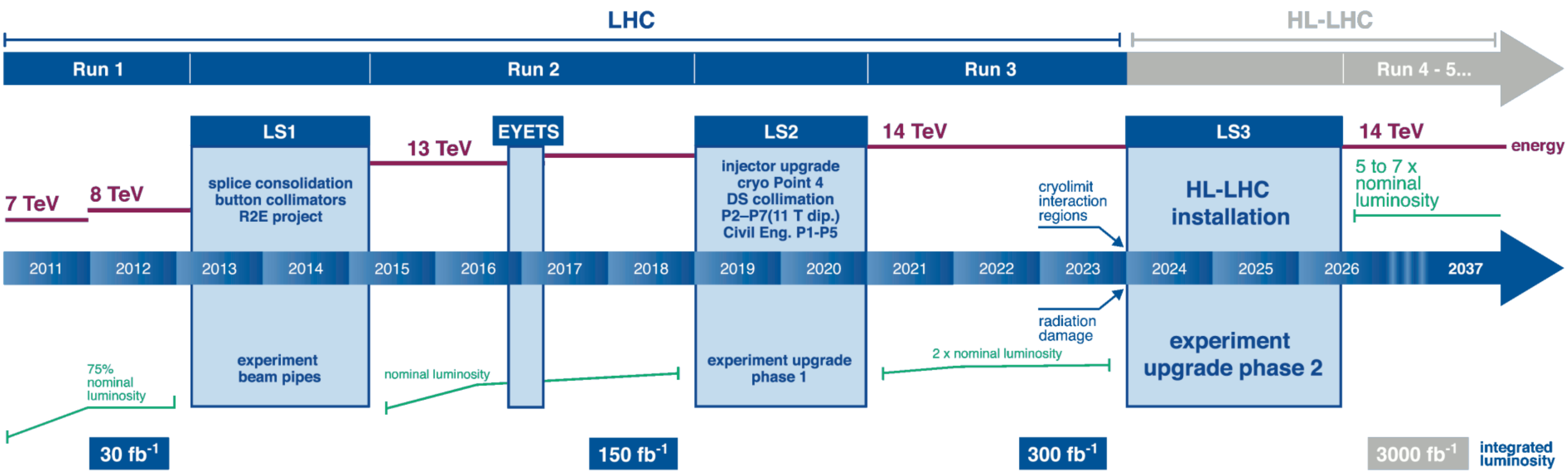
New Physics at the High Luminosity LHC with ATLAS

R Rosten on Behalf of the ATLAS Collaboration



LHC to HL-LHC

LHC

By 2023:

$\int L = 300\ \mathrm{fb}^{-1}$

$\langle \mu \rangle = 60$

2024-2026

HL-LHC

Nominal

$L = 5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

$\langle \mu \rangle = 140$

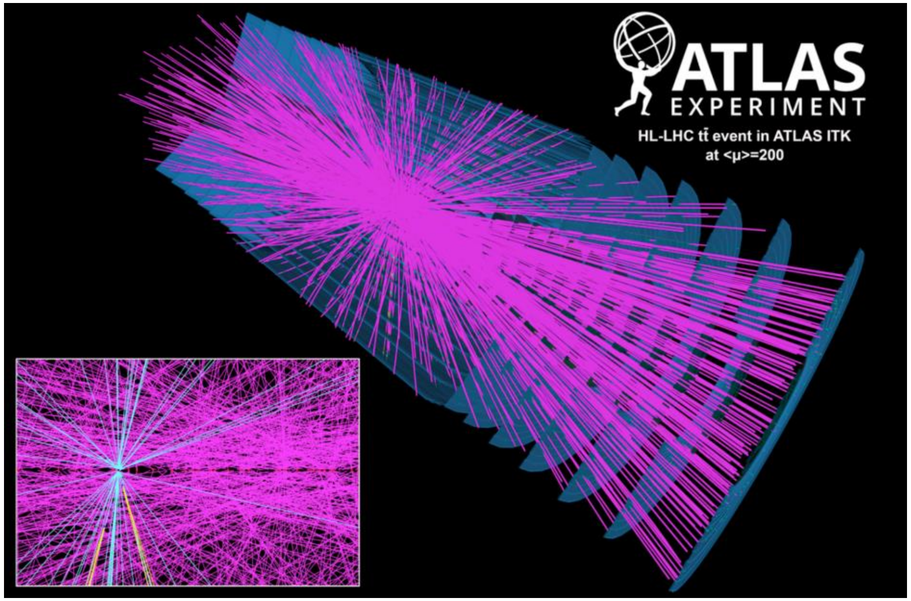
$$\int L = 3000\ \mathrm{fb}^{-1}$$

Ultimate

$L = 7 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

$\langle \mu \rangle = 200$

$$\int L = 4000\ \mathrm{fb}^{-1}$$



LHC to HL-LHC

LHC

By 2023:
$\int L = 300\ \mathrm{fb}^{-1}$
$\langle\mu\rangle = 60$

2024-2026

HL-LHC

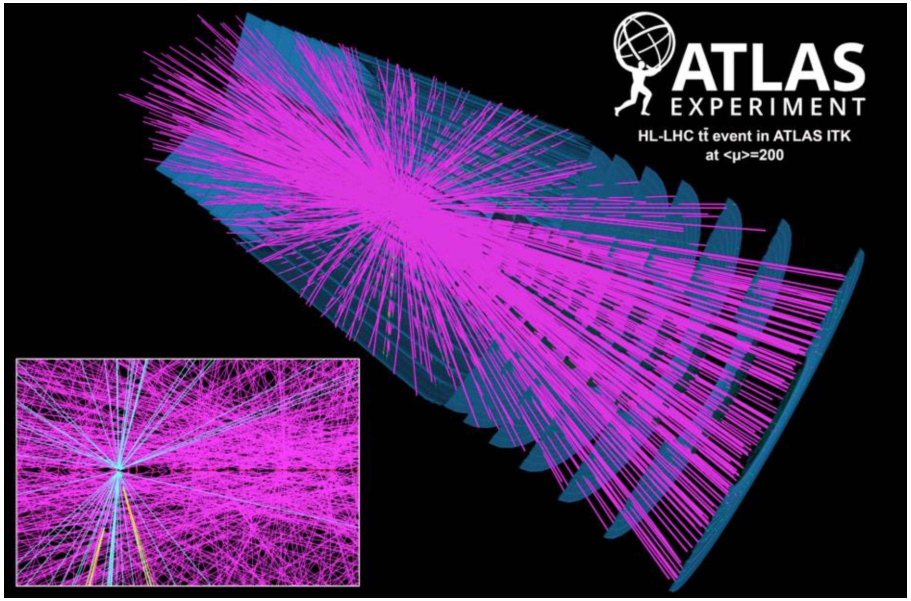
Higher pileup

Higher trigger rates

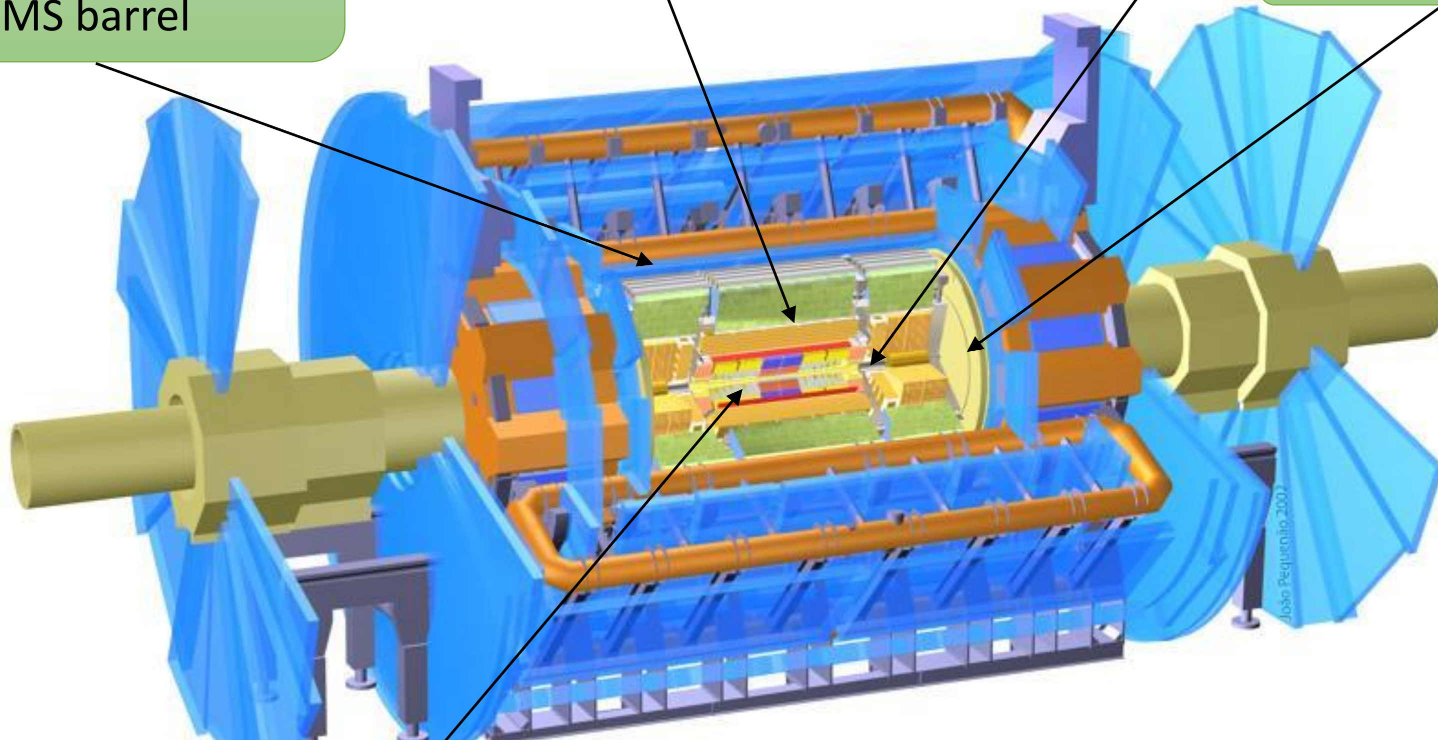
Higher radiation doses

Higher levels of beam induced background

New Physics



ATLAS Upgrades



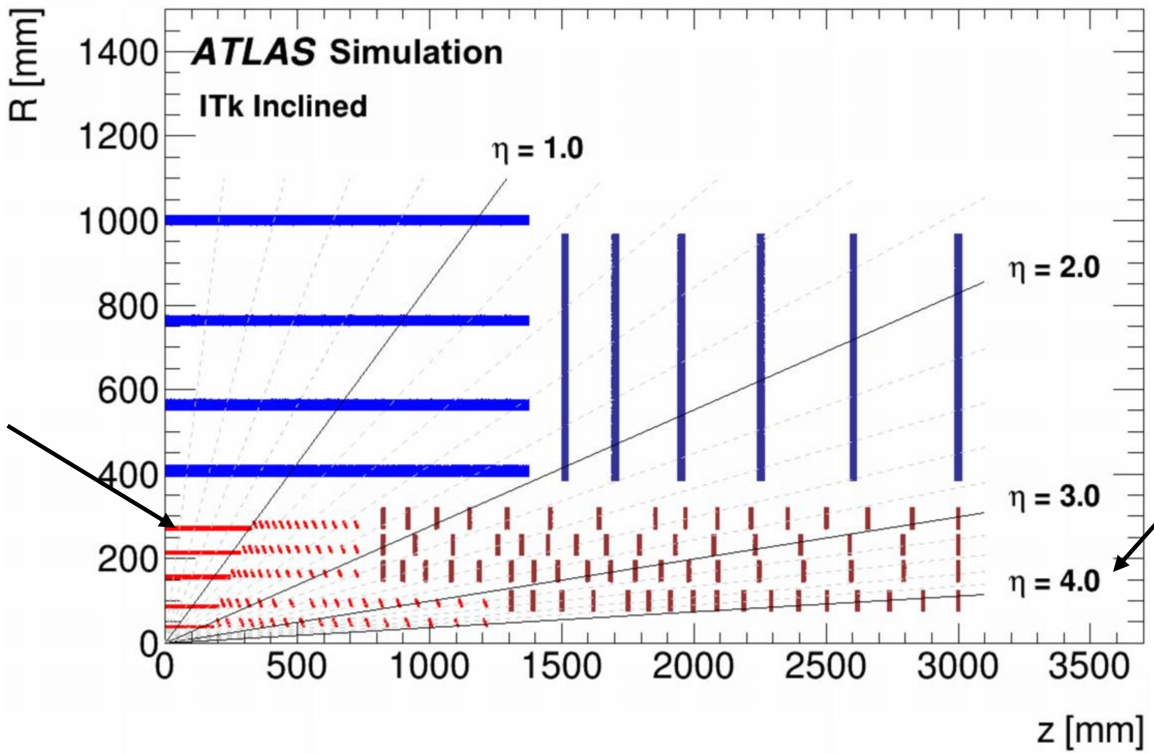
Trigger overhaul

Inner TracKer (ITK)

CERN-LHCC-2017-005

Fully Si replacement for the Inner Detector
80 million → 600 million pixel channels
6 million → 70 million strip channels

Increase in pixel granularity and number of layers



Coverage up to |η| < 4.0

Increase radiation hardness, reduce material budget

Calorimeter & Muon Upgrades

Replacement of front & back end electronics and power supplies

EM calorimeter readout upgrade will allow higher granularity at earliest trigger level

Hadronic calorimeter to provide full layer information at earliest trigger level

Replacement of readout electronics

Additional trigger layer for inner barrel layer

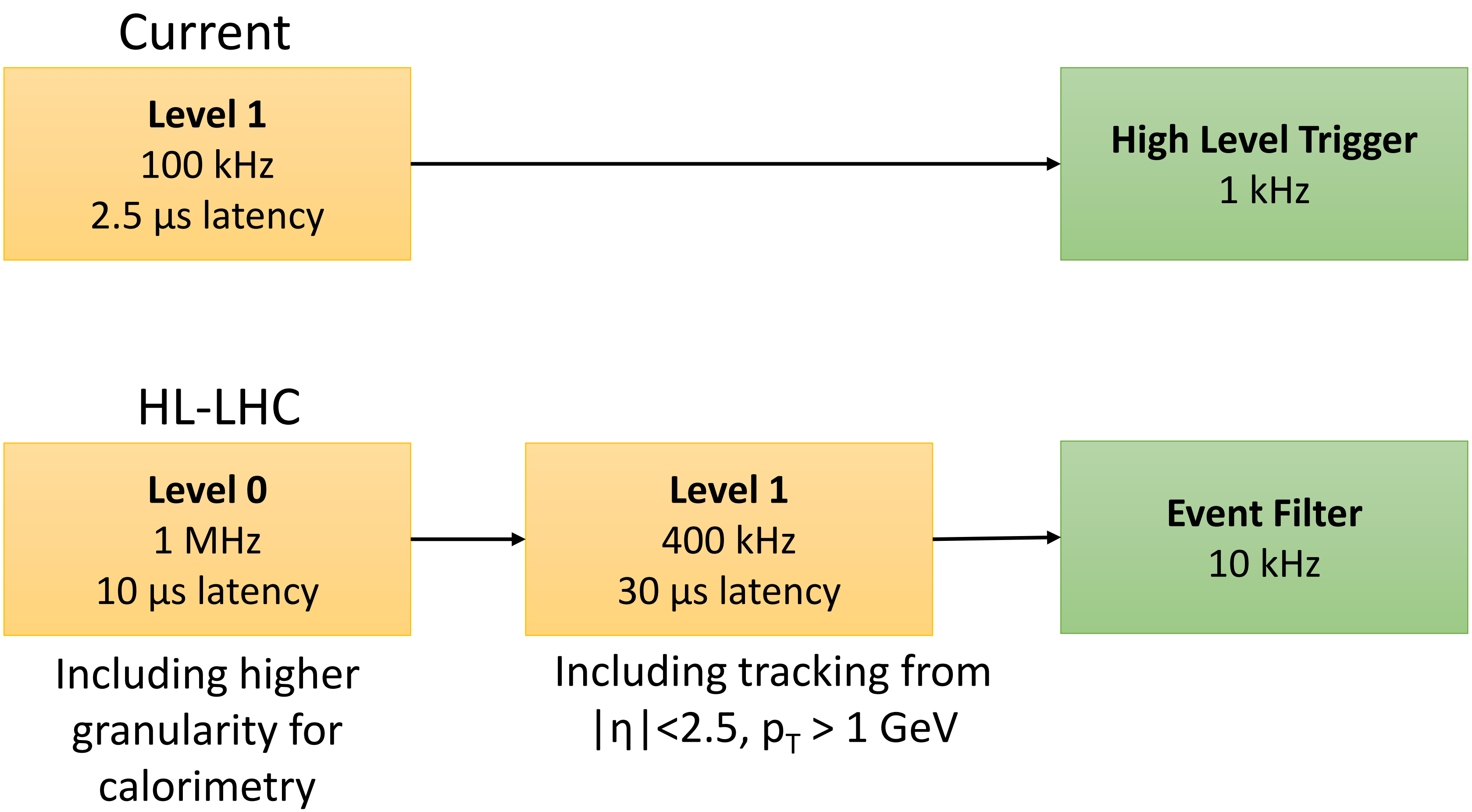
Upgrade of transition region chambers → inclusion of precision chambers for L0 trigger

Possible addition of high-η tagger

Theme:

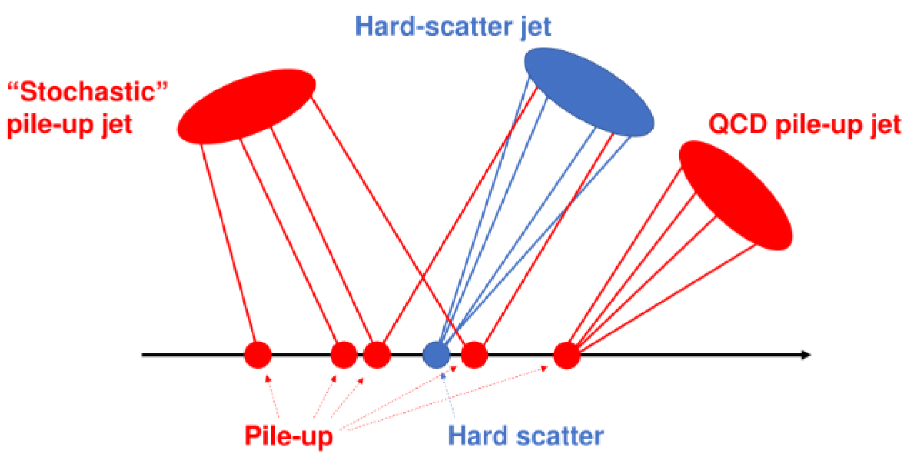
Improve triggering!

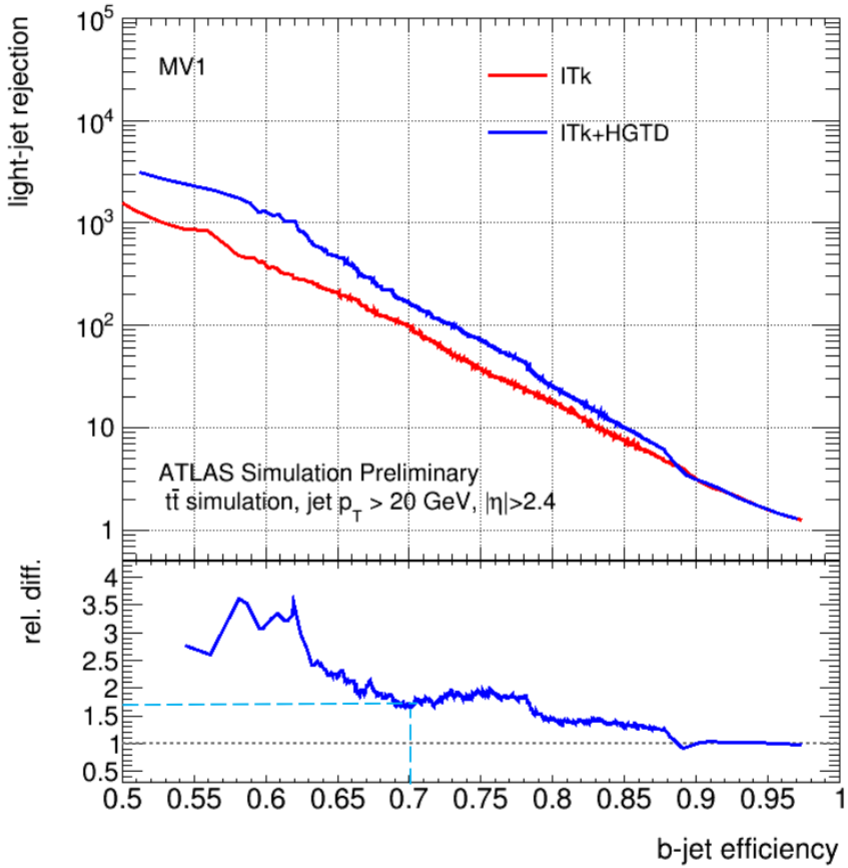
Triggering at the HL-LHC



High-Granularity Timing Detector

- Use timing in the forward regions to improve vertex reconstruction and mitigate in-time pileup
- The HGTD is a Si detector hopefully to be placed between the end of the tracker and the electromagnetic calorimeter endcap
  - 4 Si layers, 2.4 < |η| < ~4.2
  - 1.3 x 1.3 mm^2 granularity
  - 30-50 ps timing resolution (expected spread in collision is ~180 ps)





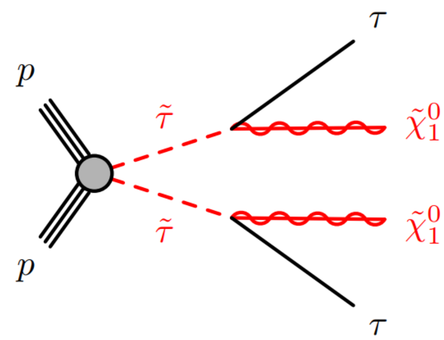
Question to Ask Regarding Physics and the Upgrades

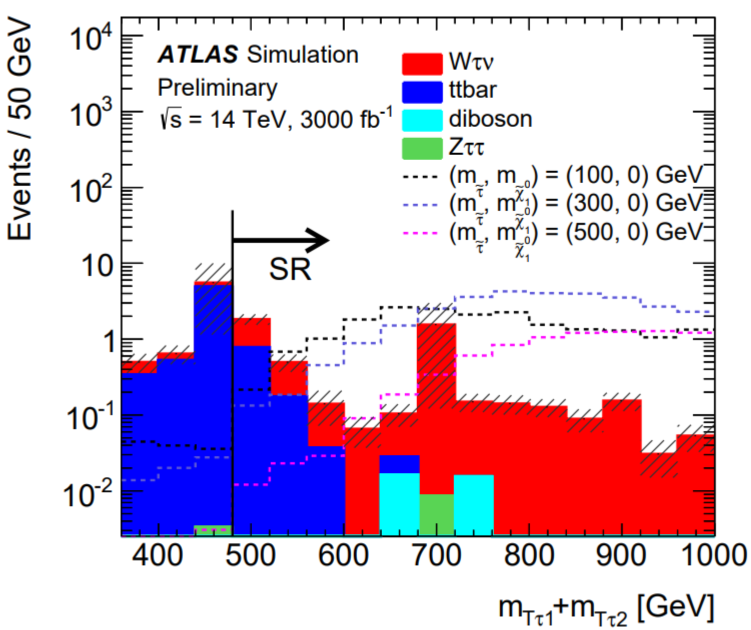
- How do we benefit from the upgraded geometry?
- Are there previously suppressed (e.g. machine) backgrounds that could become significant?
- Are there techniques (e.g. machine learning) which can improve selection efficiency?
- Can we aid in the development of new triggers to recover lost phase space from the LHC?

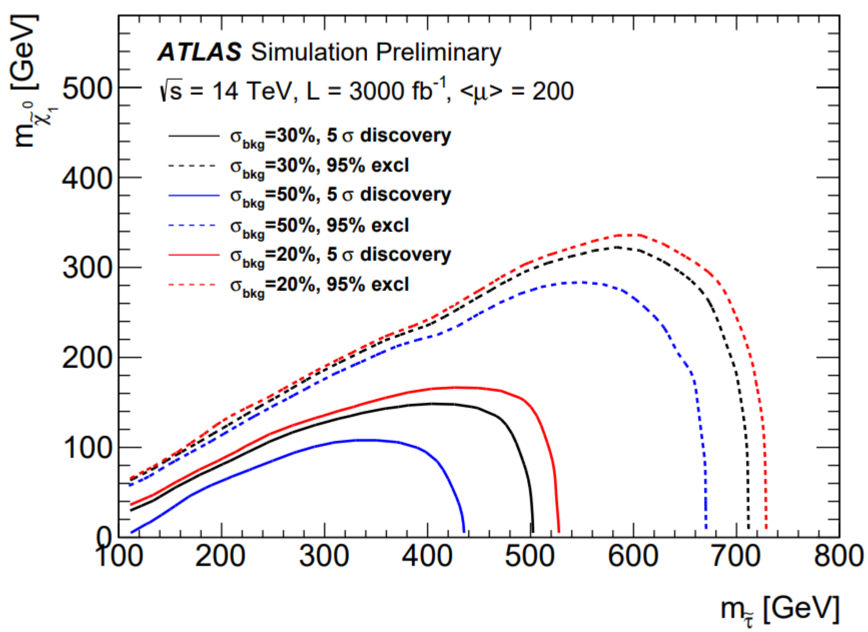
Direct stau production

ATL-PHYS-PUB-2016-021

- $\tilde{\tau}$ searches of interest in SUSY scenarios with large $\tan\beta$
    - Restrictions set by the relic density favor a light $\tilde{\tau}$ with a small mass splitting
- Current 95% CL limits on $m_{\tilde{\tau}}$ set at 109 GeV for a massless LSP
- Sensitive to MET reconstruction, pileup jet identification
- Assuming systematic uncertainty ~30%, 5σ discovery sensitivity for massless $\tilde{\chi}_1^0$ up to 500 GeV in $\tilde{\tau}$ mass, 95%CL exclusion up to 700 GeV

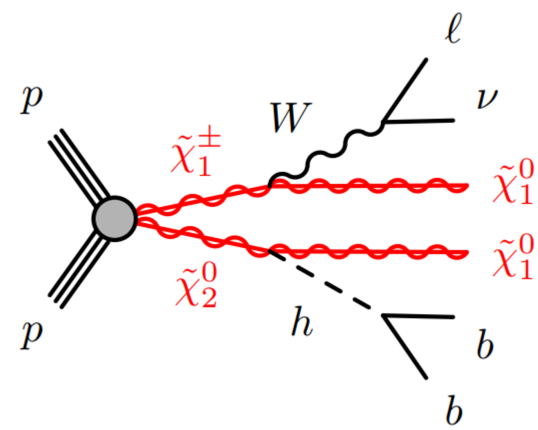


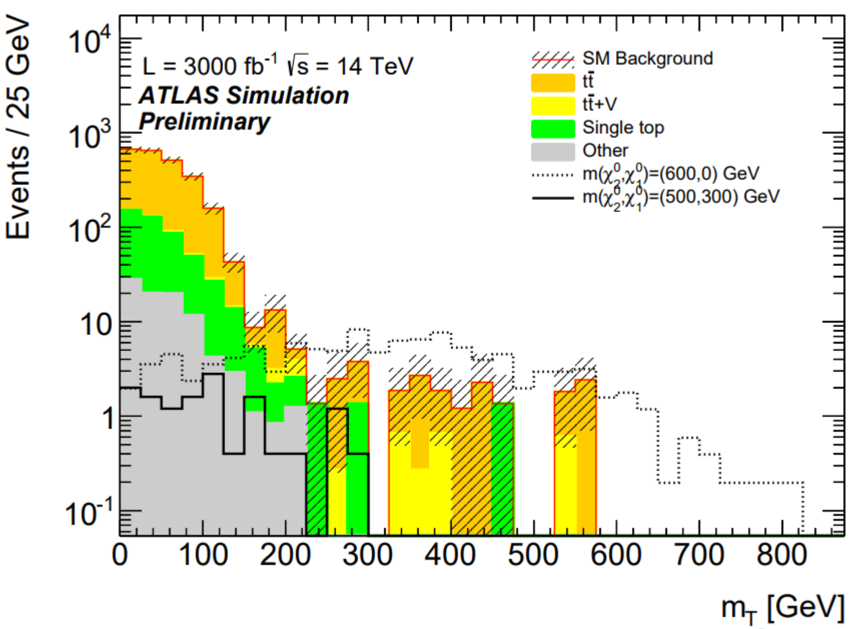




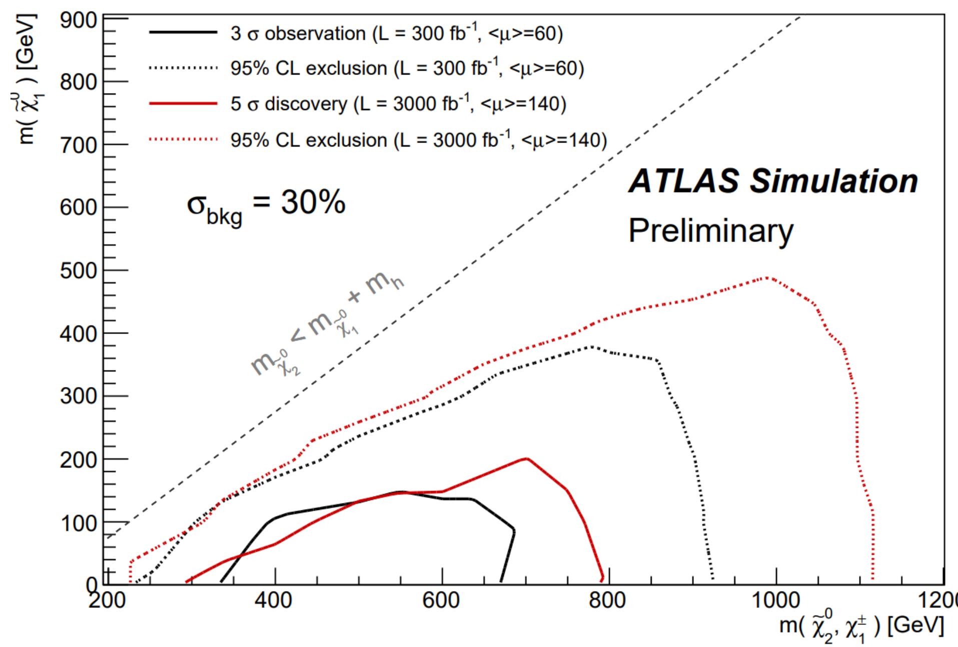
Direct chargino and neutralino production

- Final states with $\tilde{\chi}^0$ and $\tilde{\chi}^\pm$ LSPs comprise a large fraction of R-parity conserving parameter space
- Current 95% CL exclusion limits ~250 GeV for massless LSP
- Selection criteria efficiency shows a dependence on pileup, degrades limits somewhat at low masses
- Major increase in exclusion possible for HL-LHC dataset





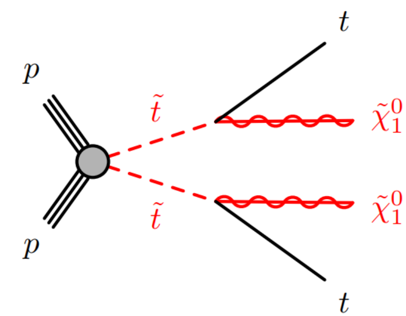
From lepton + MET

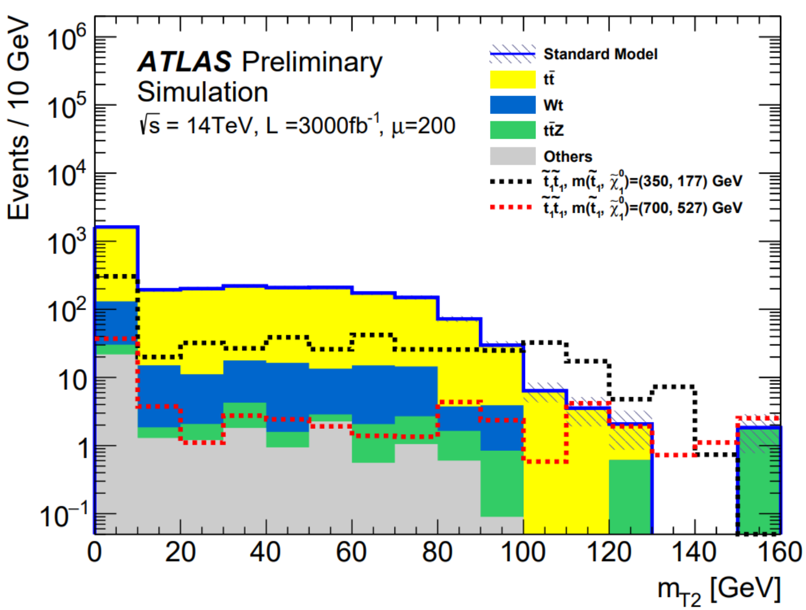


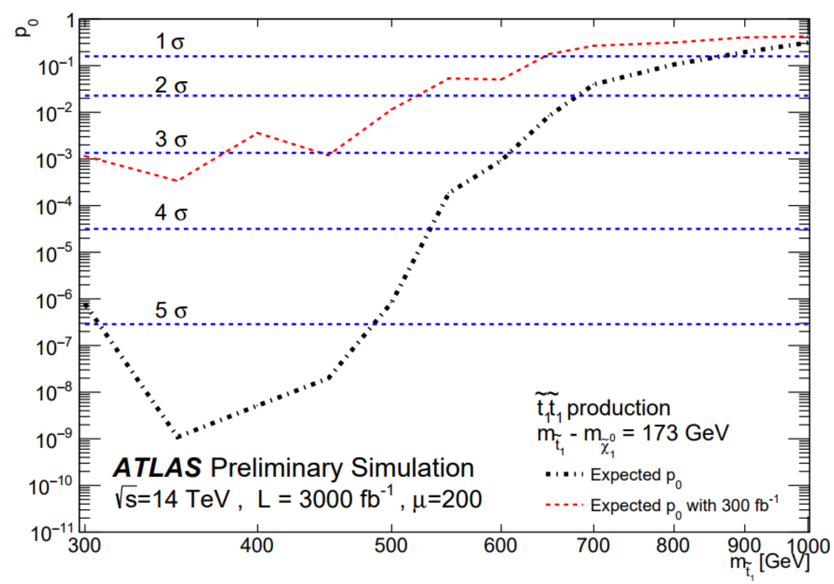
Direct stop pair production

ATL-PHYS-PUB-2016-022

- Searches for $\tilde{t}$ production challenging in compressed mass regime due to similarity in kinematics to SM $t\bar{t}$ production
- Previous exclusion from dilepton (initial state radiation based) selections set limits on the stop mass at 191 (230-380) GeV
- HL-LHC may improve limits by factor of 2 or more in dileptonic final state



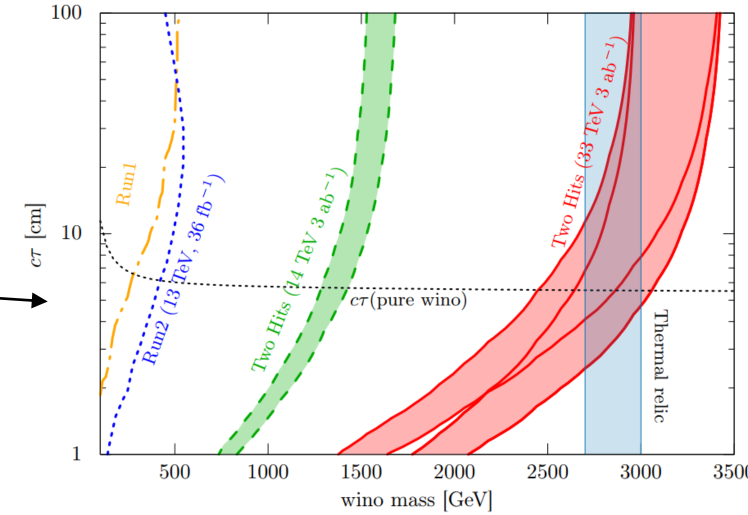


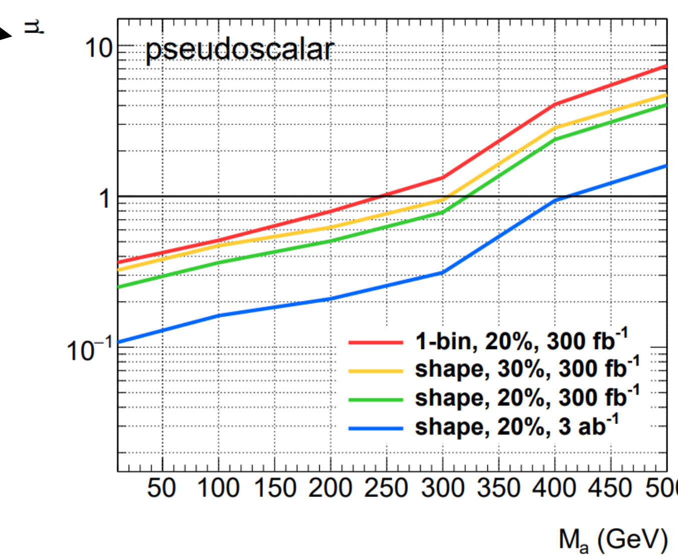


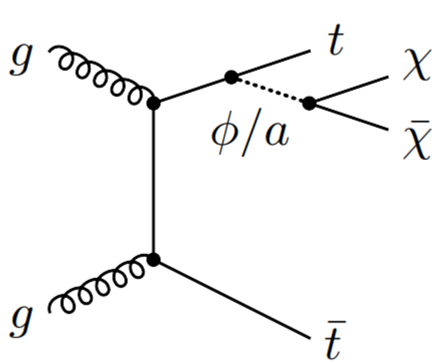
Lepton based stransverse mass

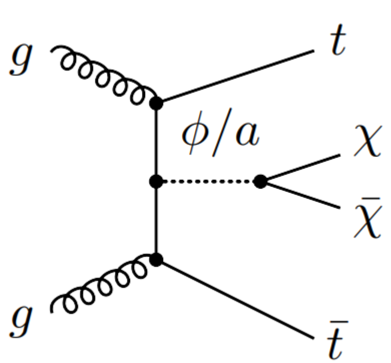
Dark Matter at HL-LHC

- Monojets: ATL-PHYS-PUB-2014-007
  - EX: Pair of WIMP DM particles recoil off initial state radiation
  - limited by systematics, increase in limits/discovery potential from 300 → 3000 fb^{-1} to gain most from suppressing systematics
- Disappearing tracks search: 1703.09675
  - charged long-lived particle decays in tracker to light charged SM particle and LSP)
  - Tracker upgrade allows for improved momentum resolution + maintaining background rejection
- Dark matter + ttbar: arXiv:1611.09841
  - Considered signature: 2 leptons, 2 b-jets, MET
  - Large increase in sensitivity, strong dependence on background systematics





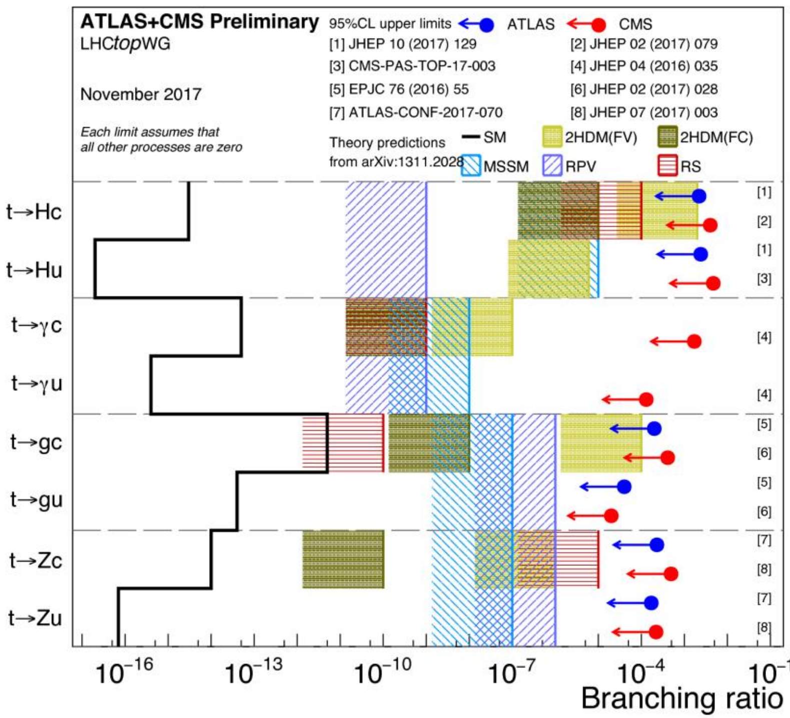




Top Quark and FCNC

ATL-PHYS-PUB-2016-019

- Decays forbidden at tree level in SM but present in various BSM models → natural probe for new physics
- Search for $t \rightarrow Zq$ and $t \rightarrow Hq$ in $t\bar{t}$ events and take advantage of HL-LHC statistics
- Analysis sensitive to fake b-jets, considered 2 and 3 b-jet events only
- Expect order of magnitude improvement on Run-I limits



$\boldsymbol{t} \rightarrow \boldsymbol{Zq} \rightarrow \ell\ell q$
$t \rightarrow Wb \rightarrow \ell\nu b$

Uncertainties dominated by relative uncertainty in ttbar and Z+jets cross-sections

or

$\boldsymbol{t} \rightarrow \boldsymbol{Hq} \rightarrow b\bar{b}q$
$t \rightarrow Wb \rightarrow \ell\nu b$

Uncertainties dominated by light-jet fake rate and normalization of ttbar background

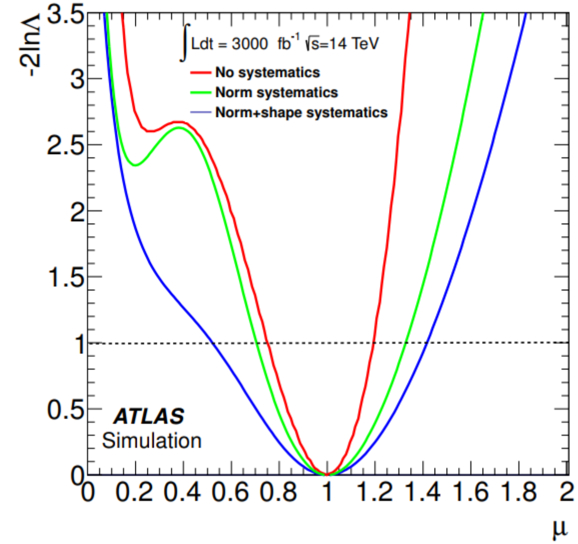
$$\mathcal{B}(t \rightarrow Zq) < (8.3 - 41) * 10^{-5}$$

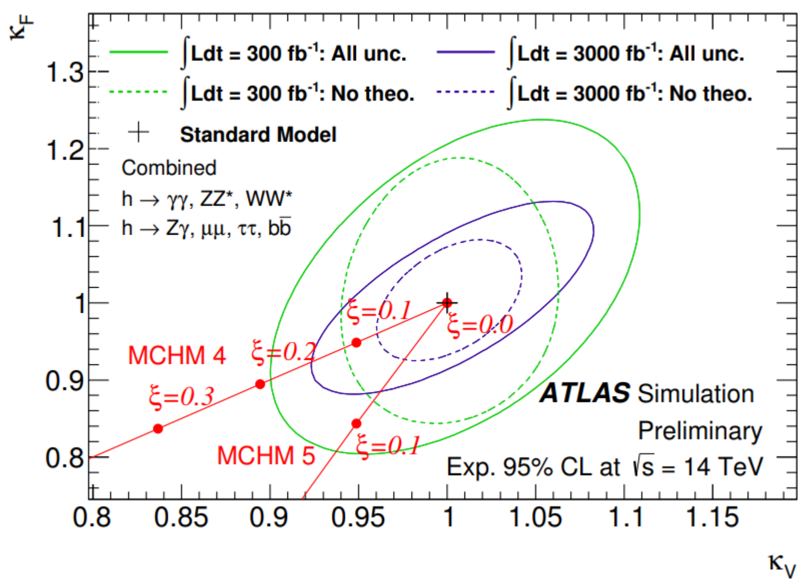
$$\mathcal{B}(t \rightarrow Hq) < (1.1 - 2.4) * 10^{-5}$$

Higgs Searches

- Mono-Higgs: ATL-PHYS-PUB-2015-024
  - Signature: DM (MET) + Higgs (4 leptons)
  - Large dataset of HL-LHC should allow reduction of some systematics
  - In general, 4-lepton search useful for constraining Higgs width
- More on Couplings:
  - Extensions to Higgs models will modify couplings to SM particles
  - Ex: Minimal Composite Higgs, 2HDM, other DM

ATL-PHYS-PUB-2014-017





Summary

- HL-LHC promises enormous amounts of data… and new challenges
- ATLAS systems to be upgraded to maintain and improve performance
- Preliminary studies suggest substantial increases in sensitivity
- Ongoing studies need to be done incorporating updated geometry and software capabilities
- Shouldn't abandon improvements in search strategy!

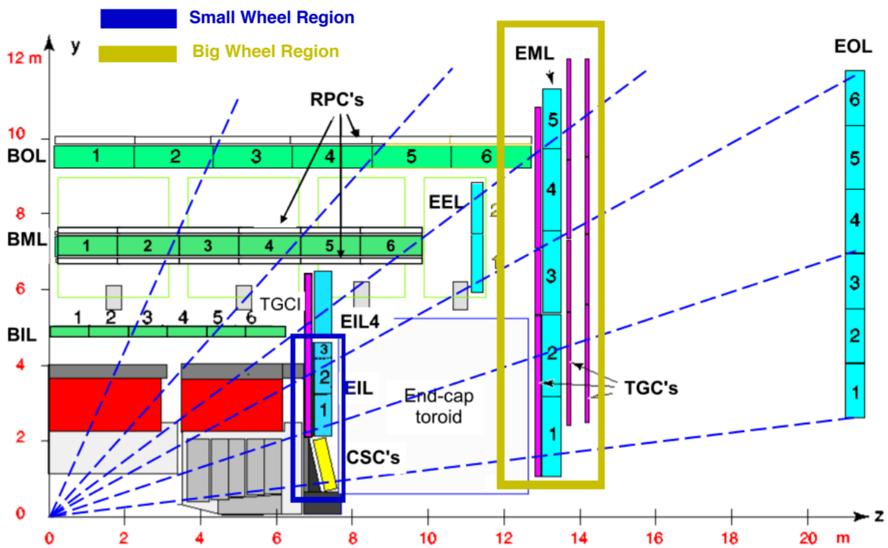
Backup Slides

Status of ATLAS Upgrade Technical Design Reports

- Muon NSW: Approved, components already under production (Phase-I upgrade)
- ITK TDR: Approved in May
- Muon TDR: Final version with LHCC
- LAr & Tile TDR: Proceeded through LHCC review, revisions ongoing
- TDAQ: Expect submission end of this week
- HGTD: Expression of Interest submitted to LHCC

Muon New Small Wheel (NSW)

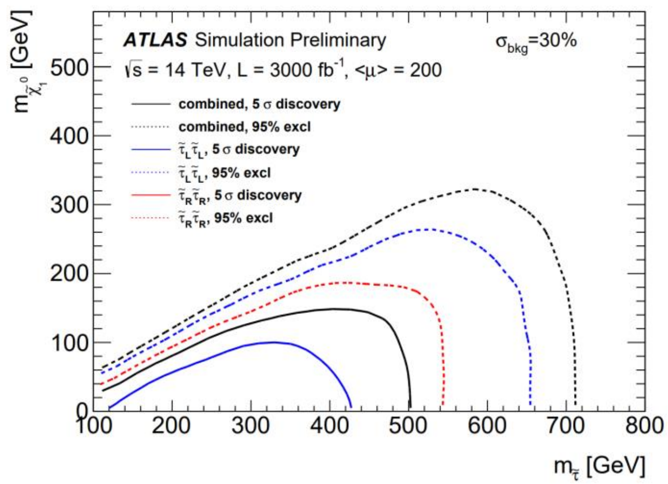
- Phase-I Upgrade, under production with first wedge to be assembled early 2018
- Replacement of inner endcap wheel with new Small-strip Thin Gap Chambers (sTGC) and MICRO MEsh GAseous Structures chambers (micromegas) based detector
- Reduce fake-rate of hardware triggering and improve tracking



Notes: Direct stau Production

- Signature: 2 tau jets + large MET
- Backgrounds: W+jets, ttbar
- Trigger: tau trigger
- Upgraded ATLAS geometry not simulated – use generator level information with parameterization of ATLAS (including resolution and reconstruction efficiencies) response after upgrade – reoptimized selections

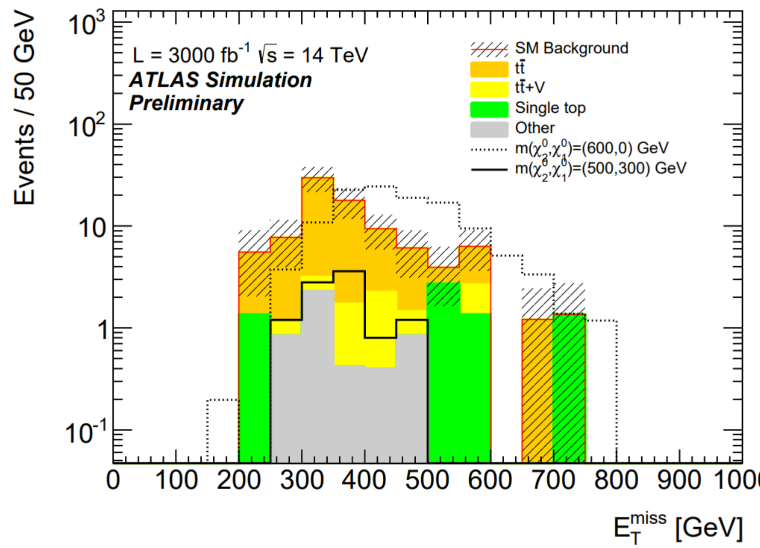
SR Definition
≥ 2 OS taus
loose jet-veto
Z-veto
$\Delta R(\tau 1, \tau 2) < 3.5$
$E_{\mathrm{T}}^{\mathrm{miss}} > 280$ GeV
$m_{\mathrm{T2}} > 40$ GeV
$m_{\mathrm{T}\tau 1} + m_{\mathrm{T}\tau 2} > 480$ GeV



Notes: Direct chargino/neutralino production

- Signature: Isolated lepton + pair of b-jets
- Backgrounds: ttbar, single top, associated production of ttbar + vector boson
- Trigger: Not included (lepton trigger may benefit from upgrades)
- Upgraded ATLAS geometry not simulated – use generator level information with parameterization of ATLAS (including resolution and reconstruction efficiencies) response after upgrade – reoptimized selections

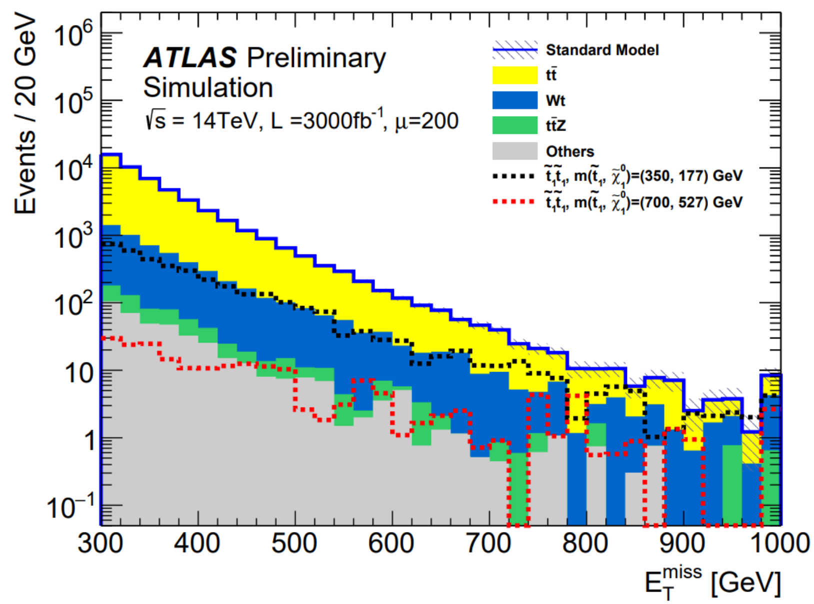
Selection	SRA	SRB	SRC	SRD
# of leptons (e, μ)	1			
# b-tagged jets	2			
m_{bb} [GeV]	$105 < m_{bb} < 135$			
# jets	2 or 3			
m_{CT} [GeV]	> 200	> 200	> 300	> 300
m_{T} [GeV]	> 200	> 250	> 200	> 250
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 300	> 350	> 400	> 450
$\langle\mu\rangle = 60$, 300 fb^{-1} scenario	yes	yes	–	–
$\langle\mu\rangle = 140$, 3000 fb^{-1} scenario	–	–	yes	yes



Notes: Direct stop production

- Signature: 2 leptons, MET, ISR jet
- Backgrounds: ttbar, ttbar + Z (Z->neutrinos)
- Trigger: lepton trigger, p_T > 25 GeV
- Upgraded ATLAS geometry not simulated – use generator level information with parameterization of ATLAS (including resolution and reconstruction efficiencies) response after upgrade – reoptimized selections

	SR
$m_{\ell\ell}$ [GeV] (SF lepton pairs only)	$81.2 < m_{\ell\ell} < 101.2$
$\min\{\Delta\phi(\text{jet}_{\text{ISR}}, E_{\text{T}}^{\text{miss}})\}$	> 0.4
$\Delta\phi(\text{jet}_{\text{ISR1}}, E_{\text{T}}^{\text{miss}})$	> 2
$R_{\ell\ell}$	> 6
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 350
Leading ISR jet p_{T} [GeV]	> 300
m_{T2} [GeV]	> 100



Long-lived particles

- Long-lived particles are present in a variety of models
  - Arise from approximate symmetries, suppressed phase space, small couplings, off-shell decays…
- Searches are heavily geometry dependent
- Searches may include dedicated triggers or object reconstructed
  - Projections for HL-LHC non-trivial

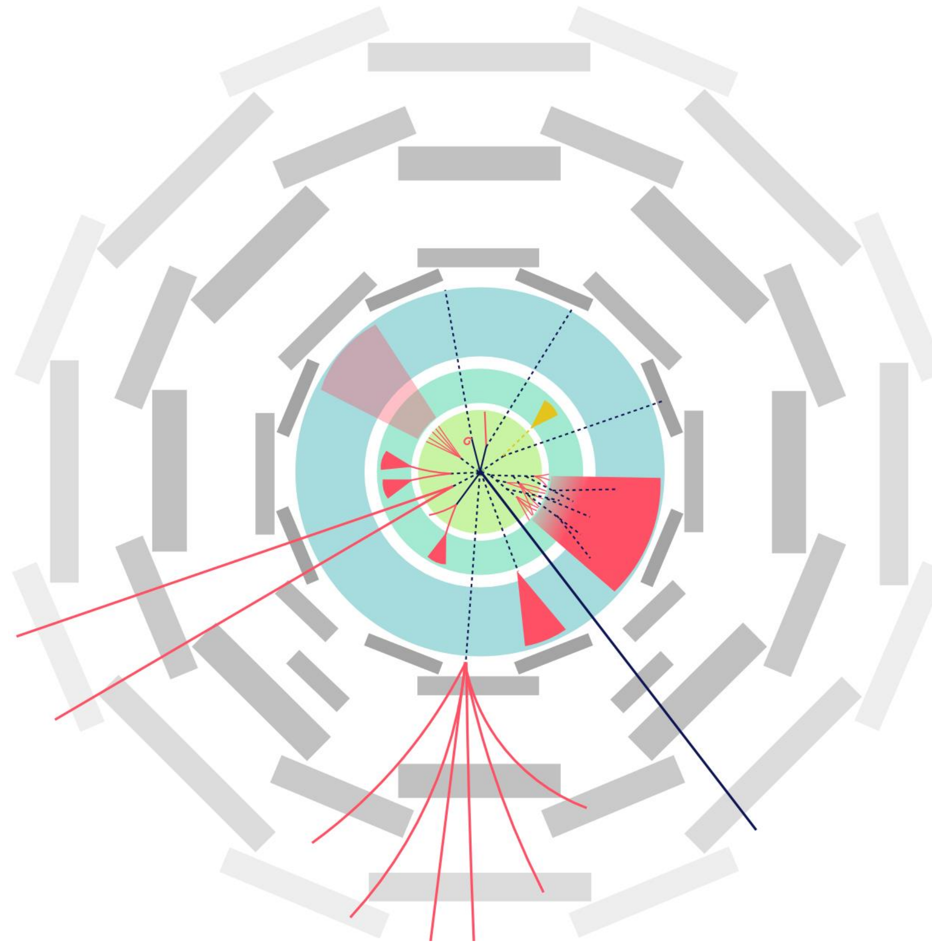


Figure by Heather Russell

Higgs Couplings