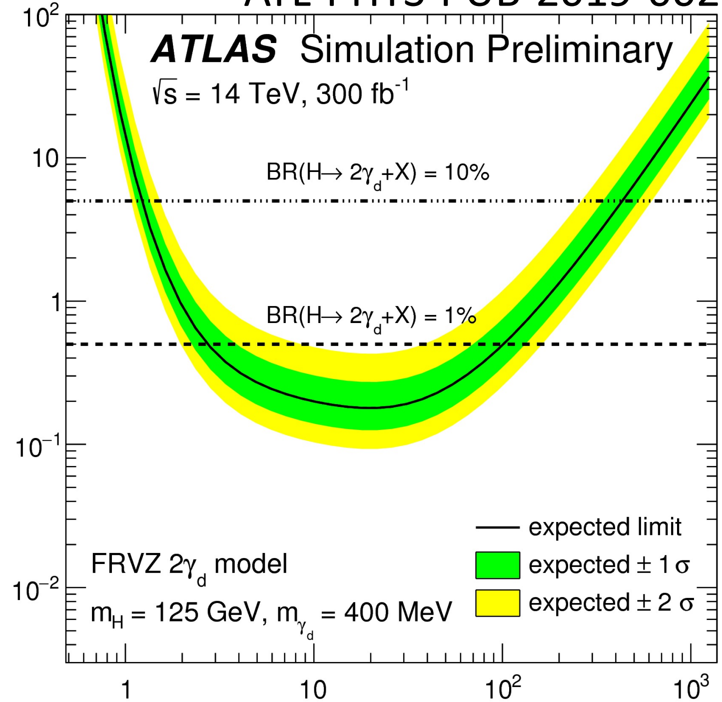
ATL-PHYS-PUB-2018-043



Dark photon decays

Higgs decay to dark photons, with subsequent decays to displaced collimated muon jets

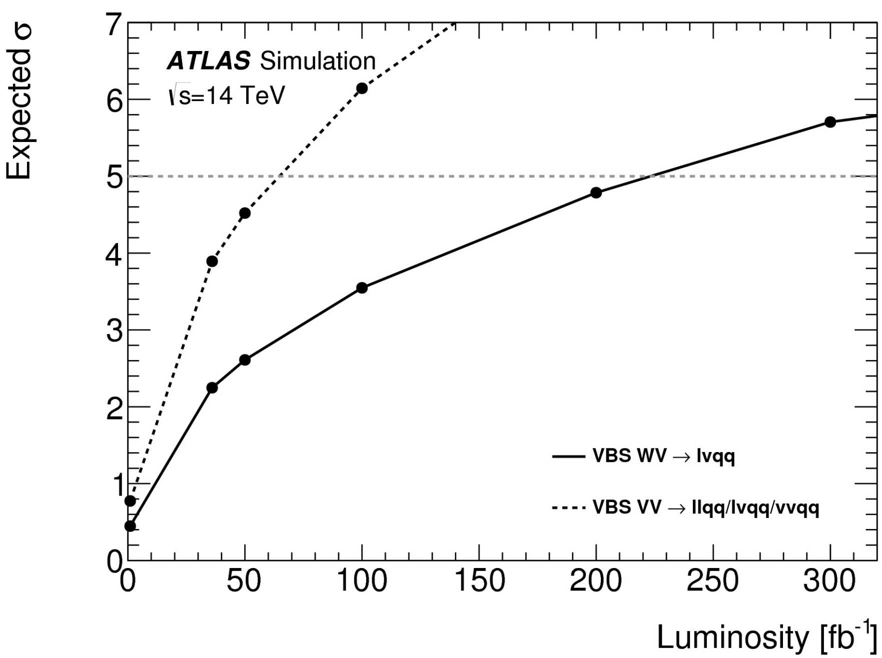
ATL-PHYS-PUB-2019-002

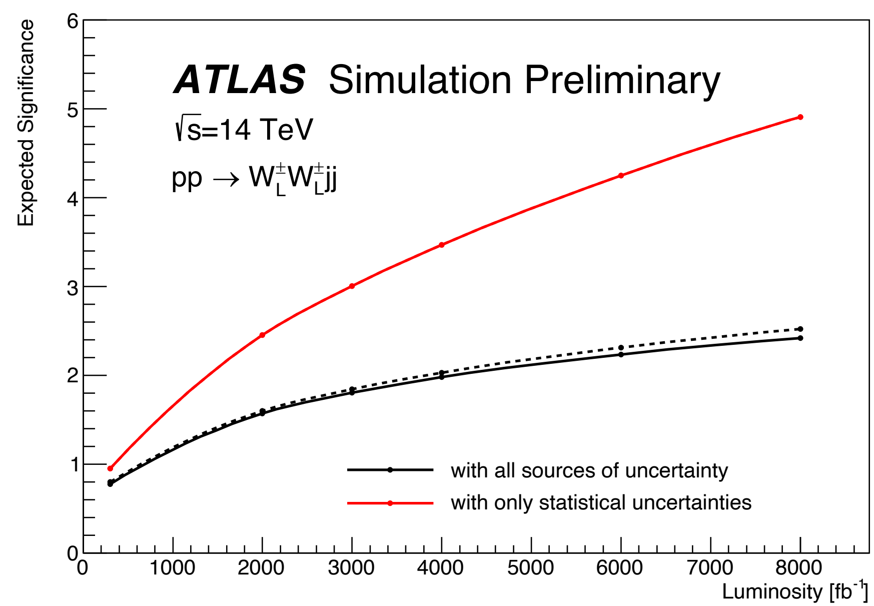


Run-3 Vector Boson Scattering

ATL-PHYS-PUB-2018-022
ATL-PHYS-PUB-2018-052

- Three channels: WW, WZ, ZZ leptonic signatures
  - All observable at HL-LHC luminosities, but extracting the longitudinal scattering component to test unitarity is much more challenging
  - New muon performance and jet-finding capabilities are key improvements
- WV and VV scattering accessible with Run 3 dataset
- WW scattering: <10% precision overall, <1σ sensitivity to $W_L W_L$





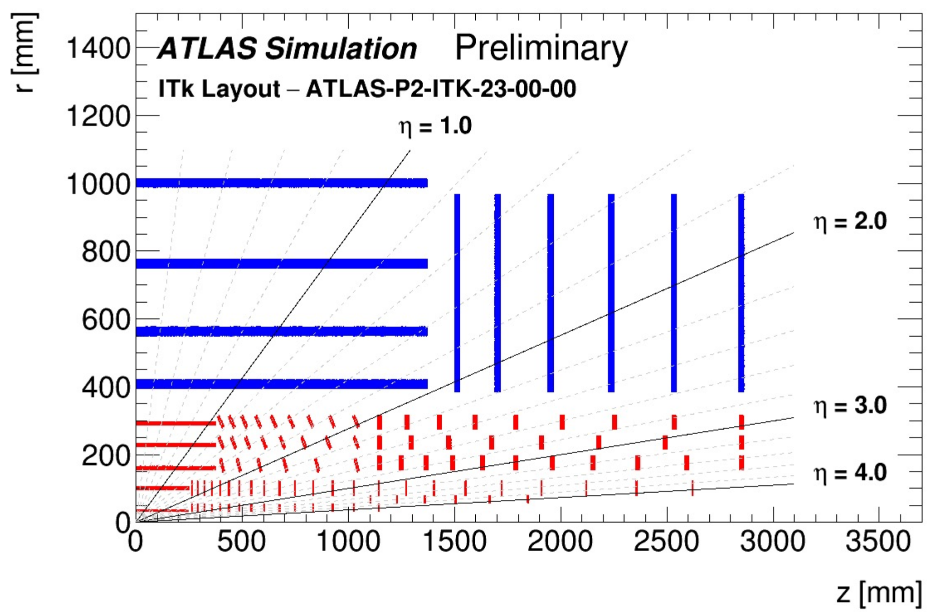
HL-LHC Physics Challenges

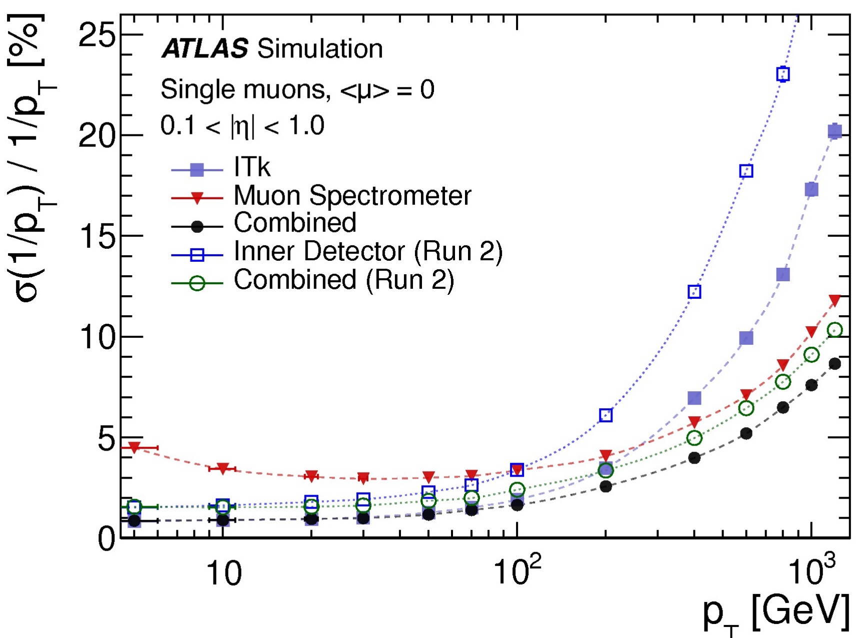
- HL-LHC is the culmination of the 27-km ring program at CERN
  - Increase of √s to 14 TeV, integrated luminosity goal of 3-4 ab^{-1}
  - Era of precision Higgs and top physics, small BSM cross sections
  - See Simone Pagan Griso's talk in Friday's plenary session
- Inst. lumi 7.5E34/cm^2/s implies pileup up to $\langle\mu\rangle$=200 per crossing
  - Higher hit occupancy in the detector, leading to higher rate of fake tracks
  - Stochastic accumulation into "pileup jets", especially in forward region
  - Additional energy in calorimeters degrades resolution
  - Increased radiation dose to sensitive detectors and electronics
- Many improvements needed to maintain or improve performance
  - Improved triggering using all detector information and improved resolution
  - Increased detector acceptance in forward regions
  - Better association of particles to primary vertex to reject pileup effects
  - Timing measurements for pileup rejection and particle flow
- Major ATLAS detector upgrades planned for Long Shutdown 2

Overview of HL-LHC Upgrades

CERN-LHCC-2012-022
ATL-PHYS-PUB-2019-005

- All-silicon Inner Tracker replacement
  - Improved pseudorapidity coverage to $|\eta| < 4$
- New calorimeter front-end electronics to digitize signal at 40 MHz
- Muon electronics upgrade with additional trigger layer
- Trigger upgrade to use full detector information for 1 MHz decision
- Improved triggers are key to physics in many different signatures

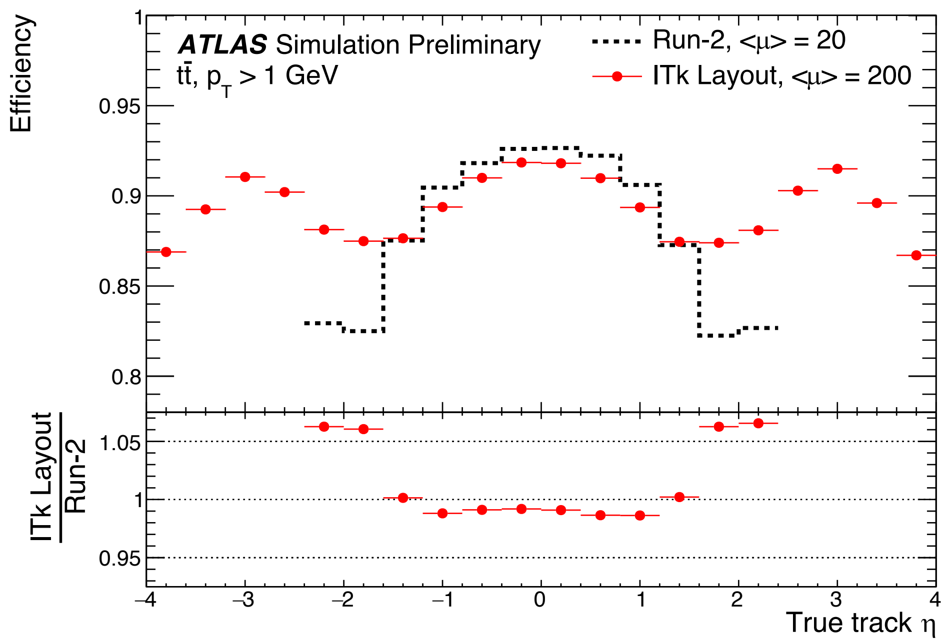


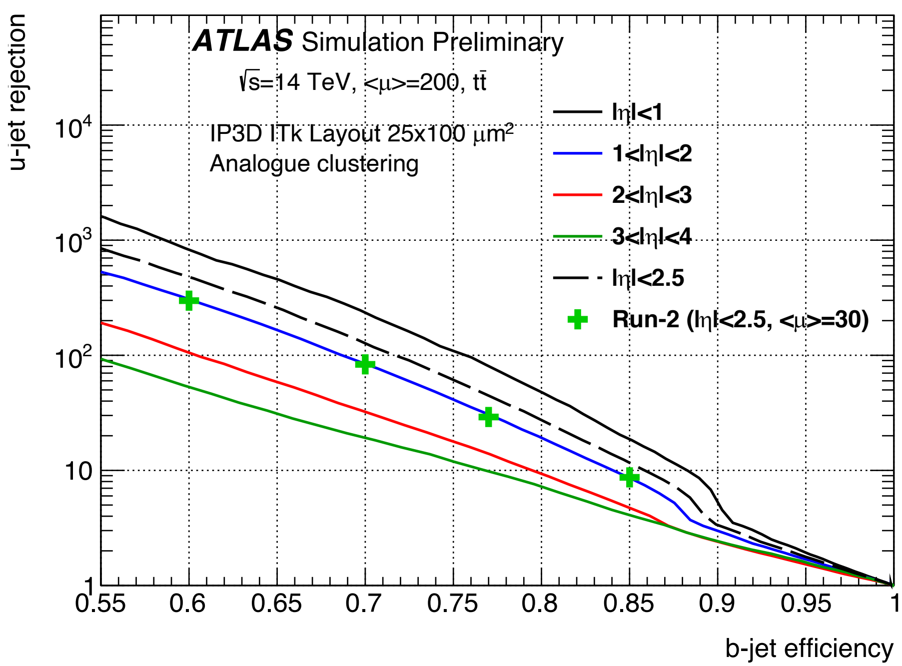


ITk Silicon Tracker

ATL-PHYS-PUB-2019-014

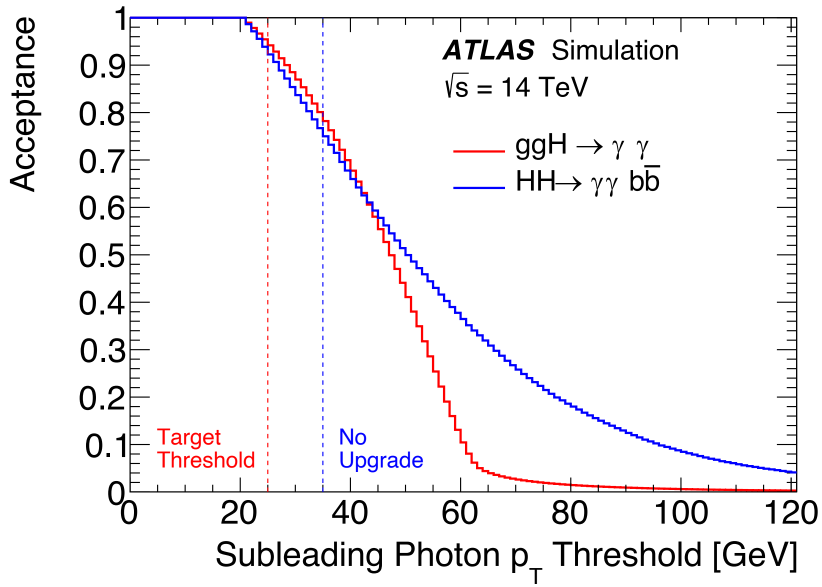
- Nearly 13 m^2 of pixels and 165 m^2 of strips with improved coverage
  - Innermost layer of "3-d" pixel sensors with 25x100 μm^2 pixel size
  - Inclined sensors and ring structures ensure normal track incidence at high η
  - New readout electronics radiation hard to 1 GRad in inner pixels, with 5 GHz digital data bandwidth to optical readout transition
- Improves tracking and b-tagging performance compared to Run-2

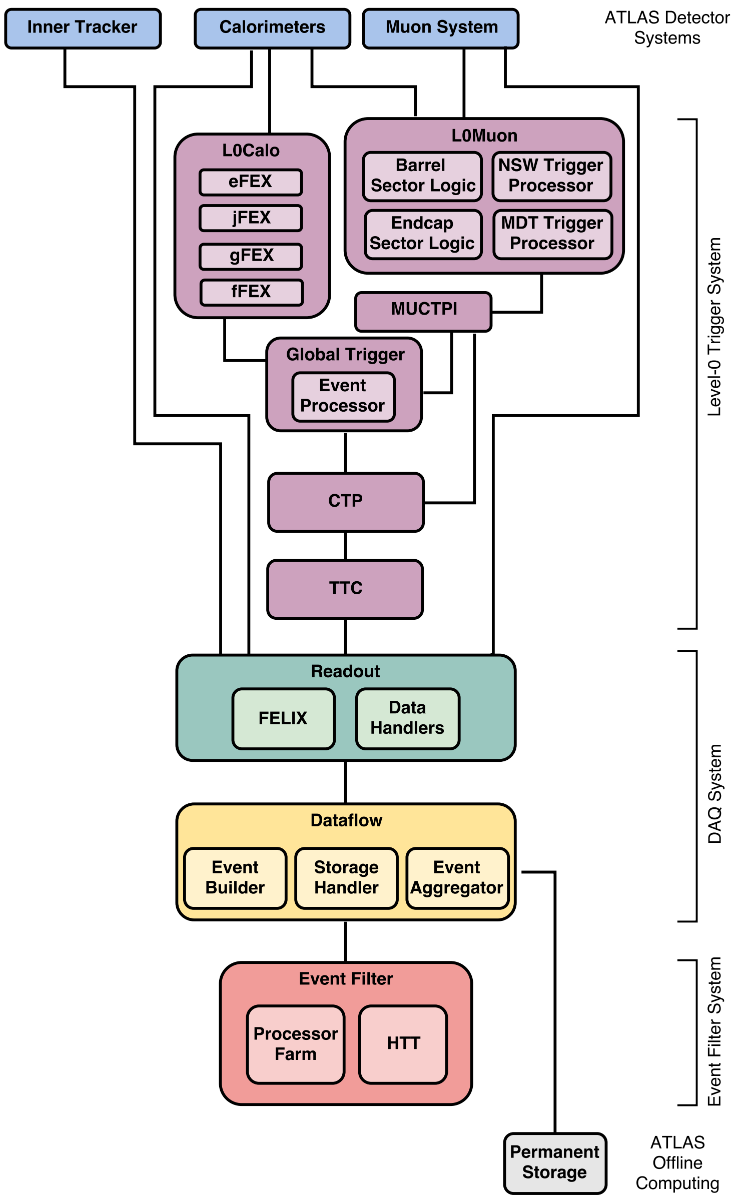




Electronics, Data Acquisition, and Trigger

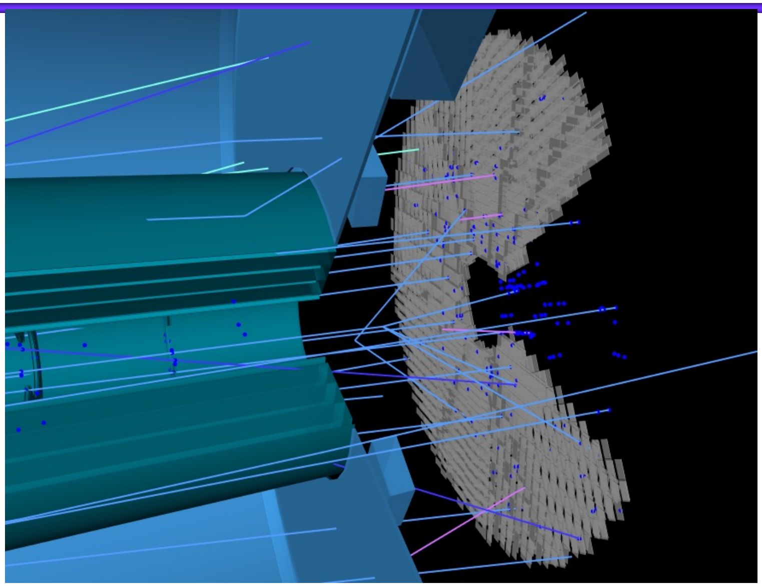
- Goal of better e, γ, τ, jet identification and measurement, at hardware and software trigger levels and in offline
  - Full granularity detector data into HW trigger at 1 MHz from calorimeters and muon system
  - Feed into L0 accept with 10 μs latency
  - Event Filter output increases to 10 kHz

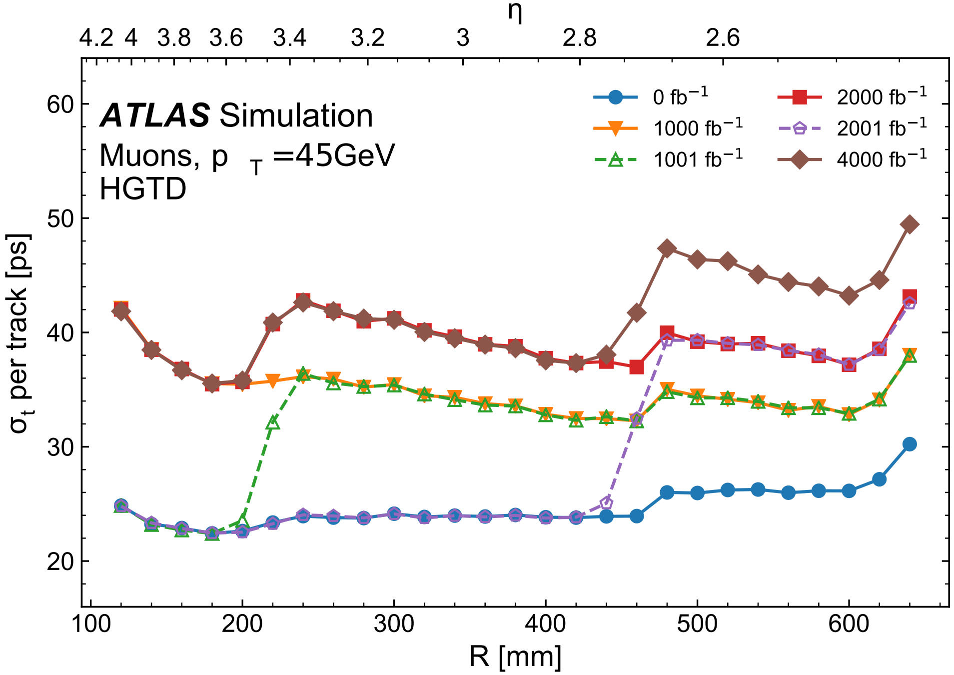


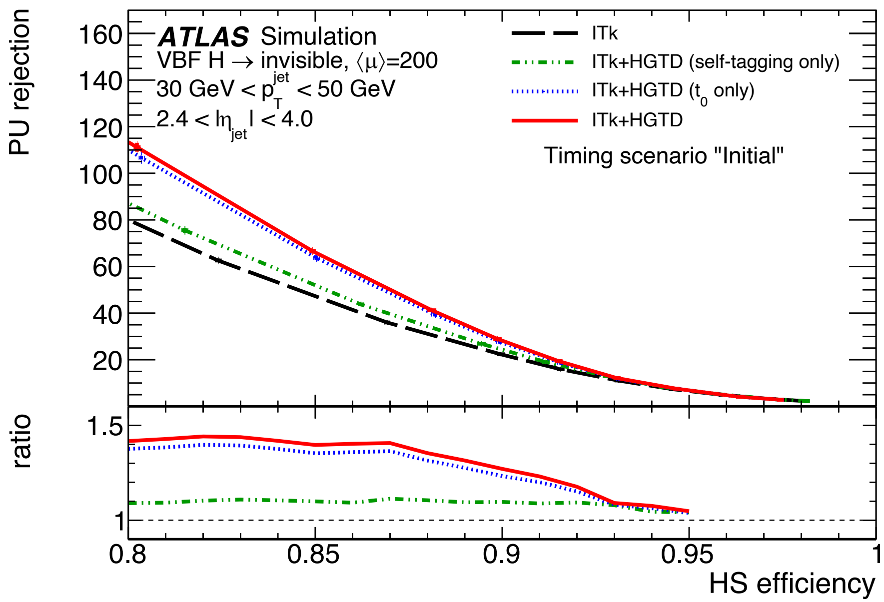


High-Granularity Timing Detector

- Vertex association at high η improved with picosecond timing
- Low-Gain Avalanche Detector stations located on cryostat wall
- Timing information enhances the ITk pileup jet rejection



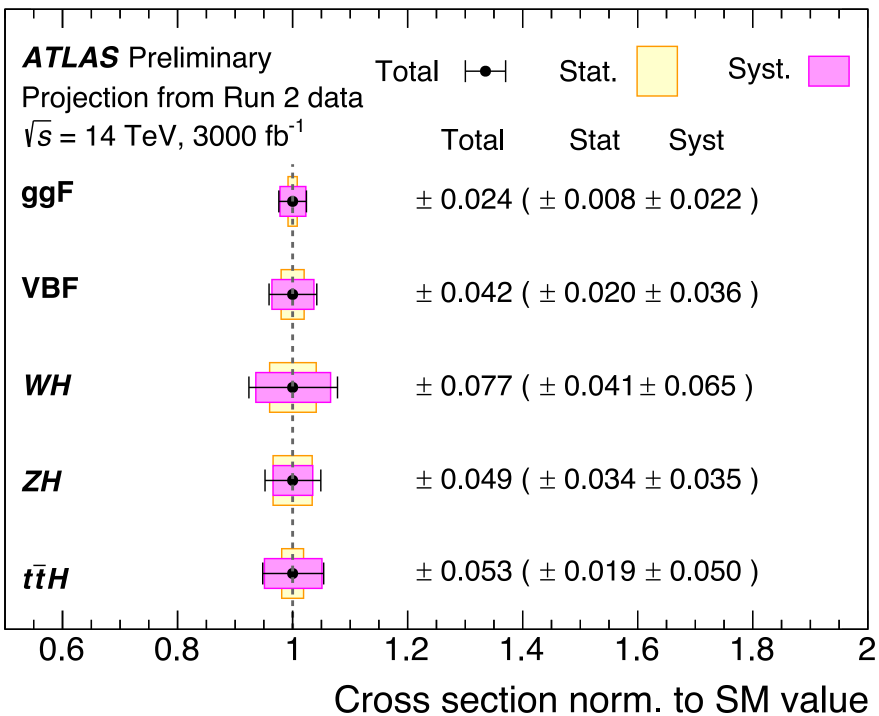


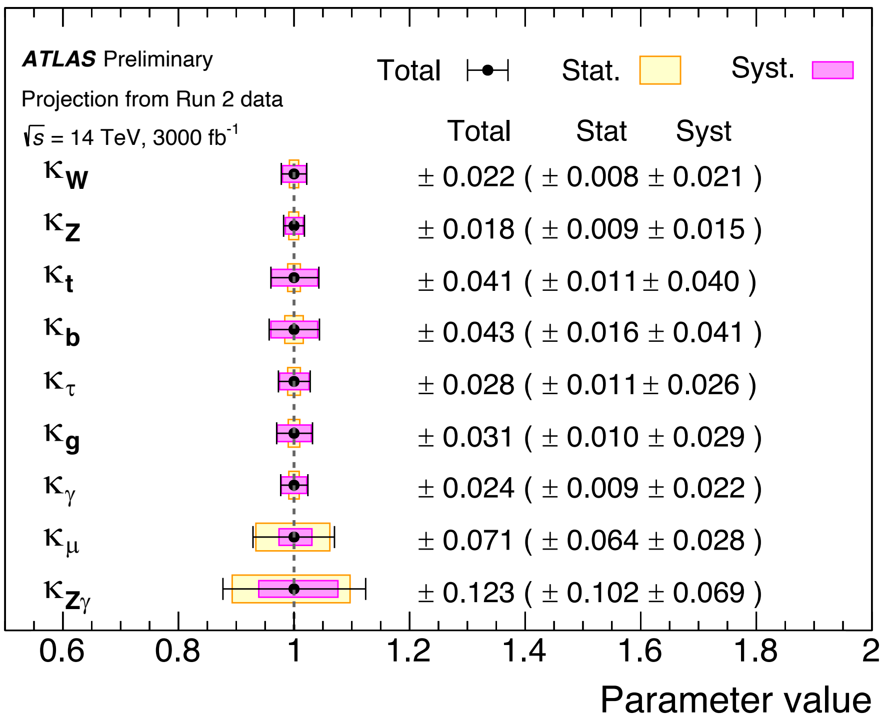


Higgs Coupling Measurements

ATL-PHYS-PUB-2018-054

- Cross section measurements improve with high statistics
  - Projections assume systematic and theory uncertainties will be halved
- Measurements re-interpreted in coupling modifier κ framework
  - All of those couplings are constrained at the 2-7% level
  - Even μμ and Zγ couplings can be constrained at HL-LHC

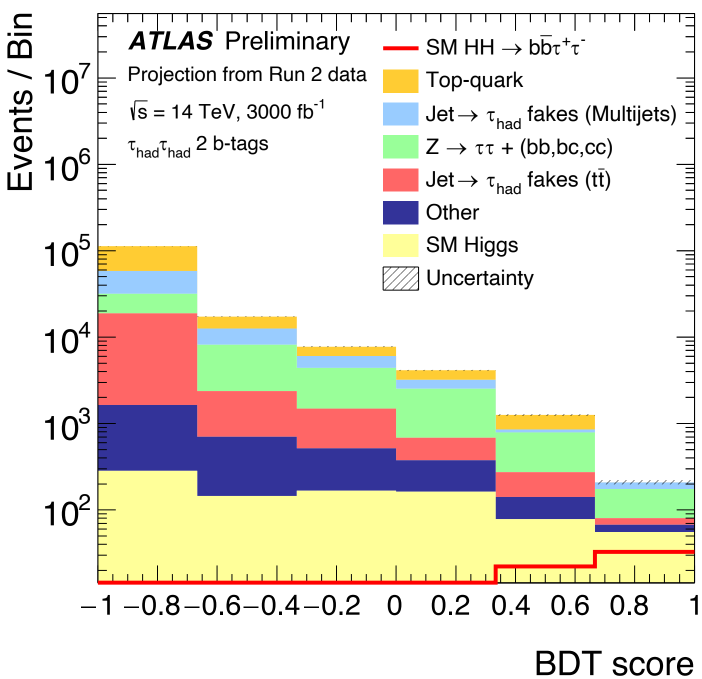


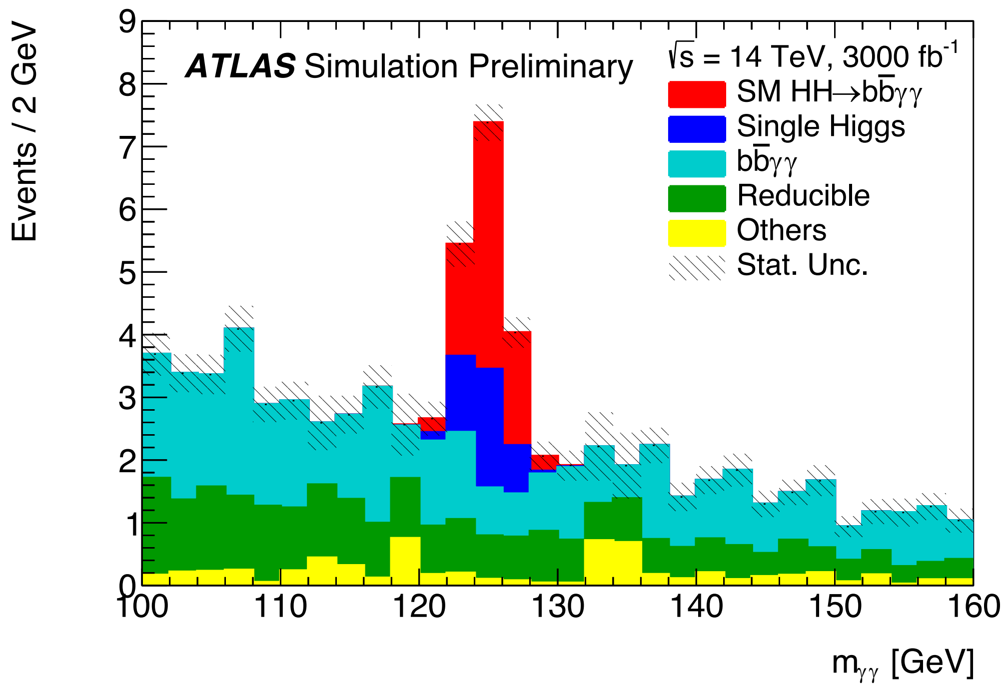


HH Production Measurements

ATL-PHYS-PUB-2018-053

- Current Run-2 ATLAS limit: 4 x SM
- Most sensitive channel: bbττ uses fit to BDT score by category
- Second channel: bbγγ analysis w/ parameterized simulation: fit m_{HH}
- Third channel: bbbb result suffers large syst. uncertainties



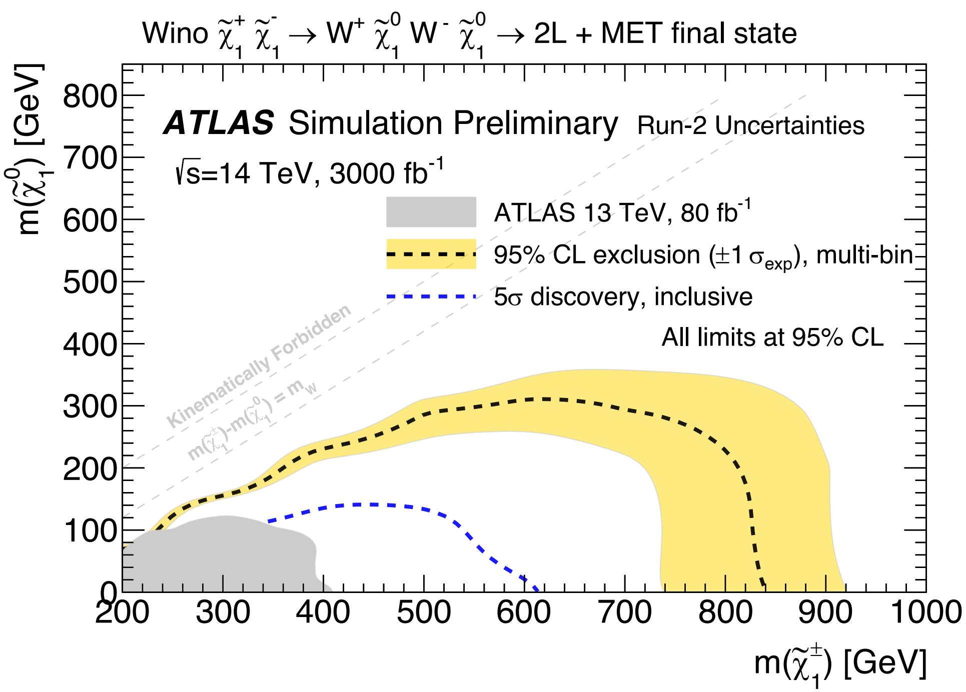


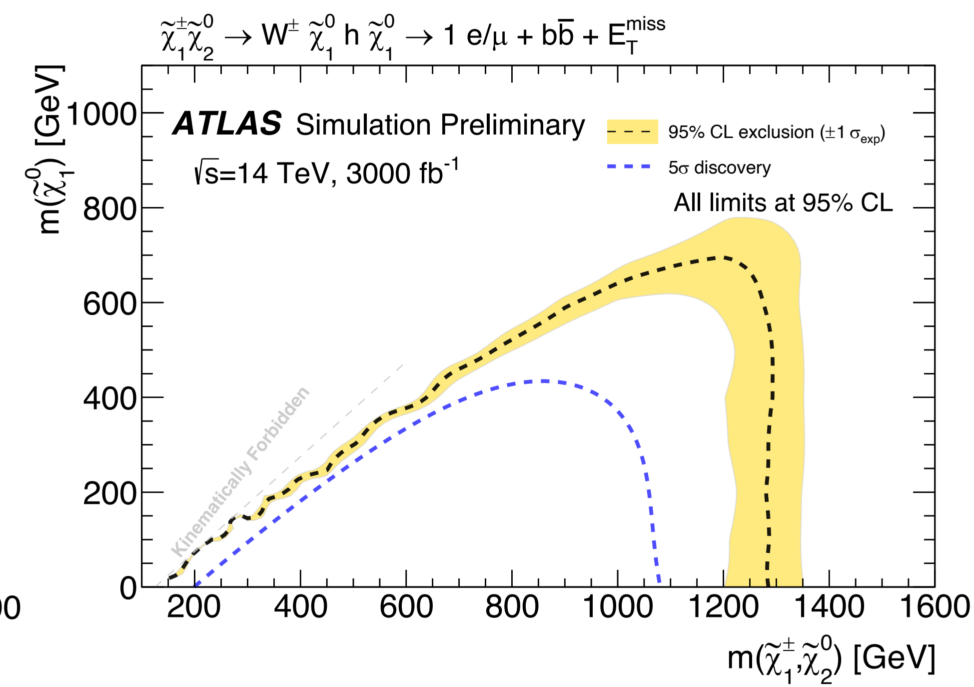
- ATLAS/CMS combination in arXiv:1902.00134: ~4σ for SM HH

SUSY Searches

ATL-PHYS-PUB-2018-048

- High-statistics HL-LHC dataset: an opportunity to test the TeV mass scale for electroweak SUSY, even for lowest cross sections
- Projections with full b-tagging simulation & realistic uncertainties



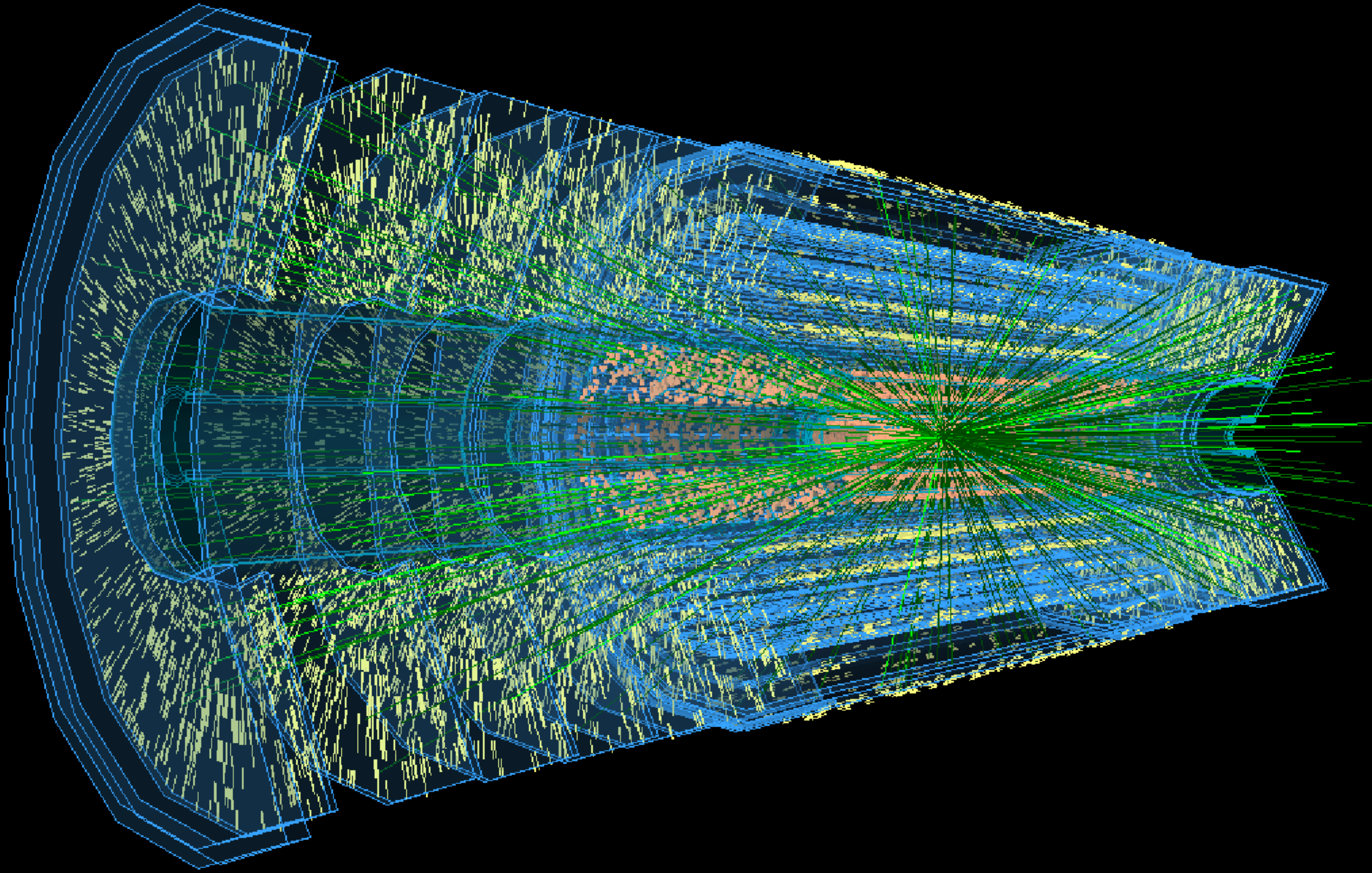


- Largest gains in statistics-limited searches with tight selections

Summary and Conclusions

- ATLAS projects a broad and deep Run-3 and Run-4 physics program
  - Precision Higgs, electroweak, and top measurements with large datasets
  - Improved PDF measurements with high lumi at 14 TeV
  - Searches for BSM physics, especially in small cross-section processes
  - High-density QCD studies in heavy-ion and pp collisions
- Detailed studies prepared both with full detector simulation and with extrapolated systematic uncertainties
- Challenging experimental conditions require new detector upgrade designs and improved reconstruction algorithms.
- These studies and improvements depend on continued progress in theoretical calculations and computational tools.

Already looking forward to lots of 14 (or 13.5) TeV data!



ATLAS Upgrade Document Library

- More public ATLAS upgrade physics results available at https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

Collections of HL-LHC studies

- High-Density QCD: arXiv:1812.06772
- Flavor Physics: arXiv:1812.07638
- BSM Physics: arXiv:1812.07831
- Higgs Physics: arXiv:1902.00134
- SM Physics: arXiv:1902.04070

Contributions to HL-LHC workshop

- Joint ATLAS-CMS addendum with collection of notes: arXiv:1902.10229 (Vol. 2 of Yellow Report)

ATLAS HL-LHC TDRs

- ITk Silicon Strips: https://cds.cern.ch/record/2257755
- Muon Spectrometer: https://cds.cern.ch/record/2285580
- LAr Calorimeter: https://cds.cern.ch/record/2285582
- Tile Calorimeter: https://cds.cern.ch/record/2285583
- ITk Silicon Pixels: https://cds.cern.ch/record/2285585
- High-Granularity Timing Detector: https://cds.cern.ch/record/2719855