Studies of Vector Boson Scattering and High-Mass Resonances with Fast Simulation

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Introduction

- Goal:
  - *Understand sensitivity to non-SM physics with simple, parameterized object reconstruction*
  - *At 14 TeV with 300/fb, 1000/fb, and 3000/fb*
- All analysis was performed on truth-level objects which were smeared according to detector resolutions.
- Trigger and reconstruction efficiencies are also taken into account.
- At the end of the talk, will few details about how analysis machinery works.
- If you are interested in using the code, please ask.

Introduction

- Considered several scenarios for possible sensitivity to non-SM physics
- Vector boson scattering
  - *WW, ZZ final states*
- High-mass exotic resonances
  - *Dilepton resonances*
  - *ttbar resonances (l+jets and dilepton final states)*
- ATL-PHYS-PUB-2012-001, ATL-PHYS-PUB-2012-004

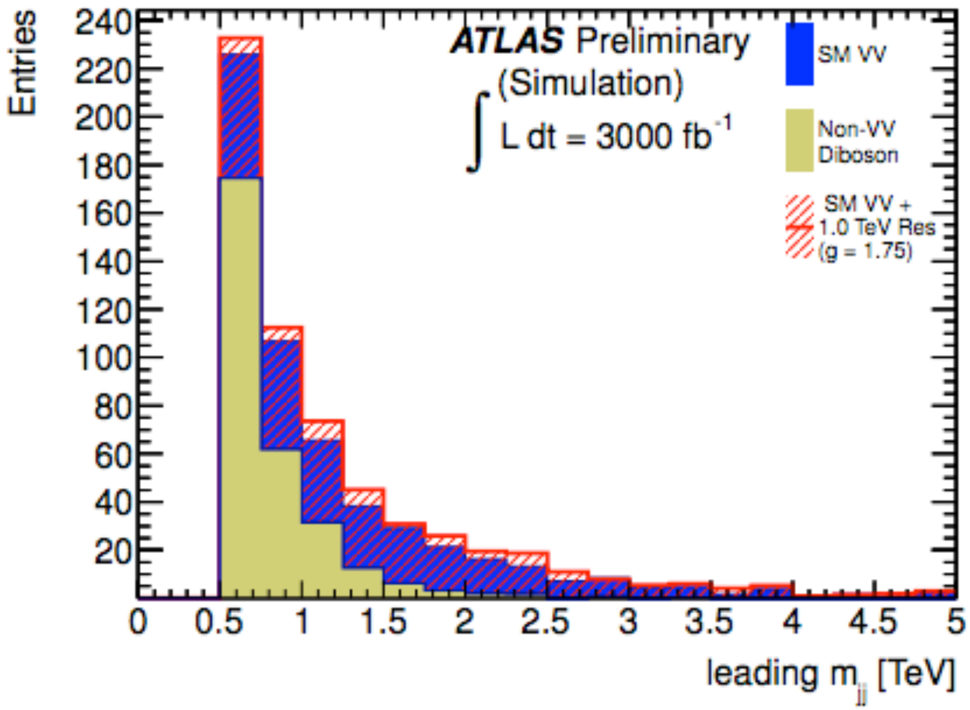
VBS Introduction

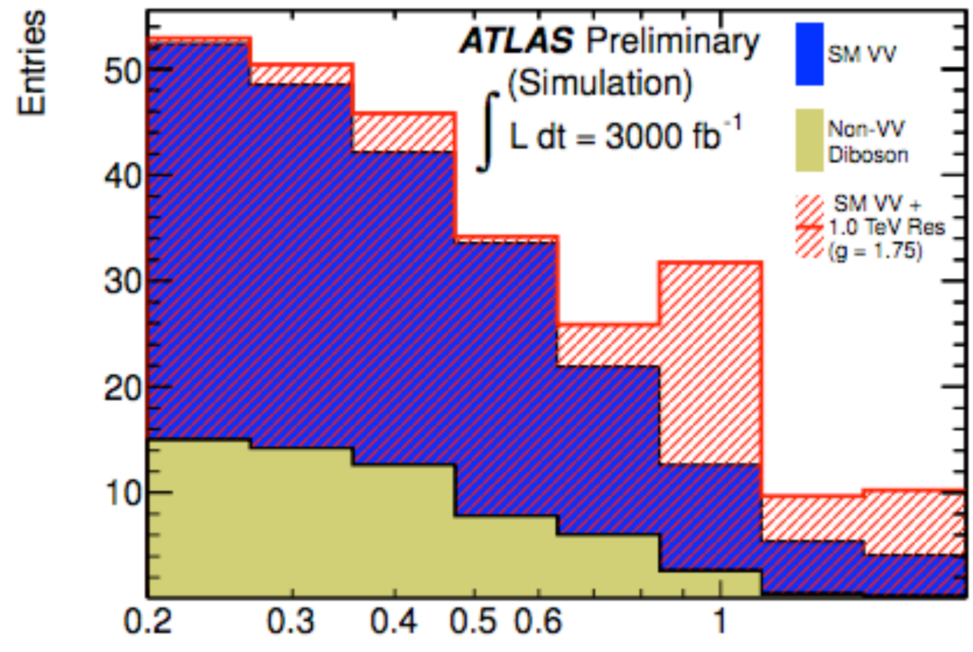
- Use BSM model to get non-SM VBS/VBF prediction
- Tested sensitivity to discrepancy between SM and non-SM model
- Details of analyses can be found in the ATLAS PUB note ATL-PHYS-PUB-2012-005
- Recently began to look at forward b-tagging for ttbar rejection.
- Collaborators:
  - *Philipp Anger, Pauline Bernat, Marco Campanelli, Michael Kobel, Jason Nielsen, Ulrike Schnoor*
  - *+ new collaborators from NIKHEF and UCSC*

VBS → ZZ Final State

- Used EW Chiral Lagrangian using a minimal K-matrix unitarization method
- A. Alboteanu, W. Kilian, and J. Reuter, Resonances and Unitarity in Weak Boson Scattering at the LHC, JHEP 0811 (2008) 010, arXiv:0806.4145 [hep-ph].
- WHIZARD was used to generate
  - *SM VV scattering prediction to the ZZ final state*
  - *Several VV resonances with various masses, couplings, and widths*
- Other included backgrounds: diboson (Madgraph)
- Require 4 leptons, one trigger, and 2 jets (see backup for details)

Final Spectrum and Expected Sensitivity





(after dijet mass cut)

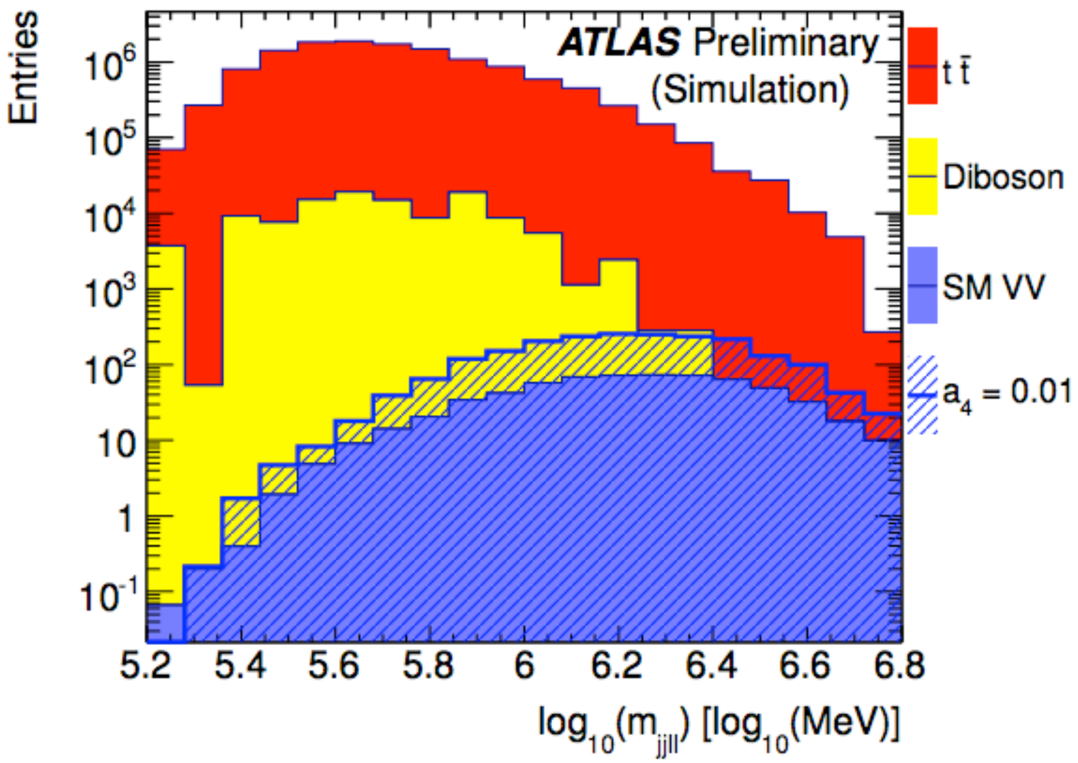
Expected Stat-only Significance

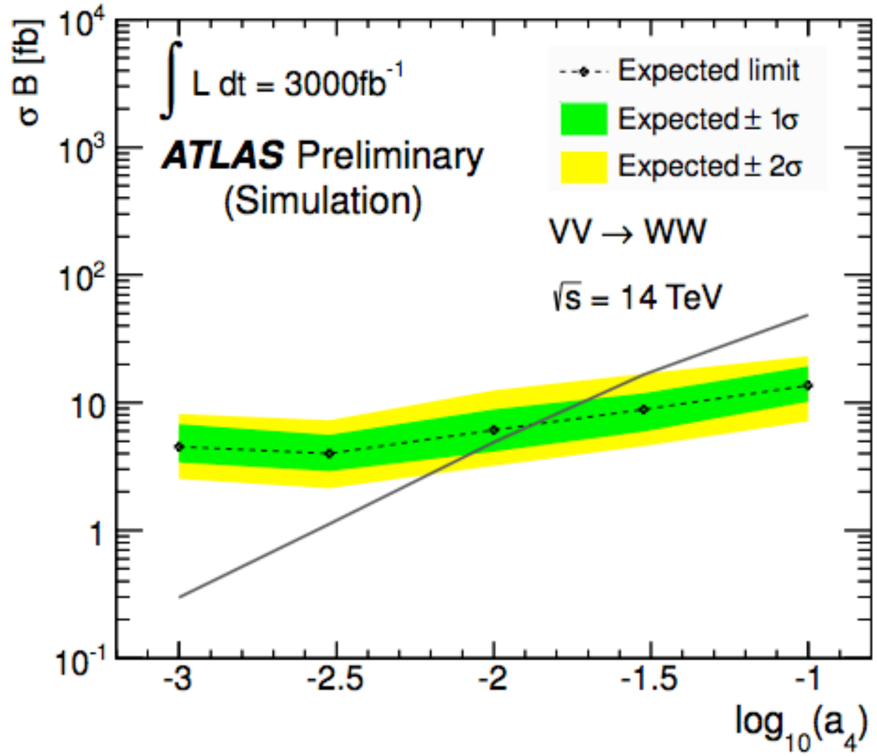
model	$300\,\mathrm{fb}^{-1}$	$3000\,\mathrm{fb}^{-1}$
$m_{\mathrm{resonance}} = 500$ GeV, $g = 1.0$	2.4σ	7.5σ
$m_{\mathrm{resonance}} = 1$ TeV, $g = 1.75$	1.7σ	5.5σ
$m_{\mathrm{resonance}} = 1$ TeV, $g = 2.5$	3.0σ	9.4σ

VBS → WW Final State

- Used EW Chiral Lagrangian with unitarization scheme from Dobado, et al
- A. Dobado, M. Herrero, J. Pelaez, and E. Ruiz Morales, Phys. Rev. D62 (2000) 055011, arXiv:hep-ph/9912224 [hep-ph].
- Pythia6 was used to generate
  - *SM (a4, a5 = 0) VV scattering prediction to the WW final state*
  - *Chiral Lagrangian with non-zero a4 values (a5 = 0)*
- Other included backgrounds: ttbar, diboson
- Require 2 leptons, MET, and 2 jets (see backup for details)

Final Spectrum and Limit





Expected Stat-only Limits:

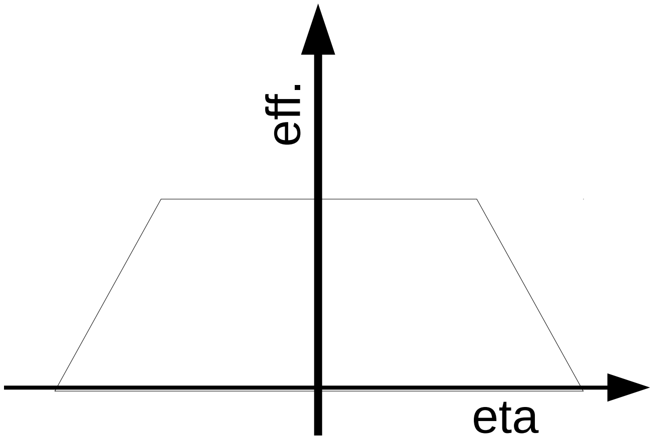
model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
a_4	0.066	0.025	0.016

Forward b-tagging Studies

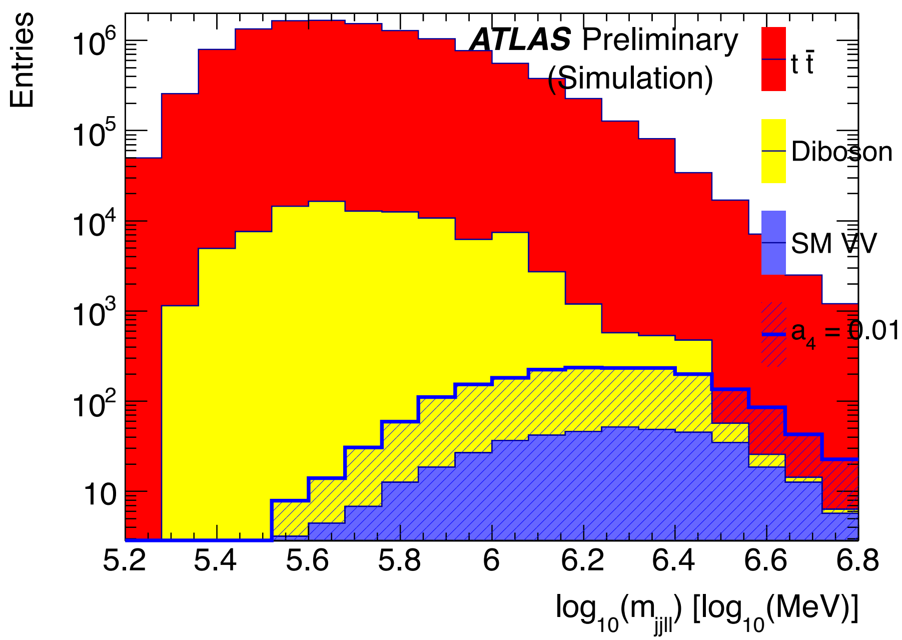
- ttbar is the dominant background in the WWjj channel, especially at high mass.
- b-tagging is one natural way to reject ttbar in the signal region.
- For VBS, we expect to be particularly sensitive to b-tagging performance in the forward region.
- Will present some preliminary studies on gains from b-tagging at different operating points
- Will quote cross section limits to be as model-independent as possible

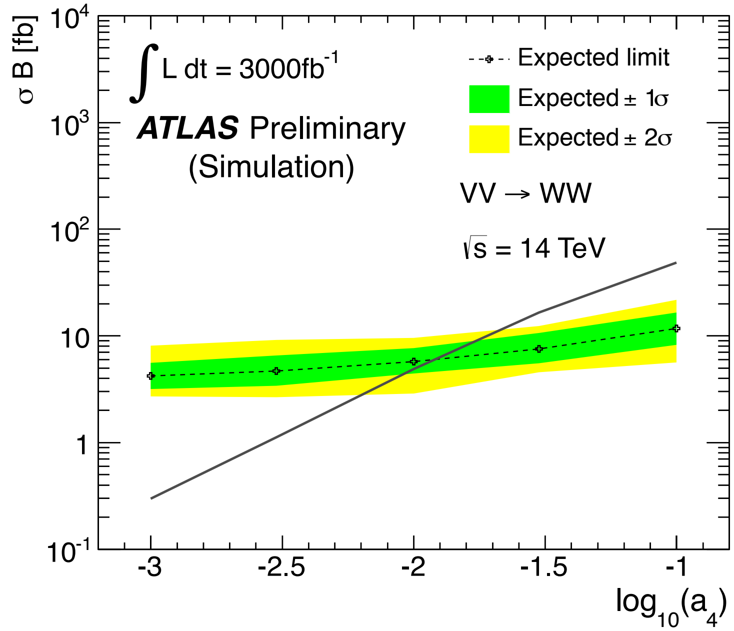
b-tagging Details

- Jets truth-matched to b-quarks if dR(jet, b) < 0.35
- Event rejected if there is at least one truth-matched b-jet which is tagged
- For now, very simple b-tagging model:
  - Assume flat efficiency centrally, linear falloff in forward region
  - eta0 → begin falloff
  - eta0 + 1 → zero efficiency
  - pt0 → zero efficiency below



b-tagging Comparison

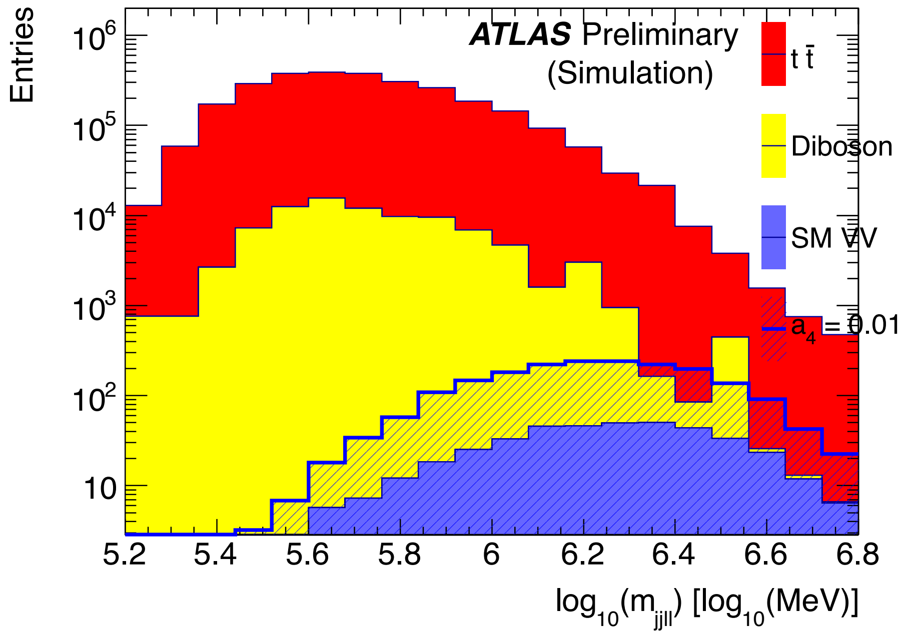


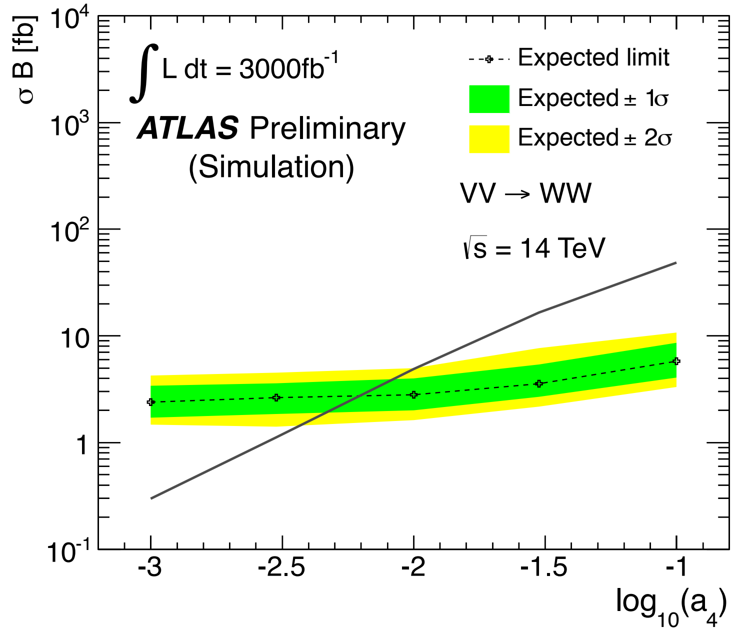


No b-tagging

Cross section limit: 5.91 fb

b-tagging Comparison

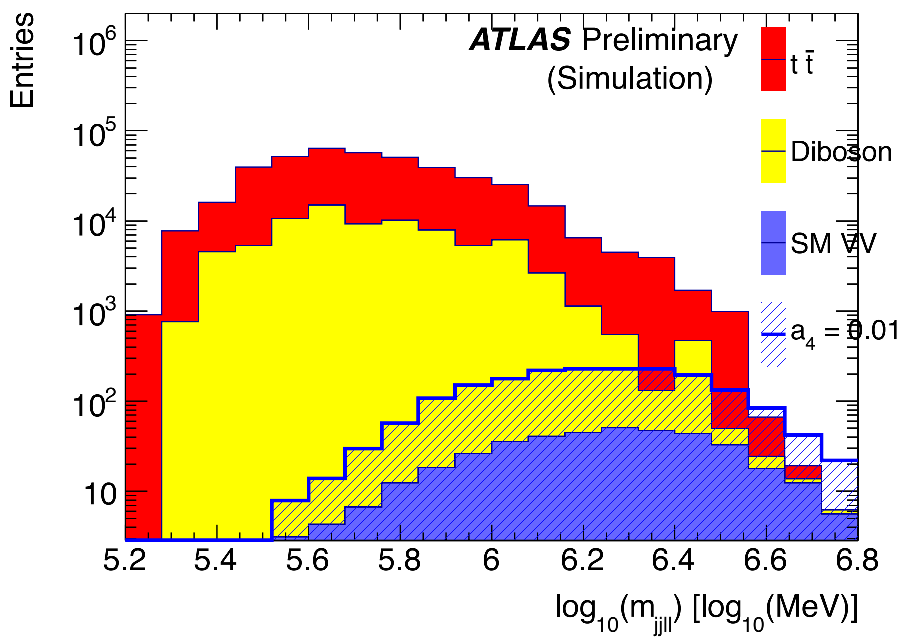


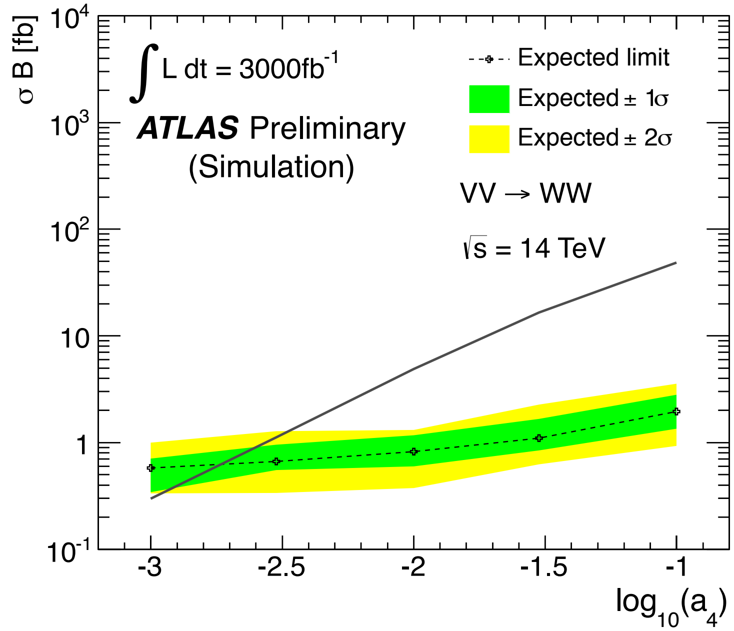


75% central efficiency
eta0 = 1.5
pt0 = 25 GeV

Cross section limit: 2.71 fb

b-tagging Comparison





90% central efficiency
Full eta coverage
pt0 = 15 GeV

Cross section limit: 0.61 fb

Summary

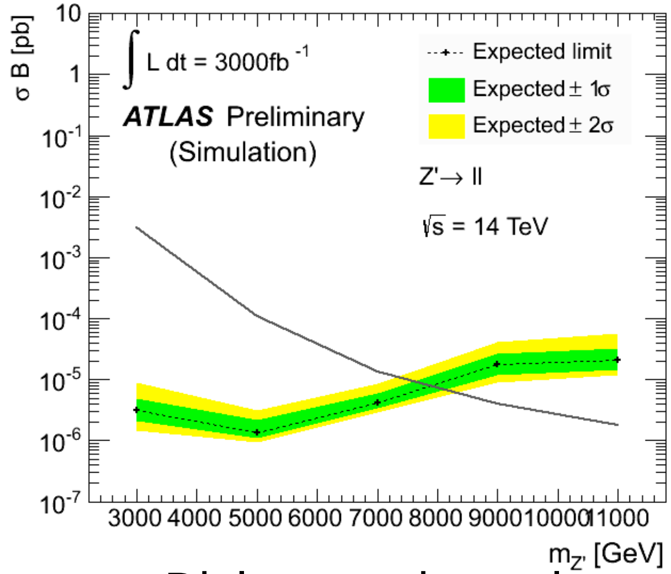
- Have begun studies of the effect of a b-jet veto on spectra and expected limits in the VBS → WW j j → e mu j j final state.
- Plan to fine-tune the parameter space that is most reasonable, but framework is working.
- Plots for all working points in the backup slides

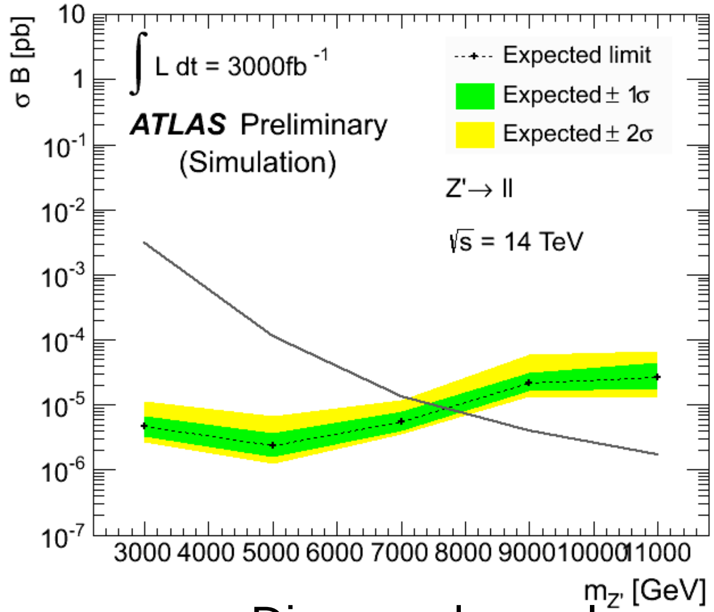
pt0 (GeV)	eta0	Central Efficiency (%)	Expected Cross Section Limit (fb)
--	--	00	5.91
25	2.5	60	2.79
25	2.5	75	2.17
25	1.5	75	2.71
15	1.5	75	2.49
15	infinity	90	0.61

High Mass Resonances

- Dilepton resonances
  - *Several models predict extensions to the electroweak sector.*
  - *A heavy Z-like resonance might be the first evidence of such an extension.*
- ttbar resonances
  - *In several BSM theories the top quark has stronger couplings to exotic particles due to its high mass.*
  - *ttbar resonance searches also serve as a proxy for a variety of heavy decays with leptons, b-quarks, and MET.*

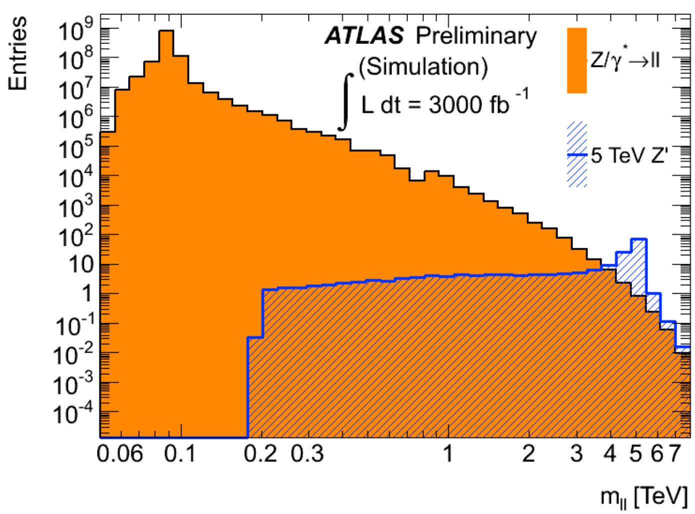
Final Spectra and Limits

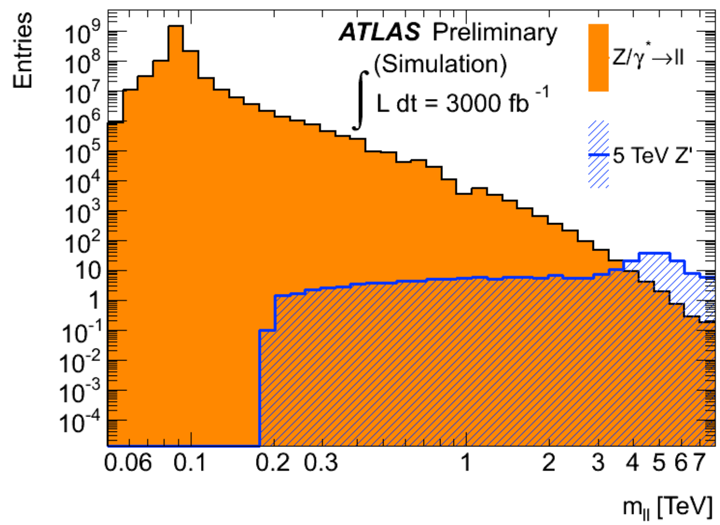




Dielectron channel

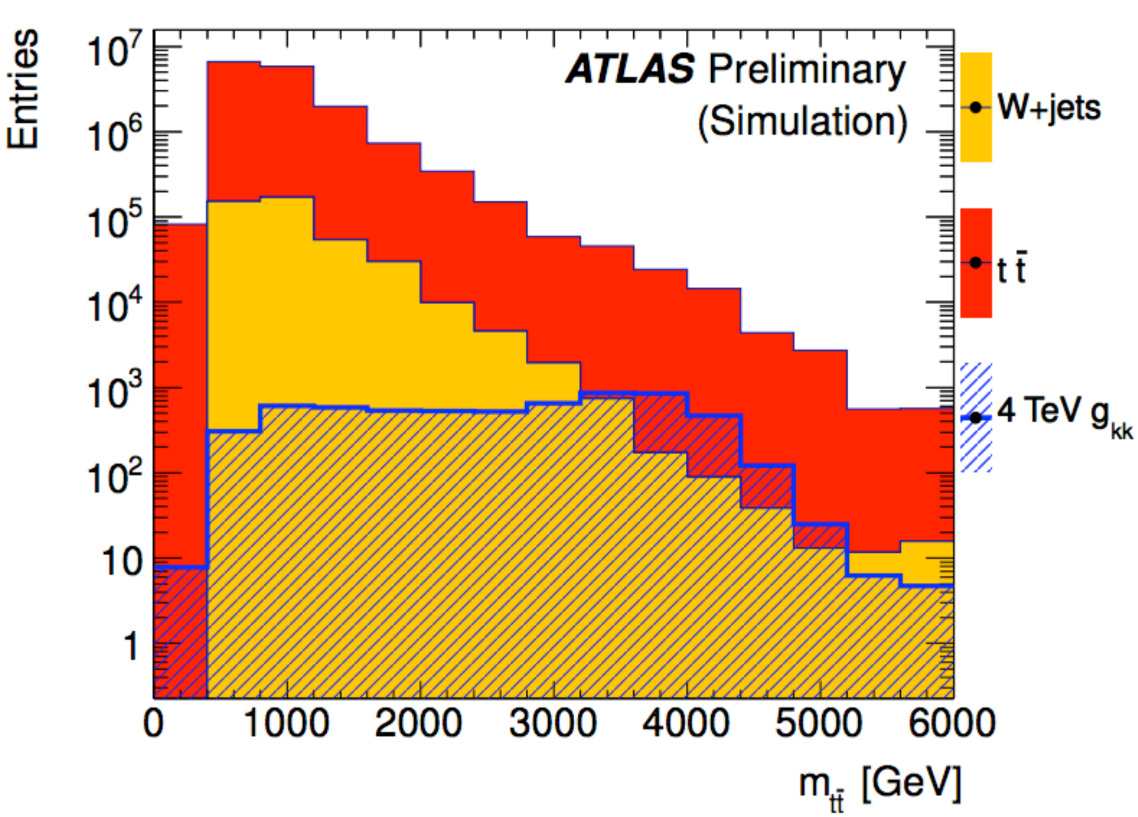
Dimuon channel



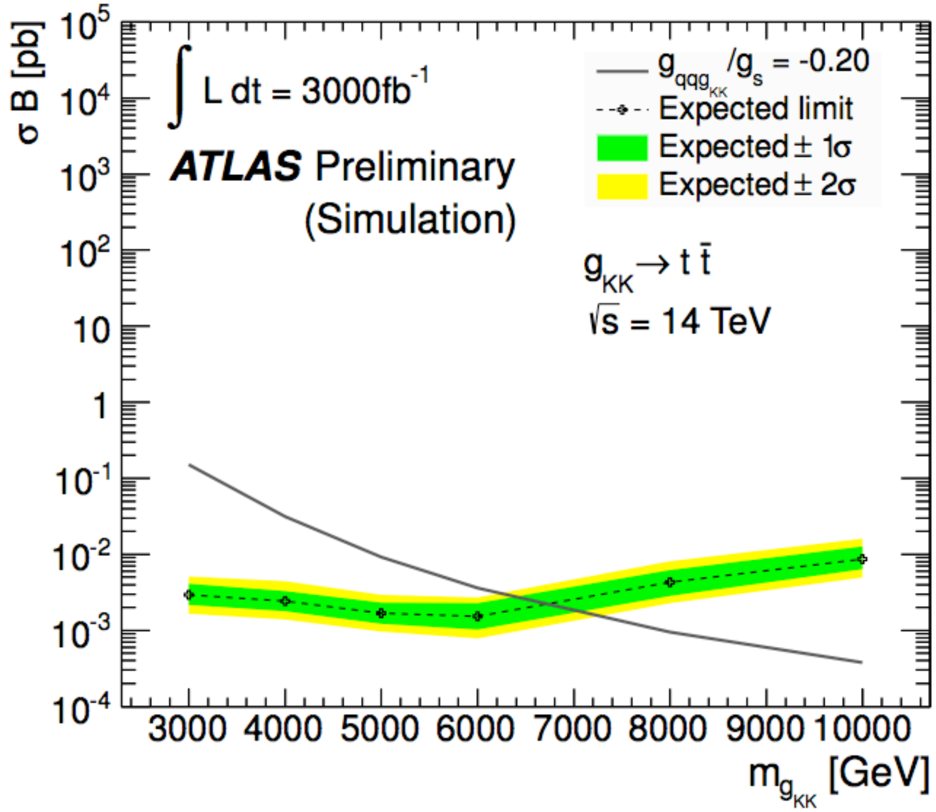


ttbar Final Spectrum and Limits

Reconstructed ttbar (l+jets) mass spectrum



Expected KKgluon mass limit in the l+jets channel



Expected stat-only lepton+jets (dilepton) limits in TeV

model	$300\,\mathrm{fb}^{-1}$	$1000\,\mathrm{fb}^{-1}$	$3000\,\mathrm{fb}^{-1}$
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
$Z'_{\mathrm{Topcolour}}$	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)

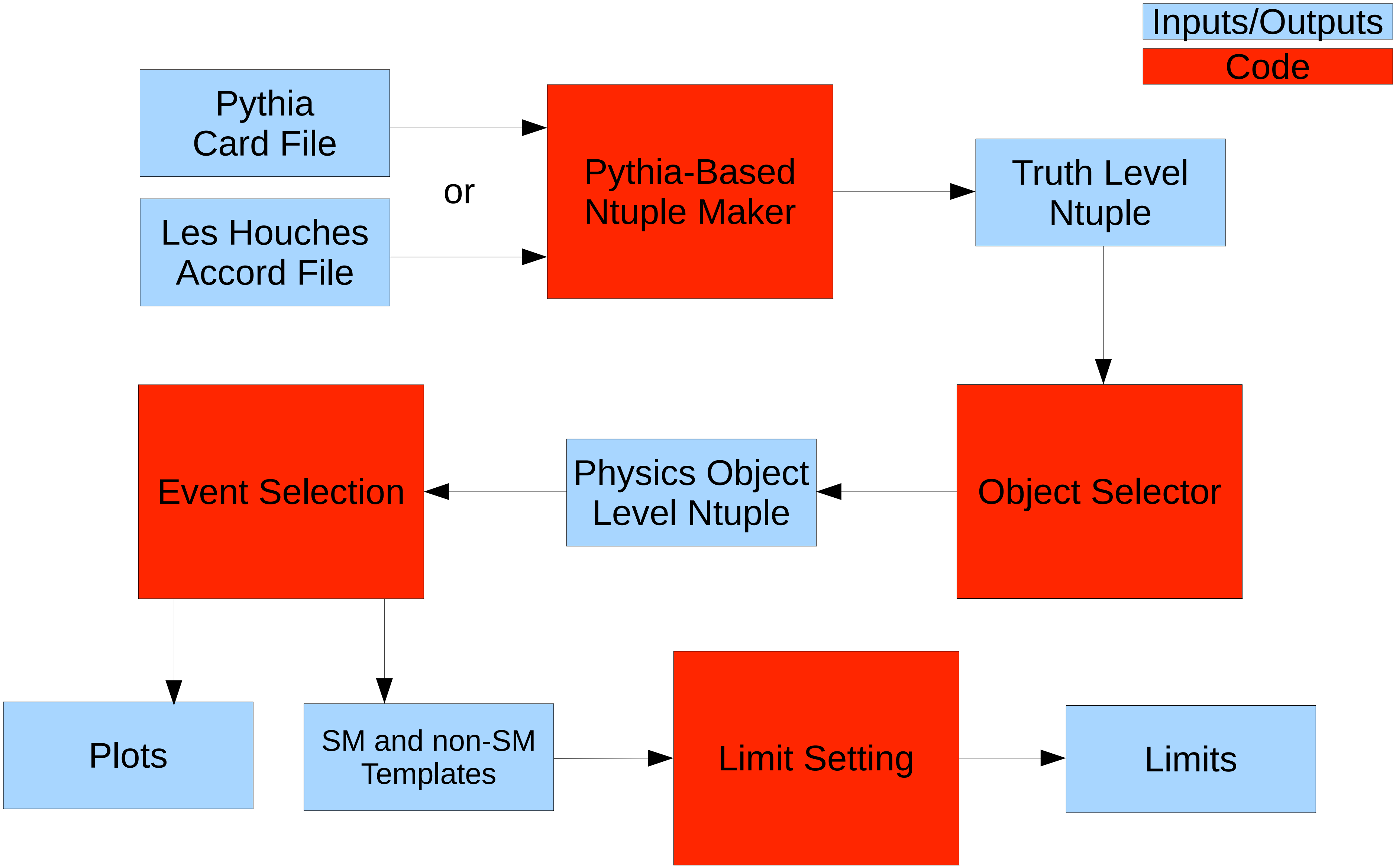
Resonances Summary

Expected limits for various BSM searches at 14 TeV.
Rows 1 and 2 are for ttbar → l+jets (dilepton) channels.
Rows 3 and 4 are for dilepton resonances.
All Limits in TeV.

model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
$Z'_{\text{Topcolour}}$	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)
$Z'_{SSM} \to ee$	6.5	7.2	7.8
$Z'_{SSM} \to \mu\mu$	6.4	7.1	7.6

Analysis Details

Overview


Inputs/Outputs
Code
Pythia Card File
or
Les Houches Accord File
Pythia-Based Ntuple Maker
Truth Level Ntuple
Object Selector
Physics Object Level Ntuple
Event Selection
Plots
SM and non-SM Templates
Limit Setting
Limits

Event Generation and Showering

- Inputs: pythia card or Les Houches Accord events
- Stores pdgId, pt, eta, phi, E, m of all truth particles
- Clusters jets with FastJet
  - Truth electrons, photons, hadrons are clustered
  - Currently clustering anti-kt (R = 0.4) and anti-kt (R = 1.0) jets, but not difficult to add more collections
- Matches jets to b-quarks (matching: dR(b, jet) < 0.35)
- Event, truth particle, and jet information written to a 'flat' TTree (only native c-types and std::vectors).

ObjSelector

- Inputs: truth level ntuple from previous transformation
- Smears electrons, muons, jets, and MET
- Applies trigger and reconstruction efficiencies
- Selects “good” objects from truth information
- MET defined as negative vector sum of all selected objects' momenta
- Should be fairly analysis independent

ObjSelector

- Most of the work is done inside ObjSelector/ObjSelector.cxx
- SmearXYZ():
  - Defines smearing for a given reconstructed object
- FillGoodXYZ():
  - Fills variables of “good” objects which are saved to ntuple
  - Calls IsGoodXYZ()
- IsGoodXYZ():
  - Determines definition of “good” electrons, jets, etc.

EventSelector

- Input: Physics Object Ntuple from ObjSelector
- Reconstructs event-wide information
  - Invariant masses, HT, etc.
- Selects “good” events based on what objects are in the event and event-wide variables
- Will vary from analysis to analysis—this is just a template.

How to check it out and run it

- The code is publicly available through git or svn:
  - git clone https://github.com/PollardSnowmass/SnowmassEWFrame.git
  - svn co https://github.com/PollardSnowmass/SnowmassEWFrame/trunk
- ObjSelector and EventSelector just require a recent version of ROOT.
- Running event generation, showering, and clustering requires PYTHIA, LHAPDF, and FastJet.
- ATLAS smearing functions and efficiencies have been replaced with something generic.
  - Perhaps it's best to settle on functions that everyone should use?
- Readmes should be enough to get started, but contact chris.pollard@duke.edu if you have questions.

Summary

- Have completed several analyses for the ATLAS upgrade effort and work is continuing on others
- Have a working framework which is fairly simple and robust and can interface with many generators through .lhe files
- Willing to collaborate on projects if there is interest

Backup Slides

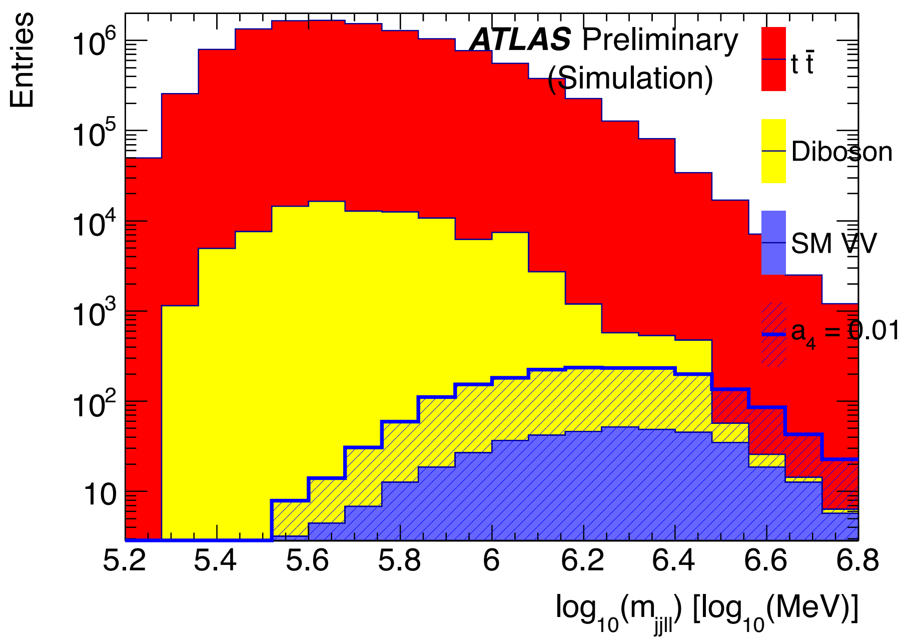
VBS → ZZ Event Selection

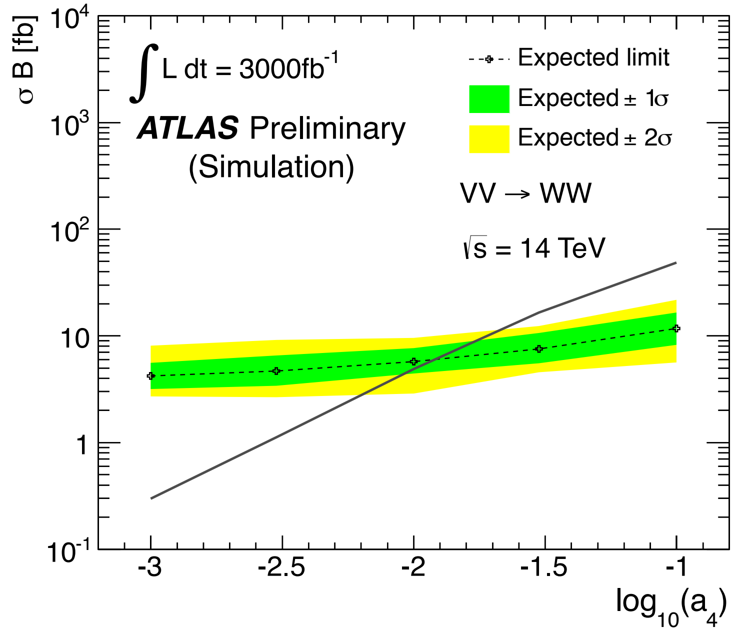
- Require
  - *4 high-pt (> 25 GeV) leptons*
    - *At least one must fire the trigger*
  - *2 anti-kt (R = 0.4) jets with pt > 50 GeV*
  - *Invariant mass of the 2 leading jets > 1 TeV*
- Use invariant mass of the 4 lepton system to set limits

VBS → WW Event Selection

- Require
  - *2 leptons with pt > 25 GeV*
    - *At least one must fire the trigger*
  - *2 anti-kt (R = 0.4) jets with pt > 50 GeV*
    - *Truth particles clustered with FastJet*
  - *MET > 50 GeV*
  - *One electron, one muon*
    - *no Z/γ* background*
- Use invariant mass of two lepton + two jet system to set limits.

b-tagging Comparison

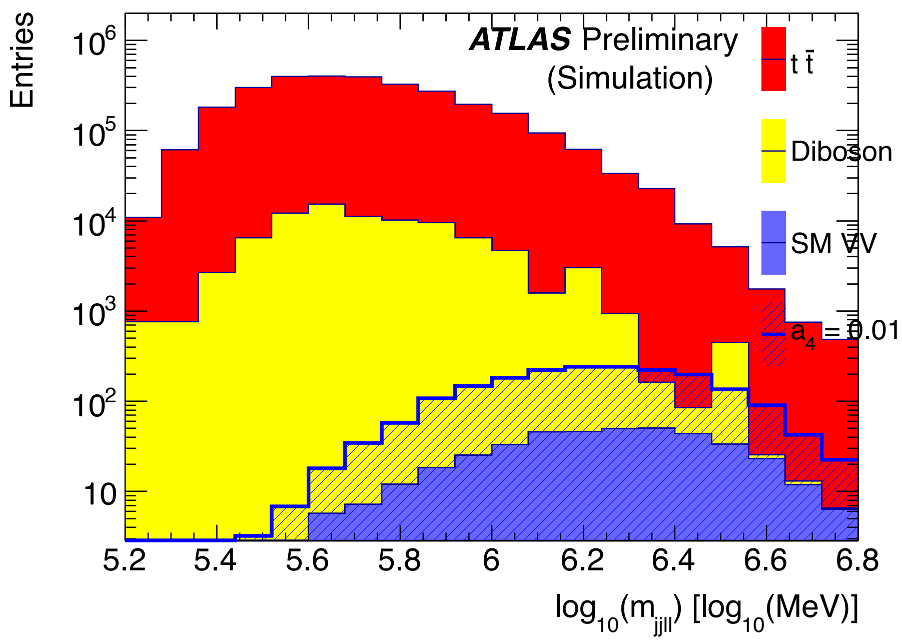


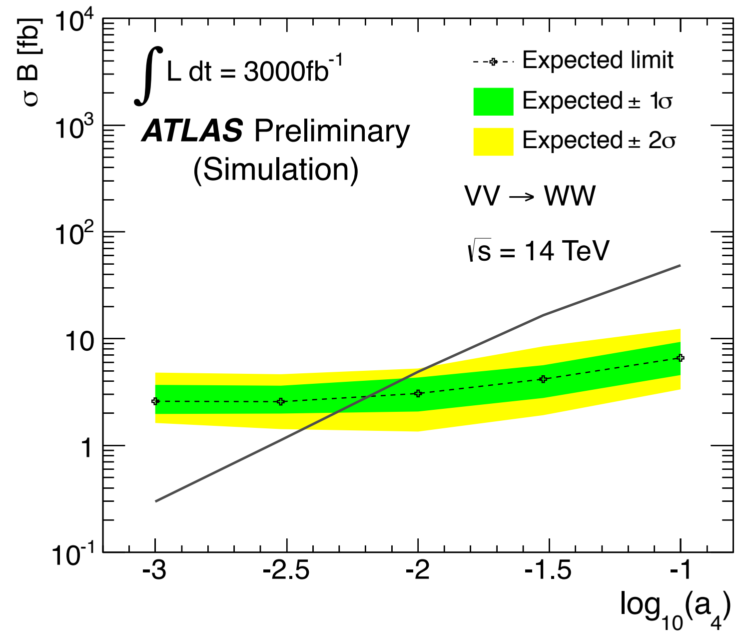


No b-tagging

Cross section limit: 5.91 fb

b-tagging Comparison

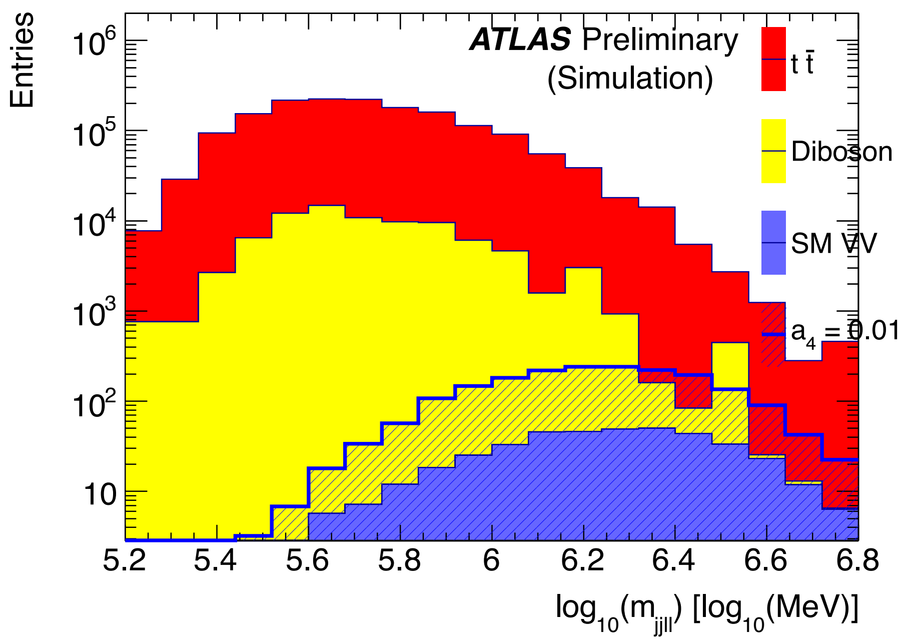


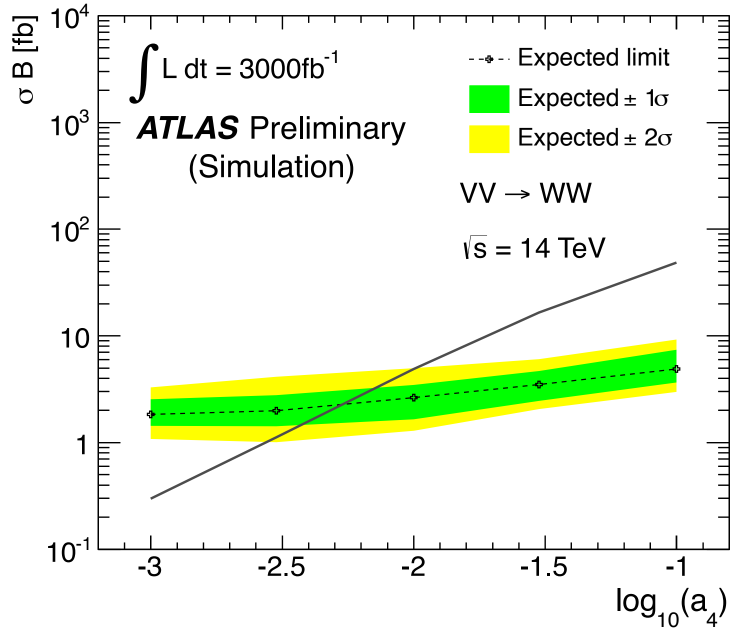


60% central efficiency
eta0 = 2.5
pt0 = 25 GeV

Cross section limit: 2.79 fb

b-tagging Comparison

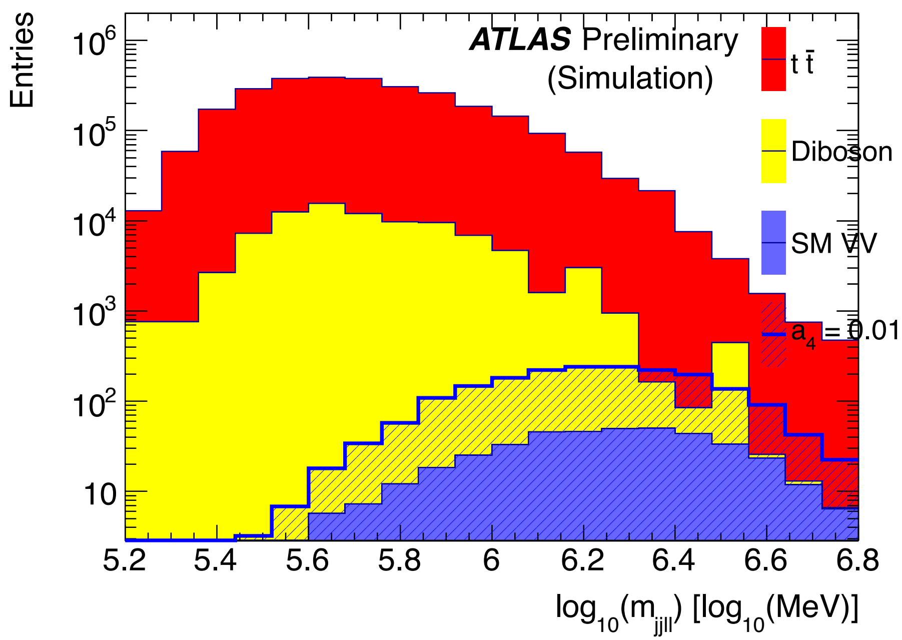


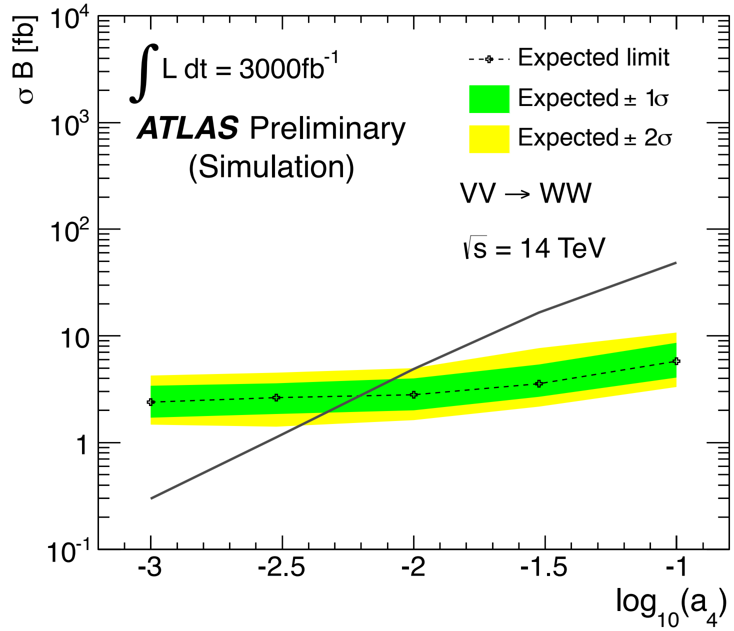


75% central efficiency
eta0 = 2.5
pt0 = 25 GeV

Cross section limit: 2.17 fb

b-tagging Comparison

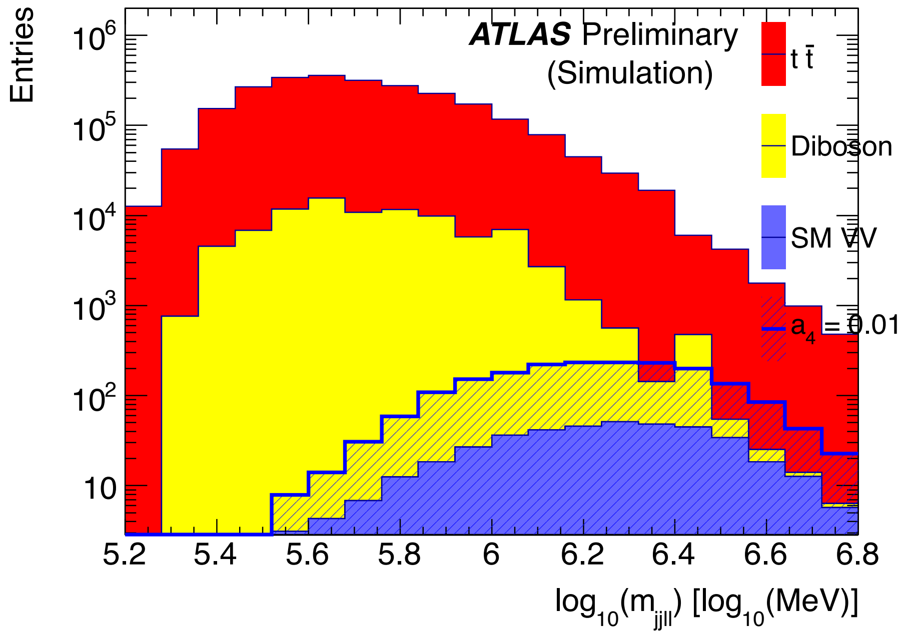


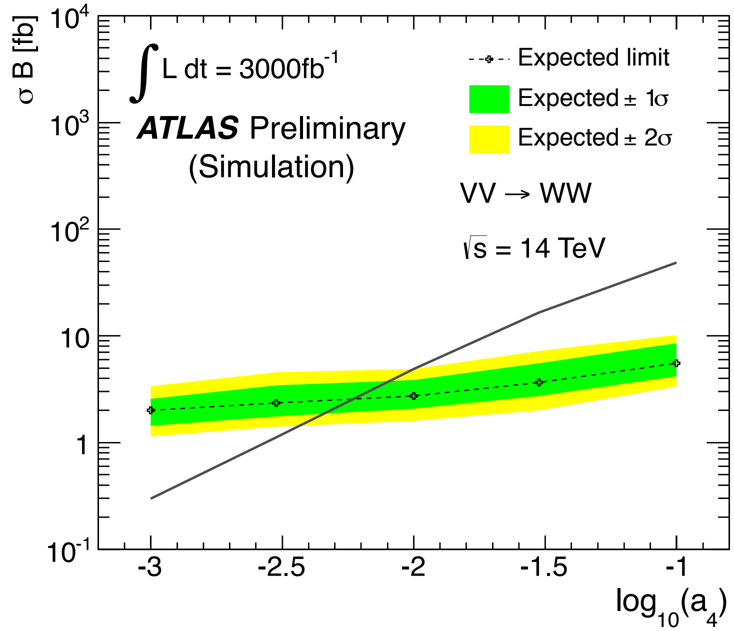


75% central efficiency
eta0 = 1.5
pt0 = 25 GeV

Cross section limit: 2.71 fb

b-tagging Comparison

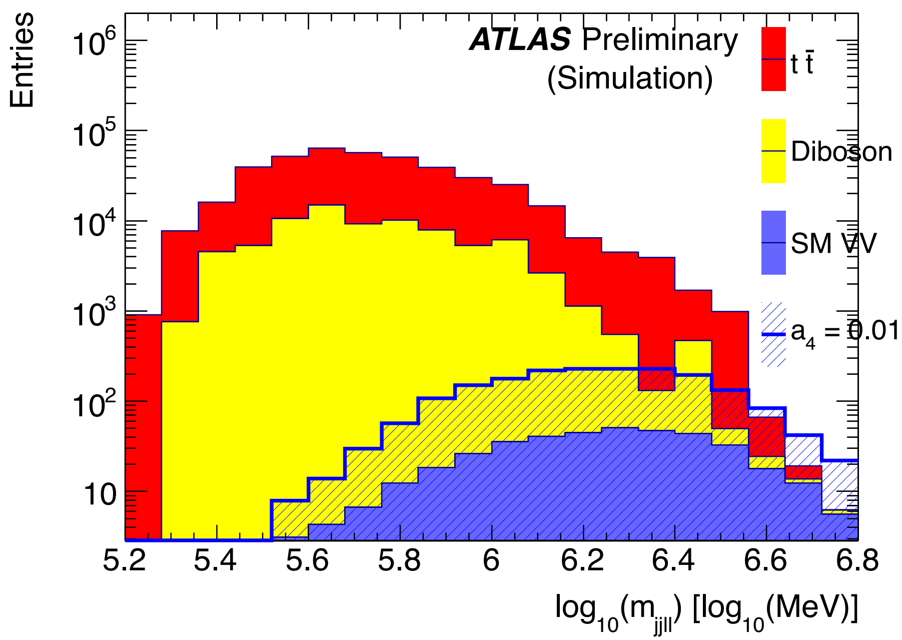


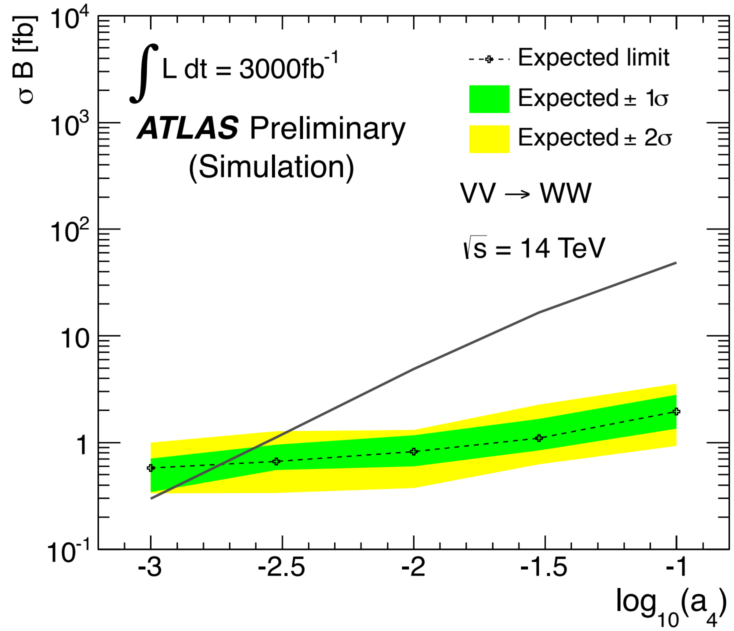


75% central efficiency
eta0 = 1.5
pt0 = 15 GeV

Cross section limit: 2.49 fb

b-tagging Comparison





90% central efficiency
Full eta coverage
pt0 = 15 GeV

Cross section limit: 0.61 fb

Z' → dilepton Sensitivity Study

- Pythia8 used to generate
  - *Dominant SM background: Z/y**
  - *Signal: Sequential Standard Model Z'*
- Selection criteria from current dilepton analyses
  - *Applied to truth level objects after parameterized smearing and efficiencies*
  - *Require two same-flavor leptons*
    - *pt > 25 GeV*
    - *Muons must be oppositely charged*
    - *At least one must fire trigger*
- log(m_ll) spectrum for expected limit (cf. current ATLAS dilepton resonance search)

ttbar Resonance Sensitivity Study

- Signal Templates:
  - *Randall-Sundrum Kaluza-Klein Gluon*
  - *Top Color Leptophobic Z'*
- Both lepton+jets and dilepton final states have been studied.
- Lepton+jets channel
  - *Generally more sensitive (higher branching fraction, fully-reconstructible ttbar mass)*
  - *More susceptible to pileup effects*
  - *Considered ttbar, W+jets backgrounds (Pythia8)*
- Dilepton channel
  - *Less sensitive (lower branching fraction, two neutrinos)*
  - *Not affected as much by pileup*
  - *Considered ttbar, Z+jets, diboson backgrounds (Pythia8)*

ttbar (Lepton+Jets) Event Selection

- Require:
  - *Exactly one triggered lepton with pt > 25 GeV*
  - *One anti-kt (R = 1.0) jet with pt > 250 GeV which does not overlap with selected lepton (top-jet)*
  - *One anti-kt (R = 0.4) jet with pt > 25 GeV* ***which does not overlap with selected akt10 jet*** *(leptonic b-jet)*
  - *At least 50 GeV of MET*
- W-mass constraint is used to determine neutrino pz
- Use invariant mass of lepton+neutrino+b-jet+top-jet system to set limits

ttbar (Dilepton) Event Selection

- Require:
  - *Exactly two leptons with pt > 25 GeV*
    - *At least one must fire the trigger*
  - *Two anti-kt (R = 0.4) jets with pt > 25 GeV (b-jets)*
  - *At least 50 GeV of MET*
- HT (scalar sum pt of selected leptons and b-jets plus MET) used to set limits