Plans for the $t\bar{t}$(H->$b\bar{b}$) measurements with Run-2 data

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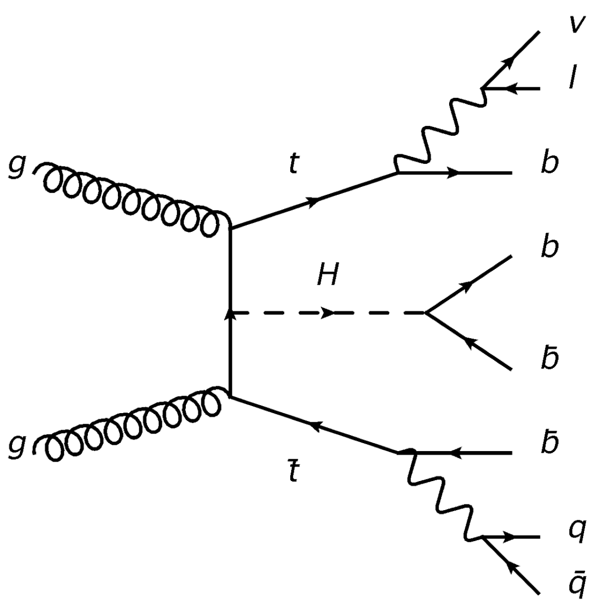
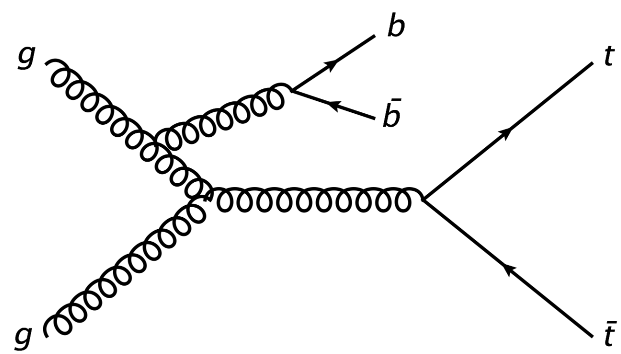
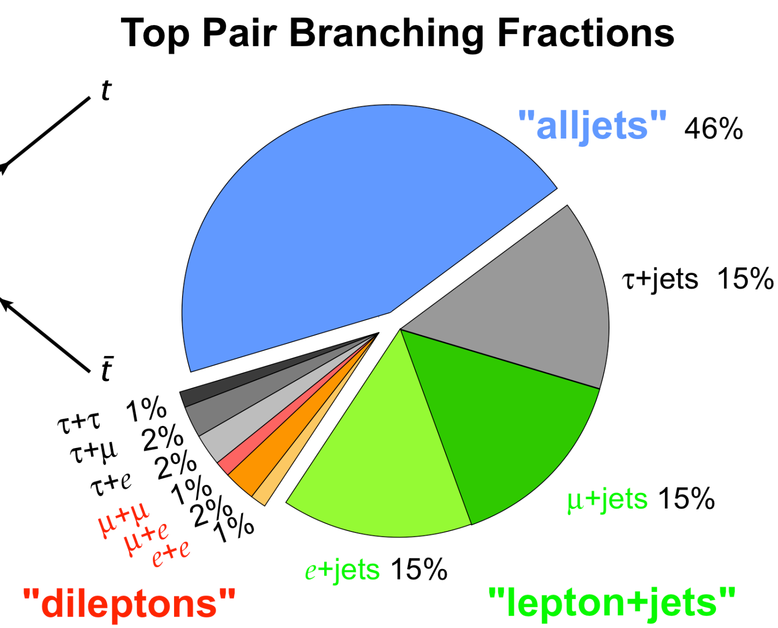
30 Oct 2015
MPP Higgs meeting

Introduction: Run 1 $t\bar{t}H(b\bar{b})$ Analysis

- Focus on lepton+jets and dilepton channels
  - Lepton = e, μ
- Lepton + jets: 1 charged lepton, 6 jets, 4 b-jets
- Dilepton: 2 charged leptons, 4 jets, 4 b-jets
- Very difficult signature modeling







MC Samples

- $t\bar{t}H$: POWHEG+PYTHIA reweighted to SHERPAOL ($t\bar{t}+b\bar{b}$)
- $t\bar{t}+Z$, $t\bar{t}+W$: MADGRAPH+PYTHIA
- W+jets: ALPGEN+PYTHIA
- Z+jets: ALPGEN+PYTHIA
- Dibosons: ALPGEN+PYTHIA
- Single top: POWHEG+PYTHIA

Selection and Object Definitions

Lepton+Jets:

- 1 isolated lepton
- $p_T > 25$ GeV
- $|\eta| < 2.5$ (excluding calorimeter gap)
- nJets ≥ 4
- $p^{jet}_T > 25$ GeV
- $|\eta^{jet}| < 2.5$
- No MET cut
- No second lepton

Dilepton:

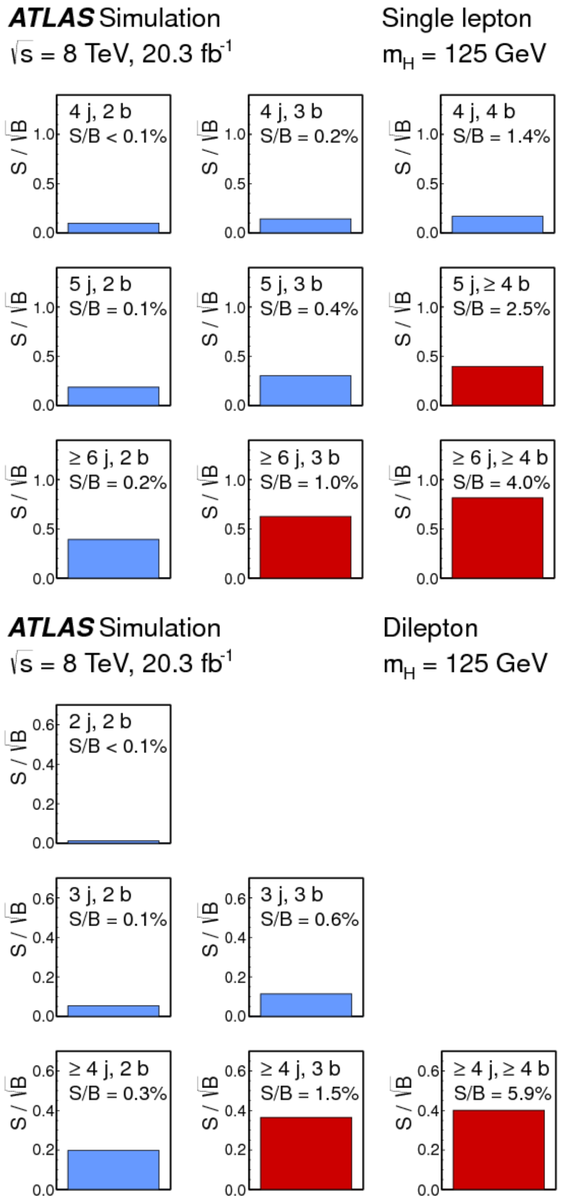
- 2 isolated leptons
- $p^{1l}_T > 25$ GeV
- $p^{2l}_T > 15$ GeV
- $|\eta^l| < 2.5$ (excluding calorimeter gap)
- nJets$\geq$2
- $p^{jet}_T > 25$ GeV
- $|\eta^{jet}| < 2.5$
- $|m_{ll}-91| > 8$ GeV
- $m_{ll} > 15$ GeV
- 2 b-tags with $m_{ll} > 60$ GeV
- $H_T > 130$ GeV for $e\mu$ selection

Considered Regions

- Single lepton:
  - Signal depleted: (4j,2b), (4j,3b), (4j,4b), (5j,2b), (5j,3b), (≥6j, 2b)
  - Signal rich: (5j, ≥4b), (≥6j, 2b), (≥6j, ≥4b)
- Dilepton:
  - Signal depleted: (2j,2b), (3j,2b), (3j,3b), (4j,2b)
  - Signal rich: (≥4j, 3b), (≥4j, ≥4b)

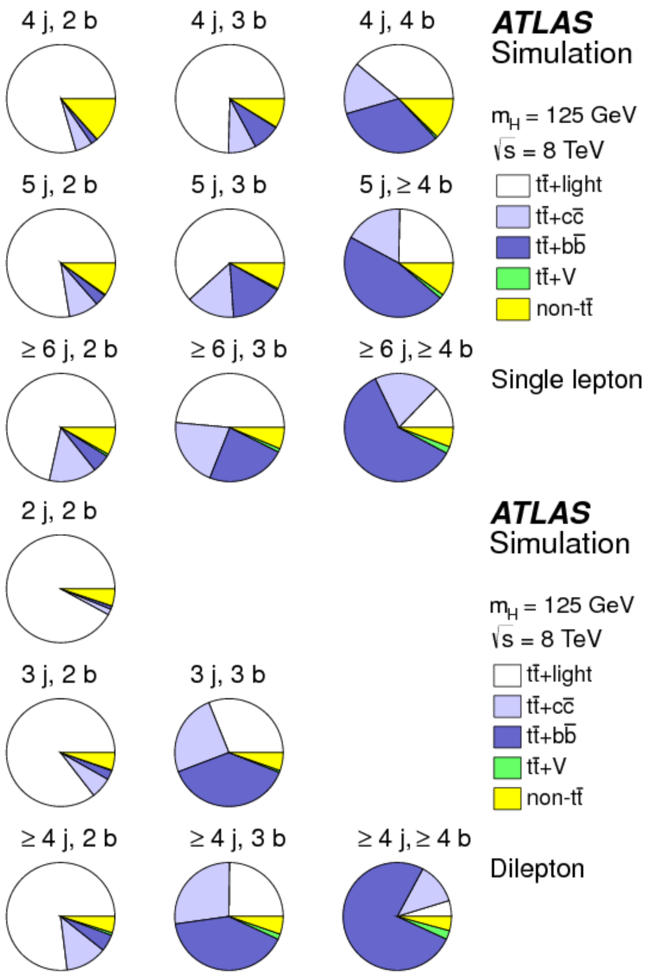
Signal Regions

- "Signal-depleted" (blue) and "signal-rich" (red) regions
- S/√B and S/B for each region shown
  - "Signal-rich" requires S/√B > 0.3 and S/B >1%



Background Composition

- Breakdown of the background for each considered region
  - Signal-depleted regions predominantly $t\bar{t}$+light
  - Signal-rich regions predominantly $t\bar{t}+b\bar{b}$
- $t\bar{t}+b\bar{b}(c\bar{c})$ has one jet matched to a b(c)-hadron
  - $t\bar{t}$+light is remainder of $t\bar{t}$+jets events



Systematic Uncertainties

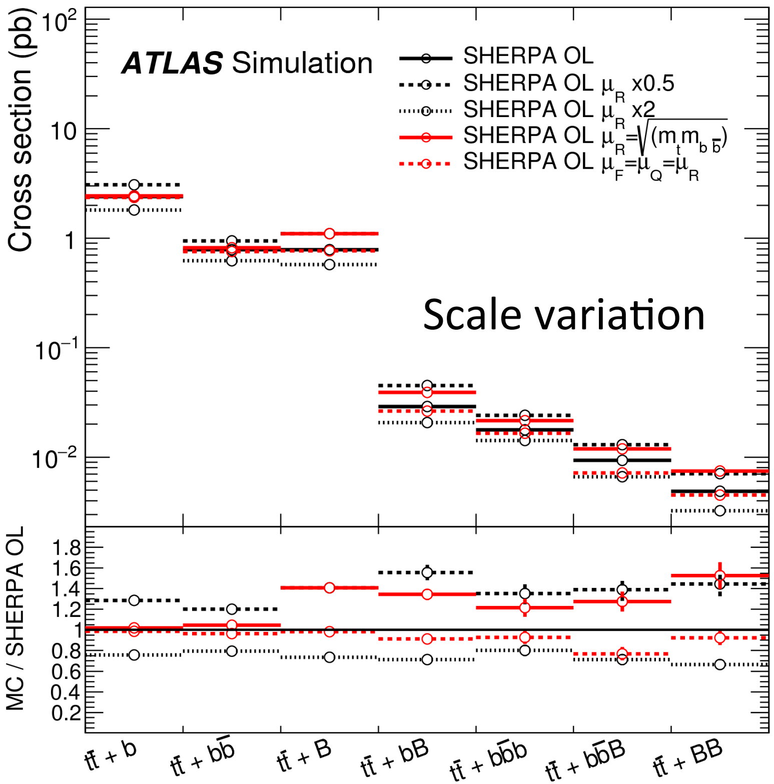
Systematic uncertainty	Type	Comp.
Luminosity	N	1
Physics Objects		
Electron	SN	5
Muon	SN	6
Jet energy scale	SN	22
Jet vertex fraction	SN	1
Jet energy resolution	SN	1
Jet reconstruction	SN	1
b-tagging efficiency	SN	6
c-tagging efficiency	SN	4
Light-jet tagging efficiency	SN	12
High-p_{T} tagging efficiency	SN	1
Background Model		
$t\bar{t}$ cross section	N	1
$t\bar{t}$ modelling: p_{T} reweighting	SN	9
$t\bar{t}$ modelling: parton shower	SN	3
$t\bar{t}$+heavy-flavour: normalisation	N	2
$t\bar{t}+c\bar{c}$: p_{T} reweighting	SN	2
$t\bar{t}+c\bar{c}$: generator	SN	4
$t\bar{t}+b\bar{b}$: NLO Shape	SN	8
W+jets normalisation	N	3
W p_{T} reweighting	SN	1
Z+jets normalisation	N	3
Z p_{T} reweighting	SN	1
Lepton misID normalisation	N	3
Lepton misID shape	S	3
Single top cross section	N	1
Single top model	SN	1
Diboson+jets normalisation	N	3
$t\bar{t}+V$ cross section	N	1
$t\bar{t}+V$ model	SN	1
Signal Model		
$t\bar{t}H$ scale	SN	2
$t\bar{t}H$ generator	SN	1
$t\bar{t}H$ hadronisation	SN	1
$t\bar{t}H$ PDF	SN	1

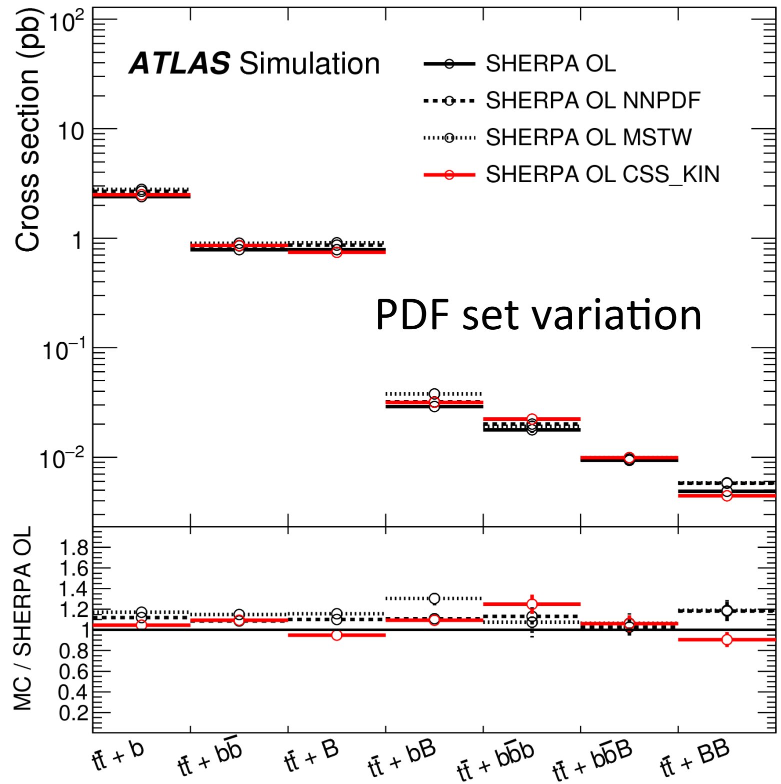
- Uncertainties due to physics objects
- JES
- JER
- b-tagging breakdown
- $t\bar{t}$ cross section (-5/+6%)
- $t\bar{t}+b\bar{b}/c\bar{c}$ 50% (e.g., scale variations, PDF set, etc)
- $t\bar{t}$ reweighting systematics
- $t\bar{t}+b\bar{b}$ modeling SHERPAOL systematics
- PYTHIA v HERWIG
- $t\bar{t}$H scale, generator, hadronisation, PDF uncertainties

Table 3 List of systematic uncertainties considered. An "N" means that the uncertainty is taken as normalisation-only for all processes and channels affected, whereas an "S" denotes systematic uncertainties that are considered shape-only in all processes and channels. An "SN" means that the uncertainty is taken on both shape and normalisation. Some of the systematic uncertainties are split into several components for a more accurate treatment. This is the number indicated in the column labelled as "Comp.".

$t\bar{t}+b\bar{b}$ Systematics

- Example of variation in scale and PDF in $t\bar{t}+b\bar{b}$ with SHERPAOL
  - Scale up and down by factor 2
  - PDF sets MSTW and NNPDF compared to CT10 (default)





Systematics

$\geq$ 6 j, $\geq$ 4 b

	Pre-fit				Post-fit			
	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}+c\bar{c}$	$t\bar{t}+b\bar{b}$	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}+c\bar{c}$	$t\bar{t}+b\bar{b}$
Luminosity	±2.8	±2.8	±2.8	±2.8	±2.6	±2.6	±2.6	±2.6
Lepton efficiencies	±1.4	±1.4	±1.4	±1.5	±1.3	±1.3	±1.3	±1.3
Jet energy scale	±6.4	±13	±11	±9.2	±2.3	±5.3	±4.7	±3.6
Jet efficiencies	±1.7	±5.2	±2.7	±2.5	±0.7	±2.3	±1.2	±1.1
Jet energy resolution	±0.1	±4.4	±2.5	±1.6	±0.1	±2.3	±1.3	±0.8
b-tagging efficiency	±9.2	±5.6	±5.1	±9.3	±5.0	±3.1	±2.9	±5.0
c-tagging efficiency	±1.7	±6.0	±12	±2.4	±1.4	±5.1	±10	±2.1
l-tagging efficiency	±1.0	±19	±5.2	±2.1	±0.6	±11	±3.0	±1.1
High p_T tagging efficiency	±0.6	–	±0.7	±0.6	±0.3	–	±0.4	±0.3
$t\bar{t}$: p_T reweighting	–	±5.4	±6.1	–	–	±4.7	±5.4	–
$t\bar{t}$: parton shower	–	±13	±16	±11	–	±3.6	±10	±6.0
$t\bar{t}$+HF: normalisation	–	–	±50	±50	–	–	±28	±14
$t\bar{t}$+HF: modelling	–	±11	±16	±8.3	–	±3.6	±9.1	±7.1
Theoretical cross sections	–	±6.3	±6.3	±6.3	–	±4.1	±4.1	±4.1
$t\bar{t}H$ modelling	±2.7	–	–	–	±2.6	–	–	–
Total	±12	±32	±59	±54	±6.9	±9.2	±23	±12

$\geq$ 4 j, $\geq$ 4 b

	Pre-fit				Post-fit			
	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}+c\bar{c}$	$t\bar{t}+b\bar{b}$	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}+c\bar{c}$	$t\bar{t}+b\bar{b}$
Luminosity	±2.8	±2.8	±2.8	±2.8	±2.6	±2.6	±2.6	±2.6
Lepton efficiencies	±2.5	±2.5	±2.5	±2.5	±1.8	±1.8	±1.8	±1.8
Jet energy scale	±4.5	±12	±9.4	±7.0	±2.0	±5.5	±4.5	±3.3
Jet efficiencies	–	±5.9	±1.6	±0.9	–	±2.6	±0.7	±0.4
Jet energy resolution	±0.1	±4.5	±1.1	–	±0.1	±2.3	±0.6	–
b-tagging efficiency	±10	±5.5	±5.4	±11	±5.6	±3.1	±3.0	±5.8
c-tagging efficiency	±0.5	–	±12	±0.6	±0.3	–	±10	±0.3
l-tagging efficiency	±0.7	±34	±7.0	±1.6	±0.4	±21	±4.2	±0.9
High p_T tagging efficiency	–	–	±0.6	–	–	–	±0.3	–
$t\bar{t}$: p_T reweighting	–	±5.8	±6.2	–	–	±5.0	±5.4	–
$t\bar{t}$: parton shower	–	±14	±18	±14	–	±4.8	±11	±8.1
$t\bar{t}$+HF: normalisation	–	–	±50	±50	–	–	±28	±14
$t\bar{t}$+HF: modelling	–	±11	±16	±12	–	±3.8	±10	±10
Theoretical cross sections	–	±6.3	±6.3	±6.2	–	±4.1	±4.1	±4.1
$t\bar{t}H$ modelling	±1.9	–	–	–	±1.8	–	–	–
Total	±12	±40	±59	±55	±6.7	±22	±22	±13

- Systematics in the most signal-rich regions of both channels
- Pre- and post-likelihood fit

In short:

- Run 1 search for $t\bar{t}H(H\to b\bar{b})$ in both single lepton and dilepton channels
  - Utilized new modelling of $t\bar{t}+b\bar{b}$ (SherpaOL)
- No significant excess observed
  - Limit at 3.4 x SM

So what about Run 2?

- Similar process
  - Look at lepton+jets and dilepton events ($l=e,\mu$)
- Currently synchronising cutflow challenges in data and MC

$\sqrt{s}$ (TeV)	8	14
$t\bar{t}H$ (m_H = 125 GeV) (fb)	130	611
$t\bar{t}$ (pb)	253	950

Dominant background for $t\bar{t}H(b\bar{b})$ is 2000x larger than signal

Synchronisation Cutflow: l+jets

INITIAL
GRL
GOODCALO
TRIGDEC
EL_N 25000 >= 1
EL_N 25000 == 1
MU_N 25000 == 0
TRIGMATCH
JETCLEAN LooseBad
JET_N 25000 >= 1
JET_N 25000 >= 2
JET_N 25000 >= 3
JET_N 25000 >= 4
JET_N 25000 == 4
MV2C20_N -0.4434 == 2
MV2C20_N -0.4434 == 3
MV2C20_N -0.4434 >= 4
JET_N 25000 == 5
MV2C20_N -0.4434 == 2
MV2C20_N -0.4434 == 3
MV2C20_N -0.4434 >= 4
JET_N 25000 >= 6
MV2C20_N -0.4434 == 2
MV2C20_N -0.4434 == 3
MV2C20_N -0.4434 >= 4

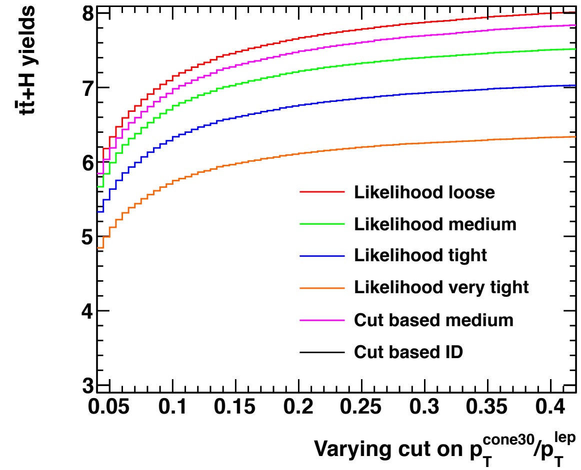
- MC
  - One file (e.g., mc15_13TeV.410000.PowhegPythiaEvtGen_P2012_ttbar_hdamp172p5_nonallhad.merge.DAOD_TOPQ1.e3698_s2608_s2183_r6765_r6282_p2413/DAOD_TOPQ1.06405917._000001.pool.root.1)
  - Matches for both e+jets and μ+jets in ttbar!
  - Data underway
    - Last step (njets ≥ 6, b-tags ≥ 4) blinded as the strongest signal region in single lepton case for run 1 (see slide 6)

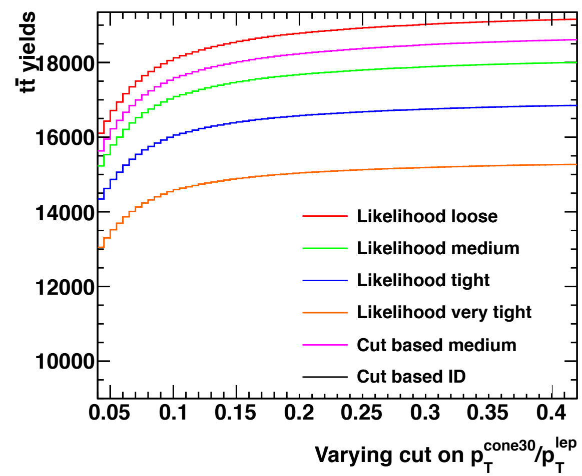
Lepton Isolations

- Start with default isolations (from Run 1)
  - Gradient [default], GradientLoose, Loose, Medium, Tight
- Use these on 25ns data and MC ($t\bar{t}H$, $t\bar{t}$, single top, W->lnu, Z->ll, diboson)
  - Currently running on grid
- Working with Bologna
  - Matteo Franchini, Silvia Biondi, and Roberto Spighi
- Compare MC to Data
  - Looser isolations possible?
  - Alternative definitions? Mini-isolation?

Lepton Isolations: Run 1 Studies

- Different lepton isolation and identifications tested
  - Final isolation for Run 1: $p_T^{cone30}/p_T^{lep} < 0.12$
  - Use this at a starting point for Run 2 studies





MC: Top Sets

- $t\bar{t}H$
  - mc15_13TeV.341177.aMcAtNloHerwigppEvtGen_UEEE5_CTEQ6L1_CT10ME_ttH125_inc.merge.DAOD_TOPQ1.e3921_s2608_s2183_r6869_r6282_p2413
  - mc15_13TeV.341270.aMcAtNloHerwigppEvtGen_UEEE5_CTEQ6L1_CT10ME_ttH125_inc_semil.merge.DAOD_TOPQ1.e3921_s2608_s2183_r6869_r6282_p2413
- $t\bar{t}$
  - mc15_13TeV. 410000.PowhegPythiaEvtGen_P2012_ttbar_hdamp172p5_nonallhad.merge .DAOD_TOPQ1.e3698_s2608_s2183_r6765_r6282_p2413
- Single Top
  - mc15_13TeV.410011.PowhegPythiaEvtGen_P2012_singletop_tchan_lept_top.merge.DAOD_TOPQ1.e3824_s2608_s2183_r6630_r6264_p2413
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  - mc15_13TeV.410013.PowhegPythiaEvtGen_P2012_Wt_inclusive_top.merge.DAOD_TOPQ1.e3753_s2608_s2183_r6630_r6264_p2413
  - mc15_13TeV.410014.PowhegPythiaEvtGen_P2012_Wt_inclusive_antitop.merge.DAOD_TOPQ1.e3753_s2608_s2183_r6630_r6264_p2413

MC: Boson Sets

- W->lν
  - mc15_13TeV.361100.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wplusenu.merge.DAOD_TOPQ 1.e3601_s2576_s2132_r6765_r6282_p2413
    mc15_13TeV.361101.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Wplusmunu.merge.DAOD_TOP Q1.e3601_s2576_s2132_r6725_r6282_p2413
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- Z->ll
  - mc15_13TeV.361106.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Zee.merge.DAOD_TOPQ1.e36 01_s2576_s2132_r6780_r6282_p2413
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- Diboson
  - mc15_13TeV.361063.Sherpa_CT10_llll.merge.DAOD_TOPQ1.e3836_s2608_s2183_r6869 _r6282_p2413
  - mc15_13TeV.361064.Sherpa_CT10_lllvSFMinus.merge.DAOD_TOPQ1.e3836_s2608_s218 3_r6869_r6282_p2413
  - mc15_13TeV.361065.Sherpa_CT10_lllvOFMinus.merge.DAOD_TOPQ1.e3836_s2608_s218 3_r6869_r6282_p2413
  - mc15_13TeV.361066.Sherpa_CT10_lllvSFPlus.merge.DAOD_TOPQ1.e3836_s2608_s2183 _r6869_r6282_p2413
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  - mc15_13TeV.361077.Sherpa_CT10_ggllvv.merge.DAOD_TOPQ1.e3836_s2608_s2183_r68 69_r6282_p2413
  - mc15_13TeV.361081.Sherpa_CT10_WplvWmqq.merge.DAOD_TOPQ1.e3836_s2608_s2183_r 6869_r6282_p2413
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  - mc15_13TeV.361086.Sherpa_CT10_ZqqZll.merge.DAOD_TOPQ1.e3926_s2608_s2183_r68 69_r6282_p2413
  - mc15_13TeV.361087.Sherpa_CT10_ZqqZvv.merge.DAOD_TOPQ1.e3926_s2608_s2183_r68 69_r6282_p2413

Data Sets

- Data
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  - data15_13TeV.00276329.physics_Main.merge.DAOD_TOPQ1.f620_m1480_p2411/
  - data15_13TeV.00276336.physics_Main.merge.DAOD_TOPQ1.f620_m1480_p2411/
  - data15_13TeV.00276416.physics_Main.merge.DAOD_TOPQ1.f620_m1480_p2411/
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