ATLAS+CMS top program at HL-LHC

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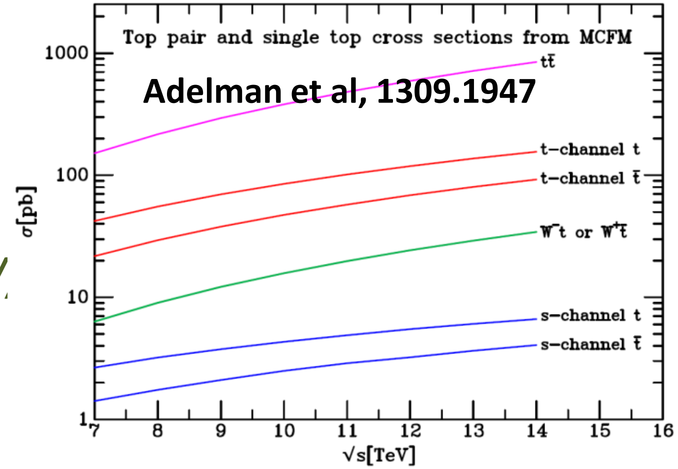
Outline

- Perspectives of top physics at HL-LHC
- Top quark identification
- Review of recent studies of top physics at HL-LHC
  - Flavor changing neutral currents
  - J/ψ reconstruction in top decays
  - tt resonances
- More top physics at HL-LHC
- Summary

Top at HL-LHC

- With projected 3000/fb of integrated luminosity, the number of top quarks produced at HL-LHC is huge
- Plenty of topics for SM physics studies:
  - Precision measurement of top production (kinematic properties, differential cross sections) and properties (mass)
  - Verification of theoretical models
  - Top couplings
  - Associated top production: tt(V/γ/H)
  - Rare decays
- Physics beyond SM:
  - Resonances decaying into top quarks
  - Asymmetries, chromomagnetic moments
  - Top quarks arising in BSM processes (SUSY, charged Higgs,..)

Process	Events/3 ab
tt	3B
ST t-channel	600M
ST tW	200M
ST s-channel	30M
tt(V/γ/H)	3M
tZ	300k
tH	30k



HL-LHC challenge

- Challenging experimental environment
  - Need to find the ways to mitigate the pileup: $\langle\mu\rangle=140$ at $L=5\times10^{34}/cm^2s$, 200 at $L=7.5\times10^{34}/cm^2s$
  - Top quark reconstruction is particularly complex, relies on all detector components
- Challenge to physics studies
  - Object performance: can't afford full simulation for all analyses, use parameterized performance functions
  - Extrapolation of analyses with background derived on real data is tricky
  - Need to figure the way to evaluate the evolution of various systematic uncertainties
    - Zero approximation: assume systematic uncertainties as in Run 2
    - Many systematic uncertainties are expected to be reduced with statistics (e.g. background production cross sections), both due to lower stat. uncertainty and ability to go to tighter operating points
    - Difficult to evaluate without dedicated studies, $\sqrt{L}$ scaling seems like a good estimate

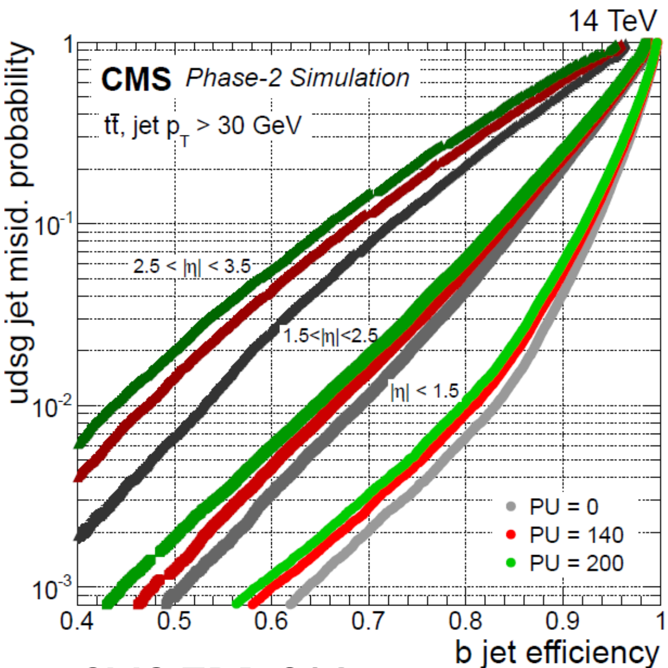
Top quark identification

- Top quarks decay right after they are born, need to be reconstructed
- $Br(t \rightarrow Wb) \sim 100\%$ unless we are looking for rare decays
- Two options: $t \rightarrow Wb \rightarrow l\nu b$ or $t \rightarrow Wb \rightarrow jjb$
  - Leptonic top: (isolated) e/μ + b-jet + MET
  - Hadronic top, resolved: three jets, one of them b-jet
  - Hadronic top, boosted: a large R jet with substructure
- Identification of jets coming from b-quarks (b-tagging) is key for top reconstruction

b-tagging performance (1)

- Current b-tagging algorithms at both ATLAS and CMS are based on track impact parameters and reconstruction of secondary vertices
- Information related to IP and SV is combined into a single discriminating variable (tag weight) using multivariate analysis techniques
  - CMS: cMVAv2 (BDT, central region), DeepCSV (deep neural network, forward region)
  - ATLAS: MV2 (BDT), DL1 (deep learning – not currently used for upgrade studies)
- Questions to address at HL-LHC:
  - algorithm sensitivity to high pileup environment up to $\langle\mu\rangle=200$
  - performance in the very forward region: both experiments intend to extend the b-tagging $|\eta|$ coverage up to 3.5—4

B-tagging performance (2)



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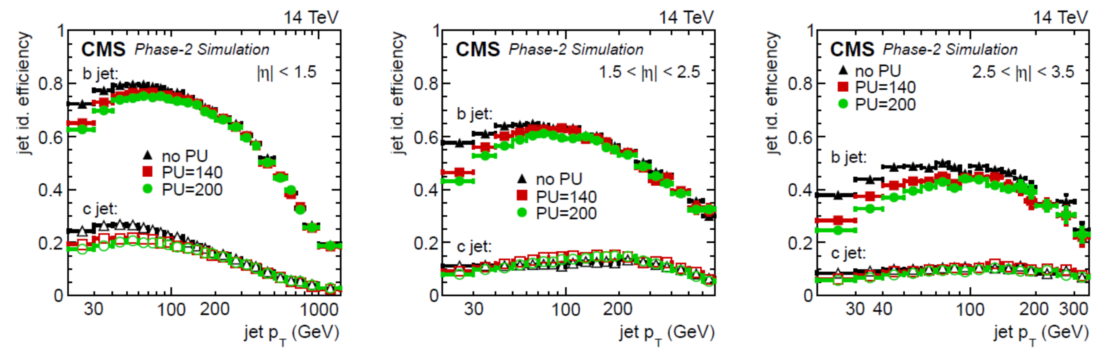

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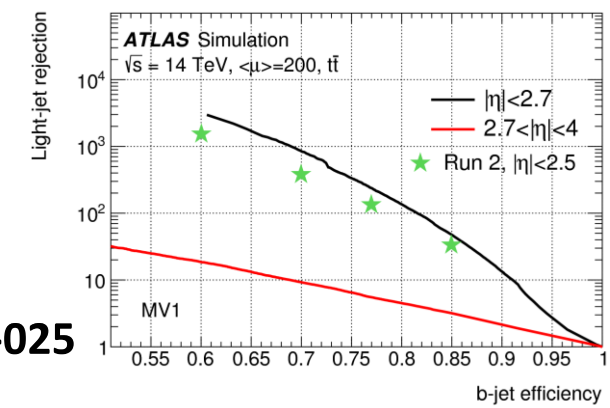
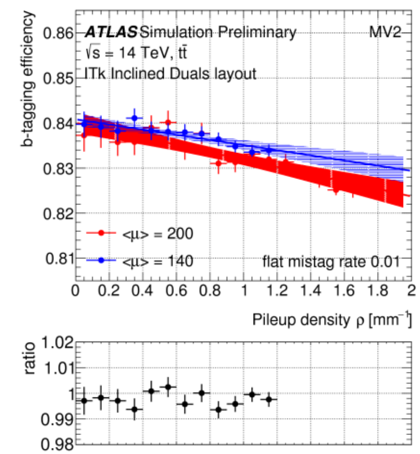


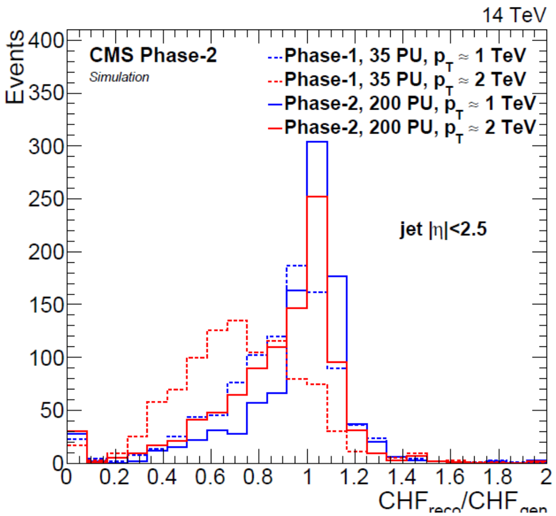


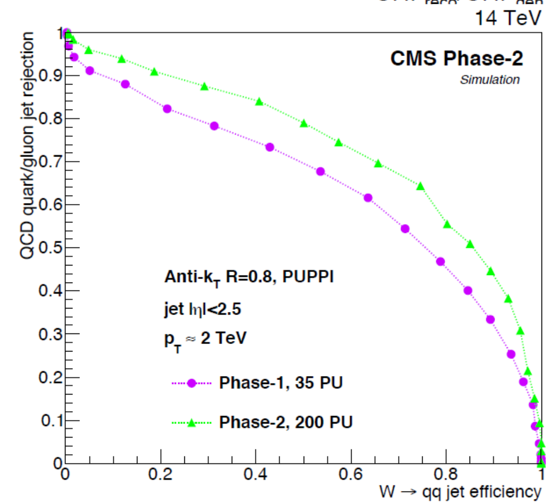
- b-tagging at high luminosity remains solid
  - b-tagging efficiency at fixed mistag rate is a function of pileup density, not <μ>
- Performance in the very forward region is a problem
  - Existing algorithms are not optimized for large |η|, tracking is losing lever arm

Jet substructure

- Jet substructure: way to identify highly boosted tops (and W,Z,H)
  - mass drop: ratio of masses of highest subjet and the large-R jet
  - N-subjettiness τ_N: p_T weighted ΔR distance between each jet constituent and its nearest subjet axis under assumption that the jet has N subjets
- With the upgraded CMS tracker, highly granular jet substructure reconstruction is available at higher jet momenta than achieved with the Phase-1 tracker
  - improved large R jet mass resolution
  - gain in identification of boosted objects

CMS-TDR-014

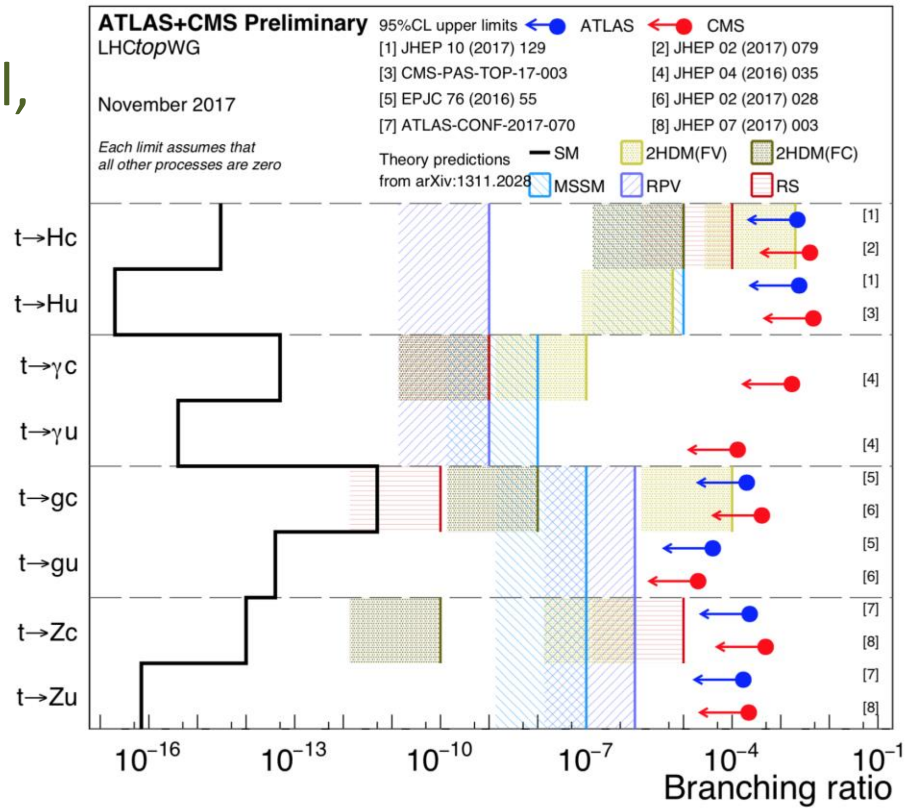




Flavor changing neutral currents (1)

- Flavor changing neutral currents: golden analysis for top physics
  - SM: not allowed at the tree level, highly suppressed in loops
  - Enhanced in BSM: RPV SUSY, technicolor

BR	SM	2HDM	MSSM
$t \to cg$	5×10^{-12}	10^{-8}-10^{-4}	10^{-7}-10^{-6}
$t \to cZ$	1×10^{-14}	10^{-10}-10^{-6}	10^{-7}-10^{-6}
$t \to c\gamma$	5×10^{-14}	10^{-9}-10^{-7}	10^{-9}-10^{-8}
$t \to cH$	3×10^{-15}	10^{-5}-10^{-3}	10^{-9}-10^{-5}



Flavor changing neutral currents (2)

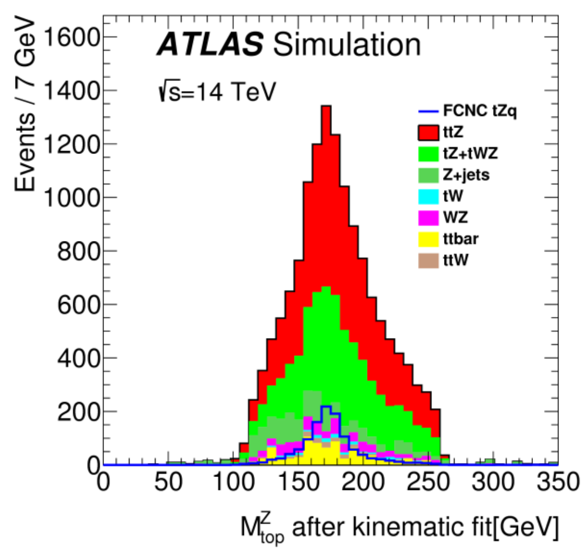
- tt→(lνb)(Zq)→3l+(≥1 b-jet)+(≥1 jet)
  - Strategy: kinematic reconstruction via χ^2
  - Dominant uncertainties: data driven fakes and tV/ttV backgrounds
- tt→(lνb)(Hq)→l+(2,3 b-jets)
  - Strategy: discriminant built from PDFs for each jet permutation
  - Dominant uncertainties: tt+HF normalization, flavor tagging

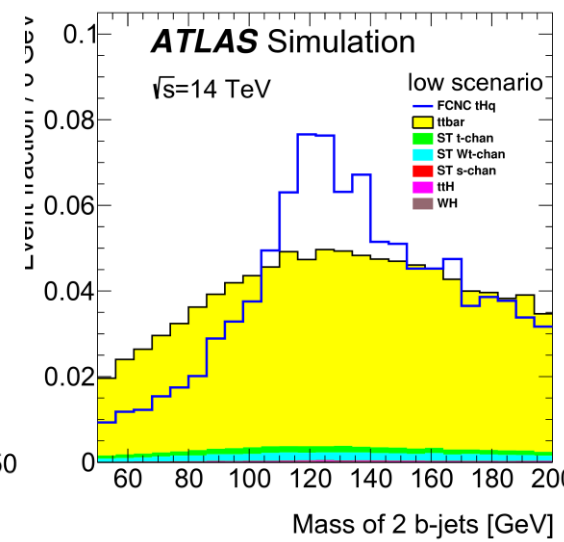
BR limits (depending on systematic extrapolation scenario):

t→Zu: $(1—2)\times10^{-4}$

t→Zc: $(2—4)\times10^{-4}$

t→Hq: $\sim2\times10^{-4}$

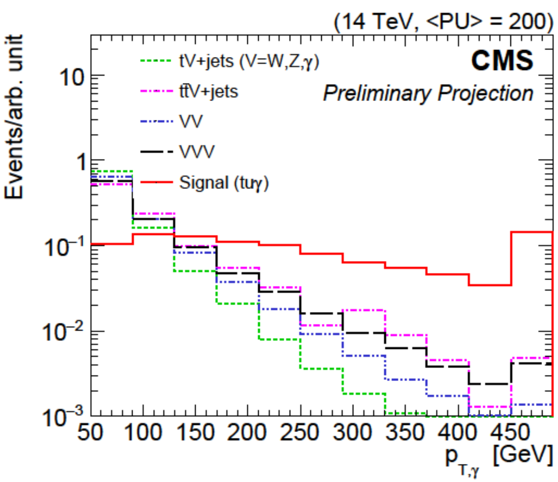




ATL-PHYS-PUB-2016-019

Flavor changing neutral currents (3)

- tt→(μνb)(γq)→μ+γ+(≥1 b-jet)
  - Strategy: cut-and-count
  - Dominant systematic uncertainties: instrumental (fake photons), tV+jets, VVγ



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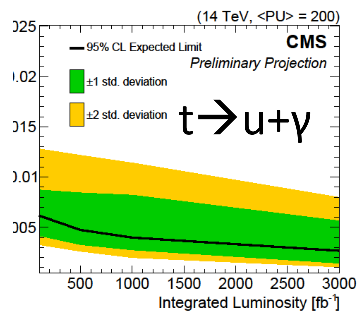
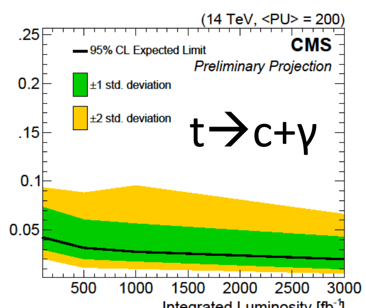
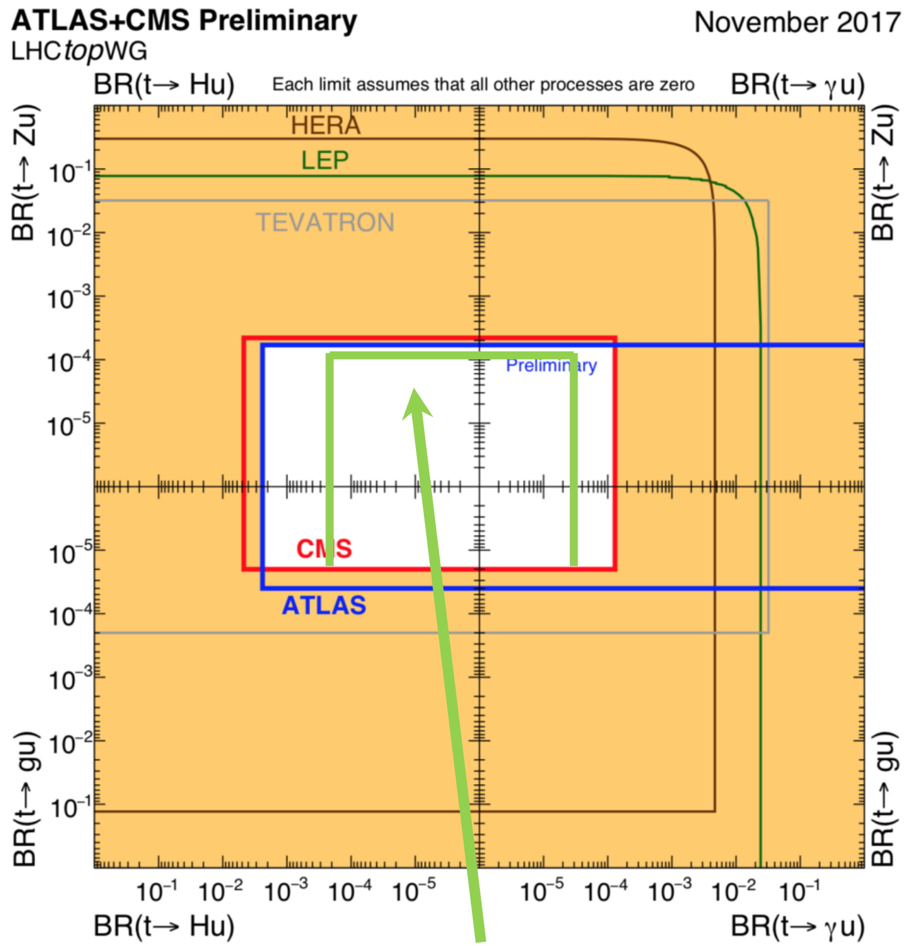


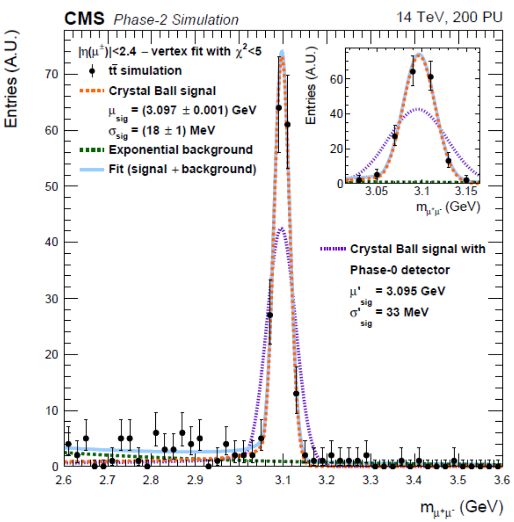




Current HL-LHC projection

J/ψ reconstruction in top decays

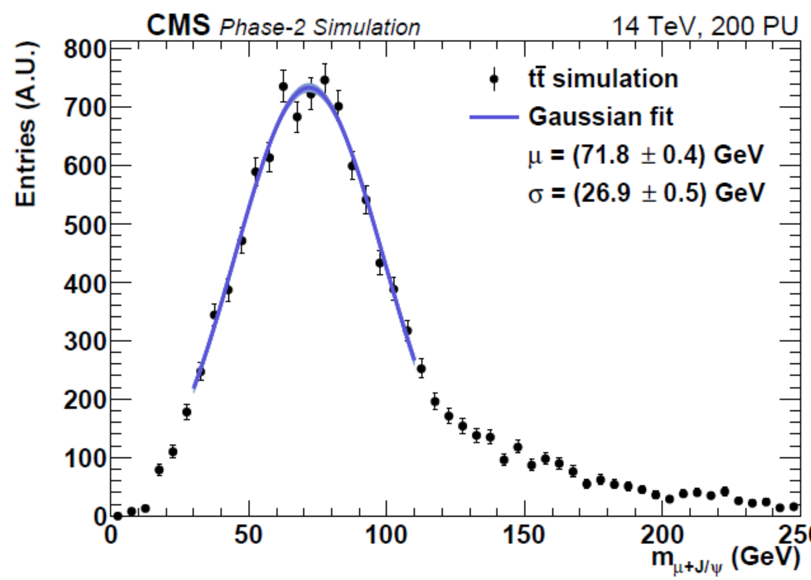
- Look at t→Wb→(μν)(J/ψ+X)→3μ+X
- Alternative measurement of top mass that does not suffer from uncertainties due to b-jet reconstruction
- An opportunity to perform a dedicated tuning of the b fragmentation



Expected number of events in the J/ψ peak at 3000/fb: 6×10^5

Expected m_t precision:
±0.24 GeV (stat)
±0.53 GeV (syst)

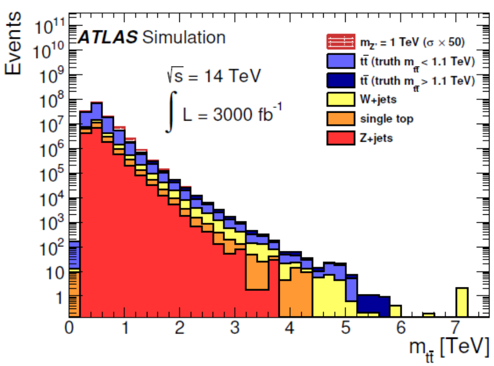
CMS-TDR-014



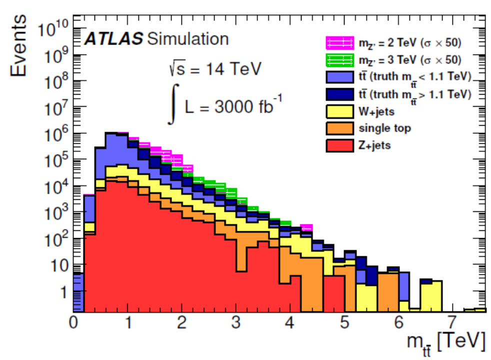
CMS-TDR-016

Heavy tt resonances

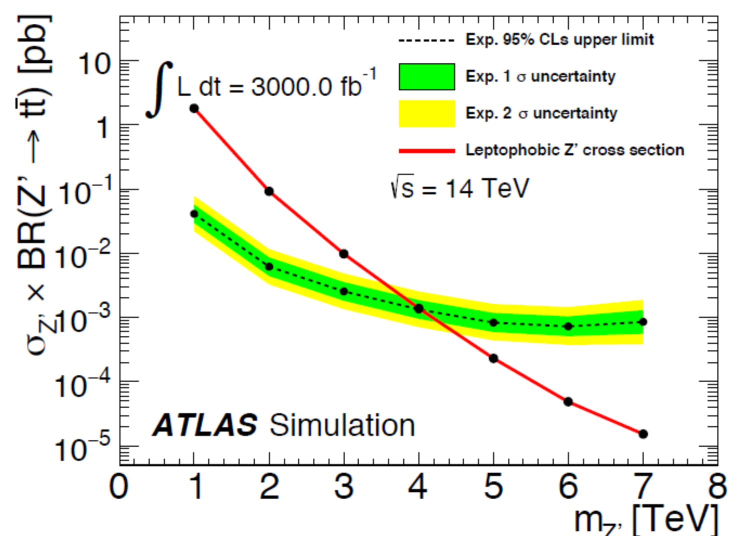
- Many theories predict heavy (TeV scale) particles decaying into top pairs
- Produced tops are highly boosted, leading to dense tracking environment
- Benchmark: leptophobic Z' from topcolor-assisted technicolor
  - Br(Z'→tt)=1/3, width << experimental resolution
  - ATLAS exclusion limit (3.2/fb, √s=13 TeV): 2.0 TeV
- Current analysis: Z'→tt→lνqq→(e/μ)+b+large-R-jet+MET (boosted) or Z'→tt→lνqq→(e/μ)+b+≥3j+MET (resolved)
- Obtained Z' mass reach: 4 TeV



e+jets resolved



e+jets boosted



ATL-TDR-025

More top physics at HL-LHC

- 4top production
  - new physics (resonances, top compositeness, 4t vertices,..)
  - sensitivity to Higgs width
  - σ_{SM}=6 fb at $\sqrt{s}$=13 TeV, need HL-LHC to discover
- Wtb couplings
  - see previous talk
- V_{ts}/V_{td} measurements
  - can be improved measuring single top production vs rapidity (arXiv:1002.4718)
- ttZ, ttγ, ttg couplings
- Charge asymmetry in top-antitop production
  - may learn a lot from comparison of tt and ttW (arXiv:1406.3262)

Summary

- Top quark studies at HL-LHC open possibilities to improve our understanding of the SM and search for BSM physics in channels that depend on statistics
  - rare decays, multidimensional differential cross sections, couplings,..
- Top quark reconstruction is complex, relies on all detector components and accurate Monte Carlo modeling
  - many current measurements are systematics driven
- Other physics analyses depend on good understanding of top production
  - top is background to most processes with heavy flavor in the final state: SM and BSM Higgs, SUSY,..
  - calibration of detector performance, particularly b-tagging algorithms
- The top studies for HL-LHC are at their beginning
  - more studies will show more potential