Z′ signals in polarised top-antitop final states

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Overview

- Introduction
  - Extra neutral gauge bosons
  - $t\bar{t}$ channel: Asymmetries at the LHC
- Benchmark Z' models and asymmetries
- Our study
- Results
  - Differential distributions
  - Significance and luminosity analysis
- Summary & outlook

Introduction

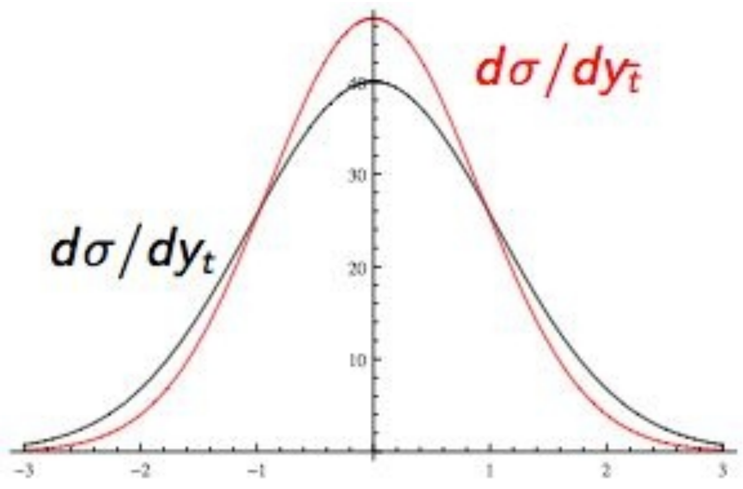
- Z': massive neutral s-channel resonance
  - Extra gauge boson from an extension of the SM symmetry group
  - KK excitation of SM gauge fields in extra dimensions
  - Many more...
- Drell-Yan: $pp(\bar{p}) \rightarrow Z' \rightarrow l^+l^-$
  - Discovery channel
  - Low background ~100% reconstruction efficiency
- $Z' \rightarrow t\bar{t}$ also has a role to play being another significant channel at the LHC

$t\bar{t}$ channel

- Mass near the EW scale
  - Strongly coupled to EWSB dynamics, important component of BSM theories
- Large production cross section at the LHC
  - BSM searches: irreducible QCD 'background'
  - More involved 6 body final state
  - Lower reconstruction efficiency ~ 10%
- Theoretical QCD cross sections well known (NNLO/NNLL), NLO EW corrections are known
- Z': access to up-type quark couplings in final state
- Top quark decays before hadronisation
  - Charge, spin information propagated to decay products

Charge asymmetry

- Measure of the symmetry of a process under charge conjugation ($q\bar{q} \to f^+f^-$) → angular asymmetry
  - Tevatron $t\bar{t}$ forward backward asymmetry
- LHC: symmetric pp collider
  - Cannot define an absolute 'forward' direction
  - Boost of CM frame correlated with incoming quark direction
  - Top rapidity distribution broadened w.r.t antitop



$$A_C = \frac{N_t(|y| < y^C_{cut}) - N_{\bar{t}}(|y| < y^C_{cut})}{N_t(|y| < y^C_{cut}) + N_{\bar{t}}(|y| < y^C_{cut})} \qquad A_{OFB} = \left.\frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}\right|_{|p^z_{t\bar{t}}| > p^z_{cut}}$$

$$A_F = \frac{N_t(|y| > y^F_{cut}) - N_{\bar{t}}(|y| > y^F_{cut})}{N_t(|y| > y^F_{cut}) + N_{\bar{t}}(|y| > y^F_{cut})} \qquad A_{RFB} = \left.\frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}\right|_{|y_{t\bar{t}}| > |y^{cut}_{t\bar{t}}}$$

Spin asymmetry

- Defined in terms of the helicity of the outgoing top/antitop
- Single (L) and double (LL) spin asymmtries
  - Can be extracted from kinematical properties of top decay products *[Stelzer, Willenbrock '96; Bernreuther; Godbole et al.]*

$$A_{LL} = \frac{N(+,+) + N(-,-) - N(+,-) - N(-,+)}{N_{Total}}$$

$$A_L = \frac{N(-,-) + N(-,+) - N(+,+) - N(+,-)}{N_{Total}}$$

- $N(h_t, h_{tbar})$ obtained by calculating unpolarised matrix elements using helicity amplitude methods *[Hagiwara, Zeppenfeld '85 ; Mangano, Parke '90; Arai et al. '08]*
- Asymmetries are an independent probe of chiral couplings of new physics to tops

Z′: models

- Study based on set of benchmark models defined in *[Accomando, Belyaev, Fedeli, King, Shepherd-Themistocleous. arXiv:1010.6058]*
- TeV scale extra U(1)':
  - Universal couplings to generations
  - Fields in the same SM representations will have the same charge under new U(1)
  - 5 independent couplings Q_L, L_L, u_R, d_R, e_R (ν_R decoupled)
- Parametrise generic Z′ interaction in vector-axial basis:

$$\mathcal{L}_{Z'} = \frac{g'}{2} Z'_\mu \bar{\psi}^i \gamma^\mu (g_V^i - g_A^i \gamma^5) \psi^i$$

Z′: asymmetries

- Charge asymmetry
  - Asymmetric part of the matrix element (cos θ term) proportional to $g_V^i\, g_A^i\, g_V^t\, g_A^t$
  - Requires all non-zero couplings to generate at tree-level
  - Purely vector/axial models only generate via interference with SM (EW)
- Spin asymmetries
  - Calculated using helicity amplitudes
  - A_{LL} depends on square of top couplings like σ_{total}
  - A_L only non-zero if both $g_V^t\, g_A^t$ non-zero, sensitive to relative sign in these couplings

$$A^i_{LL} \propto \left(3\,(g^t_A)^2\beta^2 + (g^t_V)^2(2+\beta^2)\right)\left((g^i_V)^2 + (g^i_A)^2\right)$$

$$A^i_L \propto \; g^t_A\, g^t_V\, \beta\left((g^i_V)^2 + (g^i_A)^2\right); \quad \beta = \sqrt{1 - \frac{4m_t^2}{\hat{s}}}$$

Z′: couplings

$U(1)'$	Parameter	g_V^u	g_A^u	g_V^d	g_A^d
E_6 ($g' = 0.462$)	θ				
$U(1)_\chi$	0	0	-0.316	-0.632	0.316
$U(1)_\psi$	0.5π	0	0.408	0	0.408
$U(1)_\eta$	-0.29π	0	-0.516	-0.387	-0.129
$U(1)_S$	0.129π	0	-0.129	-0.581	0.452
$U(1)_N$	0.42π	0	0.316	-0.158	0.474
G_{LR} ($g' = 0.595$)	ϕ				
$U(1)_R$	0	0.5	-0.5	-0.5	0.5
$U(1)_{B-L}$	0.5π	0.333	0	0.333	0
$U(1)_{LR}$	-0.128π	0.329	-0.46	-0.591	0.46
$U(1)_Y$	0.25π	0.589	-0.354	-0.118	0.354
G_{SM} ($g' = 0.760$)	α				
$U(1)_{SM}$	-0.072π	0.193	0.5	-0.347	-0.5
$U(1)_{T_{3L}}$	0	0.5	0.5	-0.5	-0.5
$U(1)_Q$	0.5π	1.333	0	-0.666	0

- Study of asymmetry variables in $t\bar{t}$ from broad classes of Z′ models being searched for at the LHC
  - Sensitivity to chiral couplings to up quarks
  - Distinguishability from SM and amongst themselves

Phenomenological study

Abstract

We study the sensitivity of top-antitop samples produced at all energy stages of the Large Hadron Collider (LHC) to the nature of an underlying Z' boson, in presence of full tree level standard model (SM) background effects and relative interferences. We concentrate on differential mass spectra as well as both spatial and spin asymmetries thereby demonstrating that exploiting combinations of these observables will enable one to distinguish between sequential Z's and those pertaining to Left-Right symmetric models as well as E_6 inspired ones, assuming realistic final state reconstruction efficiencies and error estimates.

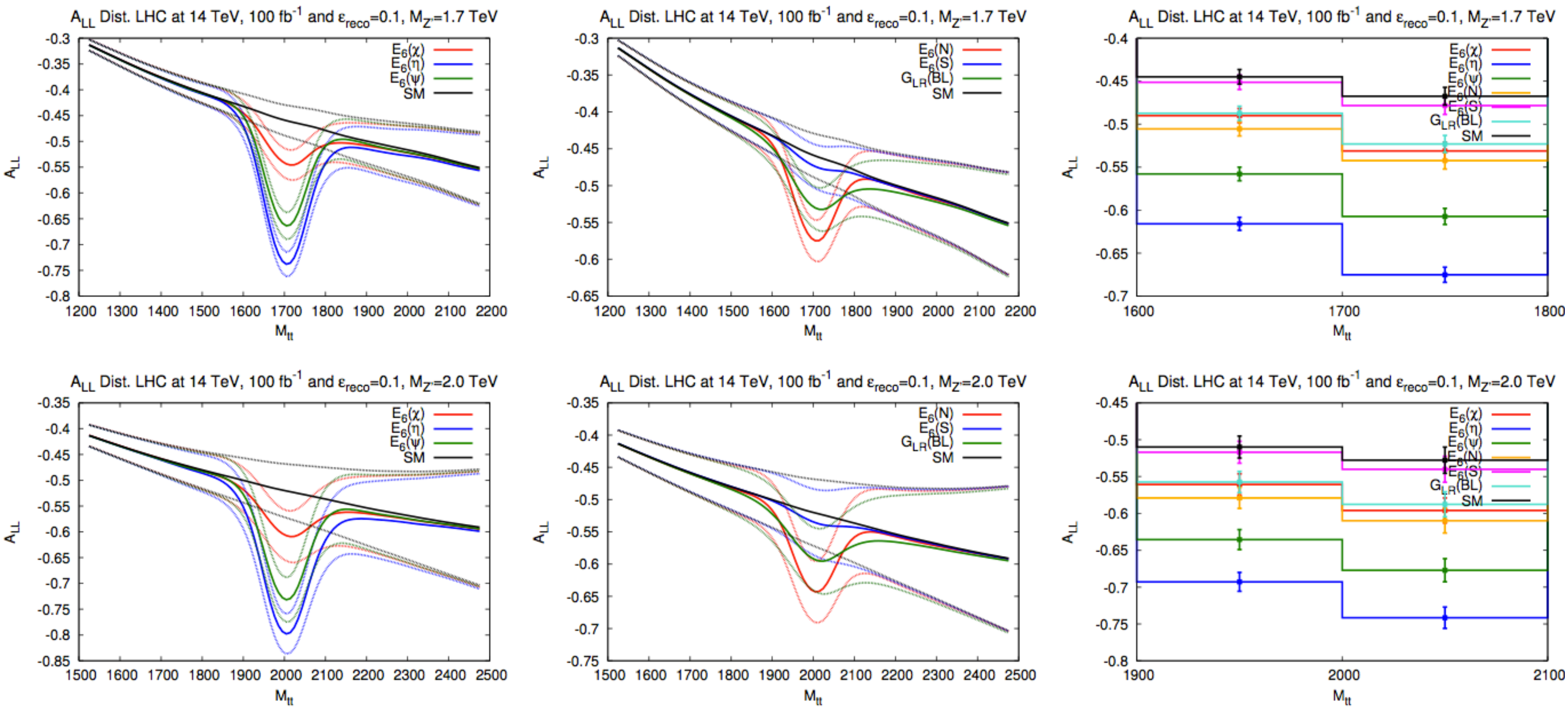
- Developed a tool based on HELAS/MADGRAPH that can output observables in $t\bar{t}$ final state
- Generated invariant mass distributions, invariant mass profiles of asymmetries for Z' models with tree-level SM and interference
- Split models into two classes
  - 'E6 type': E_6 + G_{LR}(B-L) - only one non-zero up-type coupling
  - 'Generalised': G_{LR} + G_{SM} - both non-zero
- Focus around Z' peak: $|M_{t\bar{t}}-M_{Z'}| < 500$ GeV

Details

- Numerical code:
  - CTEQ6L1 PDF set with $Q=2m_t$
  - Simulated LHC at 7, 8, 14 TeV assuming L_{int} = (5,15,100 fb^{-1})
  - $M_{Z'}$=1.7 and 2 TeV
  - Folded in $t\bar{t}$ reconstruction efficiency ε=10%
- Statistical error on generic asymmetry δA
  - Based on invariant mass bins of 50 GeV
- Systematics require detailed detector simulation
- 'Significance' measure s of distinguishability between models

$$\delta A \equiv \delta\left(\frac{N_F - N_B}{N_F + N_B}\right) = \sqrt{\frac{2}{\mathcal{L}\varepsilon}\left(\frac{\sigma_F^2 + \sigma_B^2}{\sigma_{Total}^3}\right)} \qquad s \equiv \frac{|A(1) - A(2)|}{\sqrt{\delta A(1)^2 + \delta A(2)^2}}$$

E_6 type models: A_{LL}



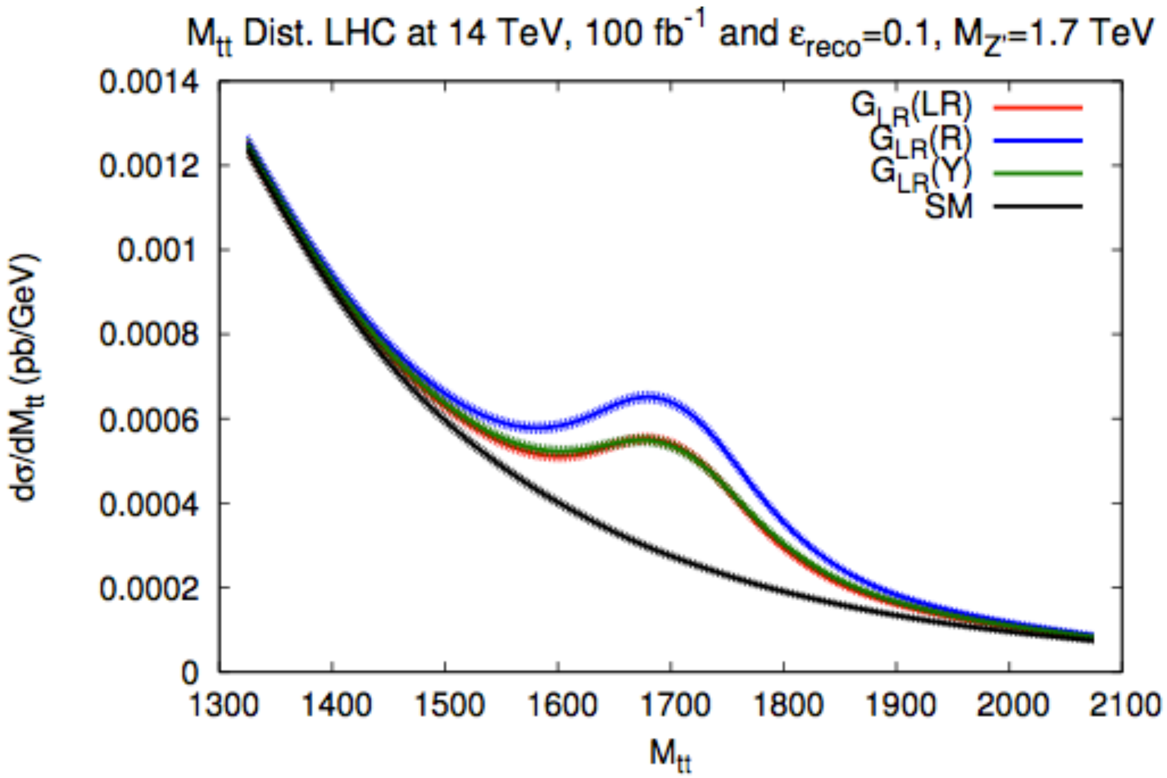
- Clear signatures with distinction between most models and the SM when up-type coupling is large enough
- Set of overlapping models have similar magnitude v/a couplings
- Neither A_{LL} nor cross section measurements can distinguish these

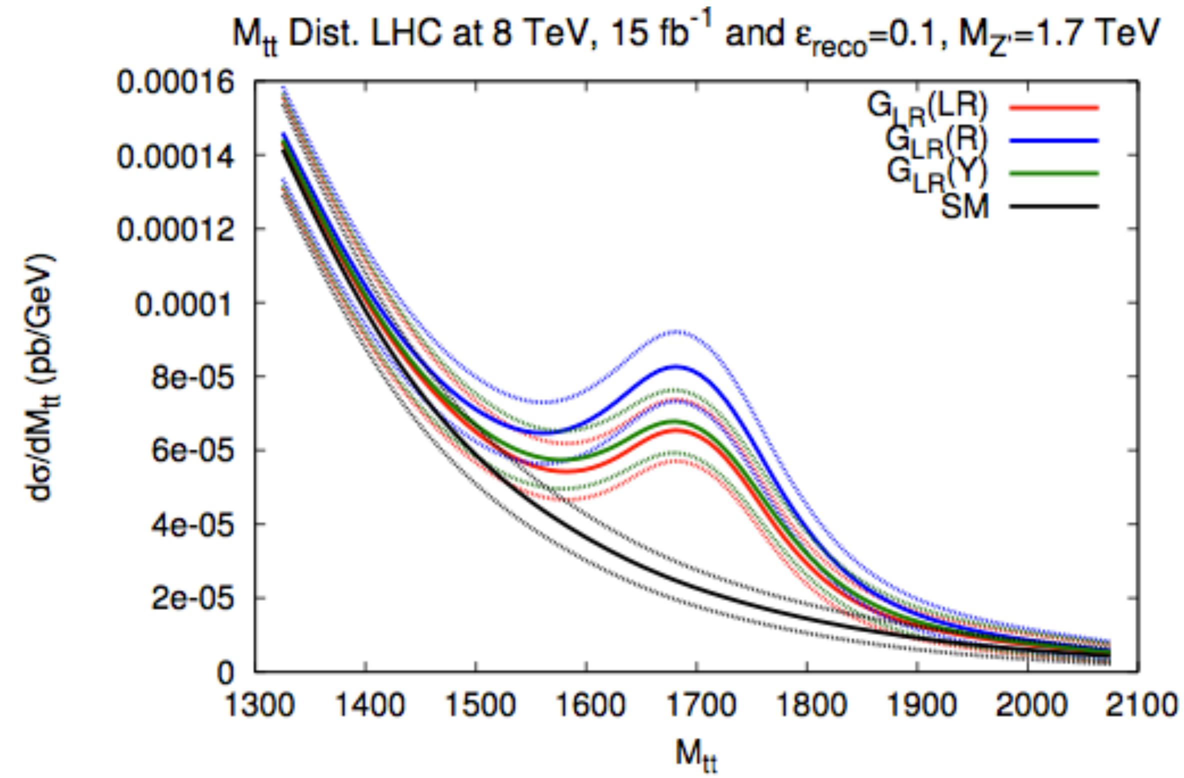
E_6 type models: A_{LL}

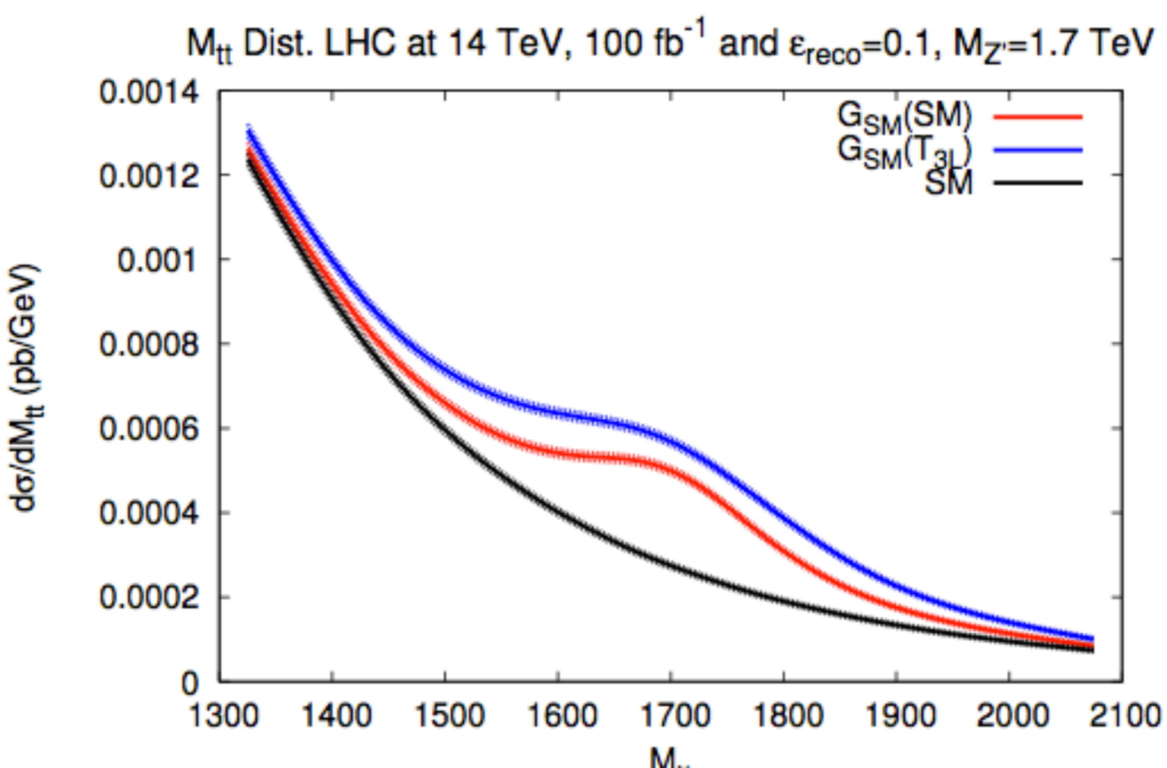
- Integrating over narrow mass window around the peak increases significances

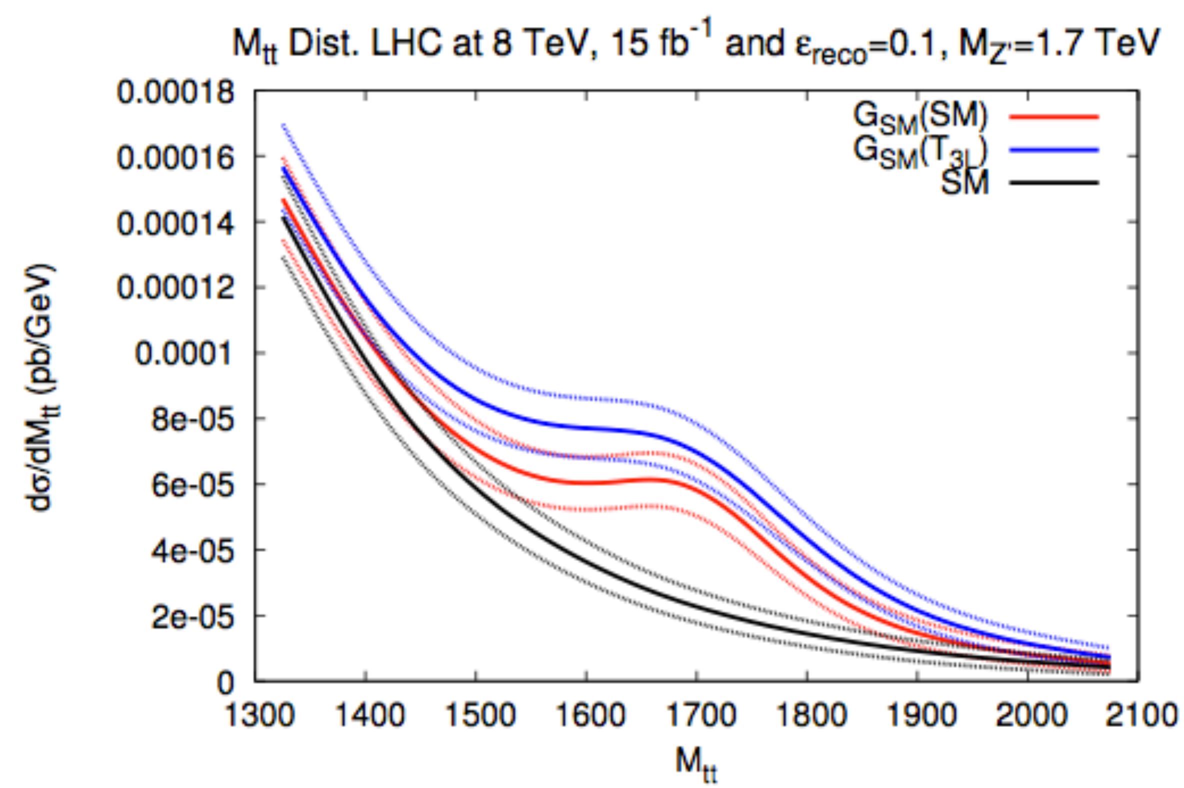
$A_{LL}(\times 10)$	$\sqrt{s} = 14$ TeV	$\mathcal{L}_{int} = 100$ fb^{-1}	$\sqrt{s} = 8$ TeV	$\mathcal{L}_{int} = 15$ fb^{-1}
$M_{Z'} = 1.7$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV
SM	-3.79 ± 0.05	-4.54 ± 0.07	-4.75 ± 0.39	-5.65 ± 0.61
$E_6(\chi)$	-3.88 ± 0.05	-5.07 ± 0.06	-4.85 ± 0.39	-6.35 ± 0.58
$E_6(\eta)$	-4.17 ± 0.05	-6.42 ± 0.06	-5.22 ± 0.38	-7.85 ± 0.48
$E_6(\psi)$	-4.01 ± 0.05	-5.79 ± 0.06	-5.02 ± 0.33	-7.22 ± 0.52
$E_6(N)$	-3.90 ± 0.05	-5.21 ± 0.06	-4.88 ± 0.39	-6.54 ± 0.57
$E_6(S)$	-3.80 ± 0.05	-4.62 ± 0.07	-4.76 ± 0.39	-5.76 ± 0.61
$G_{LR}(B-L)$	-3.88 ± 0.05	-5.02 ± 0.06	-4.86 ± 0.39	-6.31 ± 0.57
$M_{Z'} = 2.0$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV
SM	-4.66 ± 0.09	-5.17 ± 0.11	-5.68 ± 0.84	-6.32 ± 1.23
$E_6(\chi)$	-4.77 ± 0.09	-5.76 ± 0.11	-5.81 ± 0.83	-7.03 ± 1.14
$E_6(\eta)$	-5.13 ± 0.09	-7.15 ± 0.10	-6.26 ± 0.80	-8.44 ± 0.89
$E_6(\psi)$	-4.94 ± 0.09	-6.54 ± 0.10	-6.02 ± 0.82	-7.90 ± 1.00
$E_6(N)$	-4.79 ± 0.09	-5.92 ± 0.11	-5.84 ± 0.83	-7.23 ± 1.11
$E_6(S)$	-4.67 ± 0.09	-5.27 ± 0.11	-5.70 ± 0.84	-6.43 ± 1.22
$G_{LR}(B-L)$	-4.77 ± 0.09	-5.70 ± 0.11	-5.82 ± 0.83	-7.00 ± 1.13

Generalised models

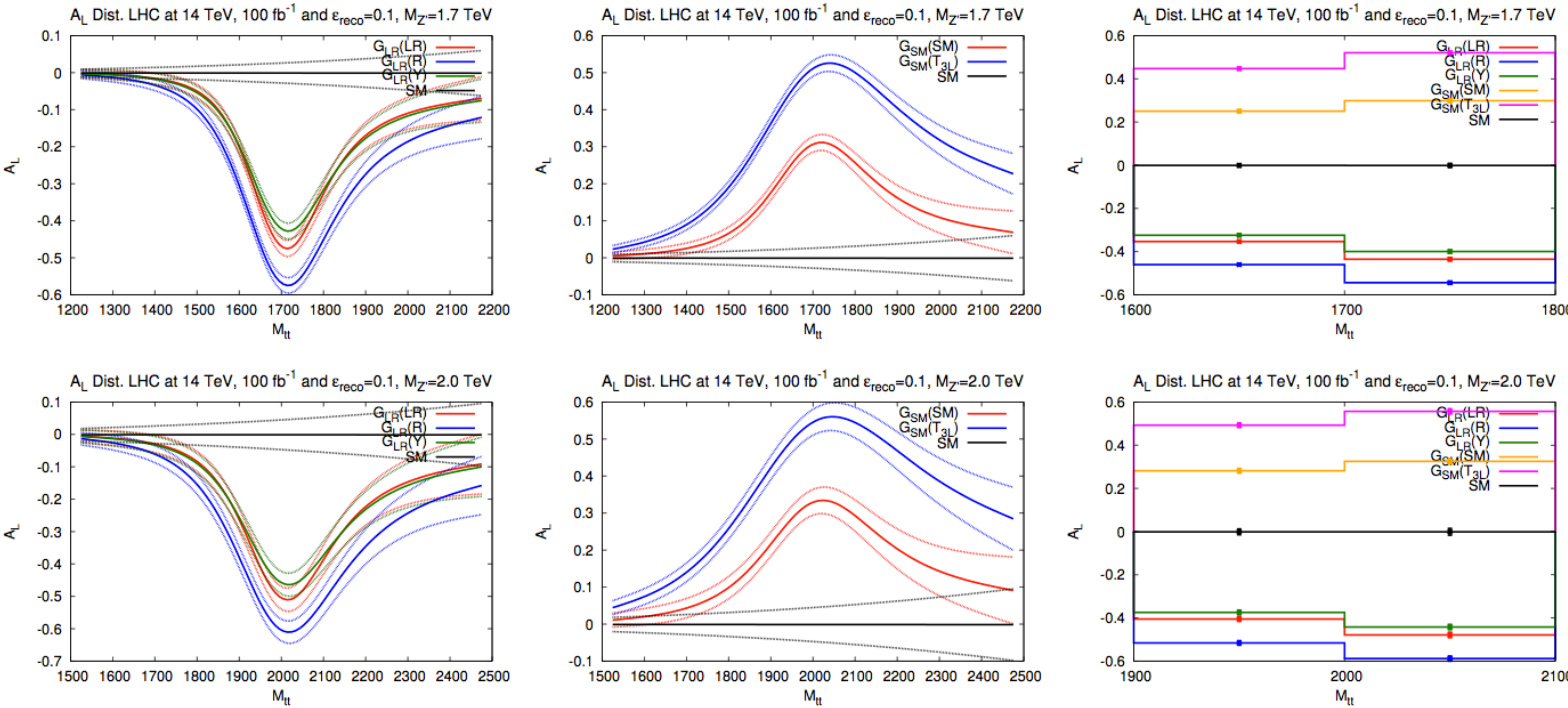








Generalised models: A_L



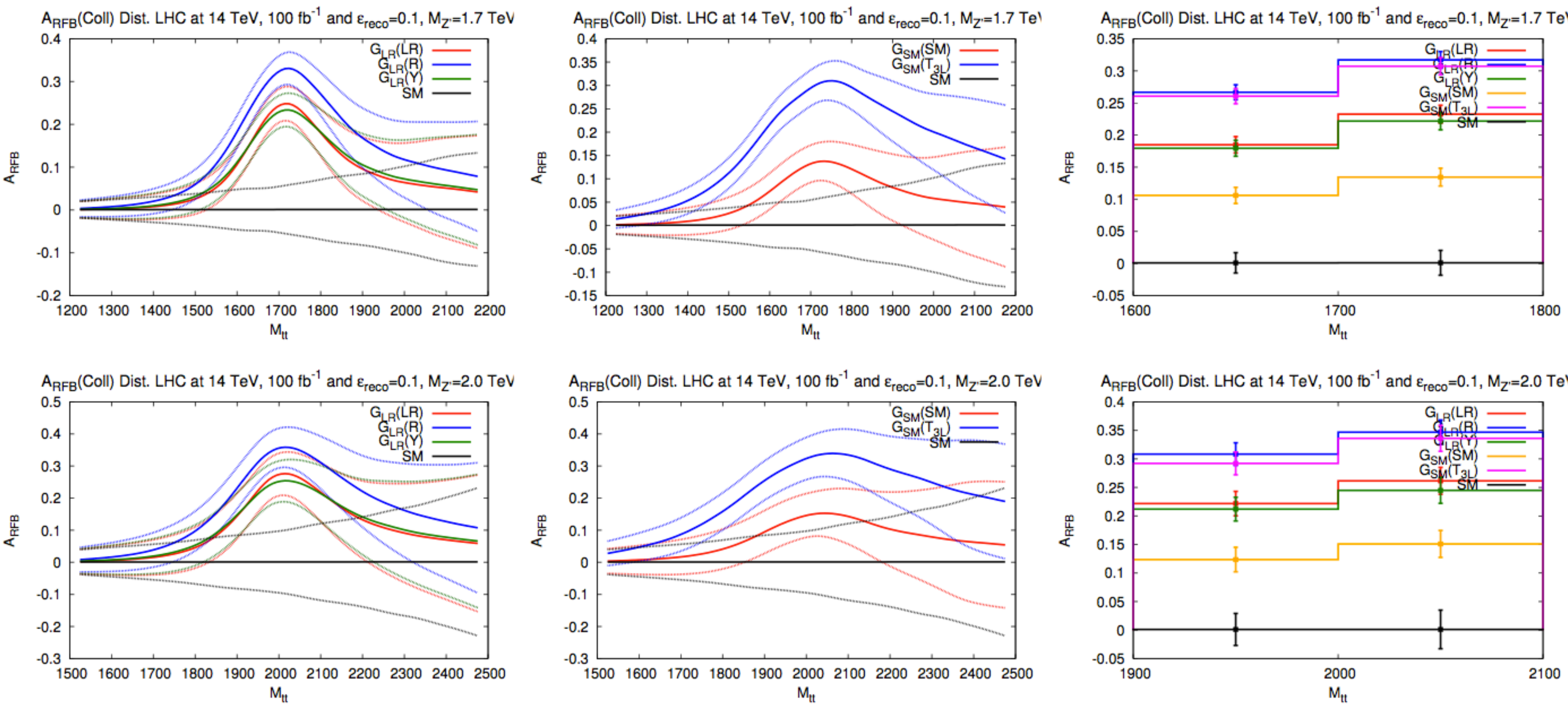
- Larger couplings contribute to more visible effects, increased width
- Good discrimination among models, sensitivity to relative sign of vector and axial couplings: G_{LR} and G_{SM} can be separated

Generalised models: A_L

- $G_{LR}(LR)$ and $G_{LR}(Y)$ are not visibly distinguishable in the invariant mass distributions due to similar magnitude of couplings but can be disentangled by the narrow mass window

$A_L(\times 10)$	$\sqrt{s} = 14$ TeV	$\mathcal{L}_{int} = 100$ fb^{-1}	$\sqrt{s} = 8$ TeV	$\mathcal{L}_{int} = 15$ fb^{-1}
$M_{Z'} = 1.7$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV
SM	-0.009 ± 0.044	-0.010 ± 0.059	-0.017 ± 0.35	-0.020 ± 0.53
$G_{LR}(LR)$	-0.971 ± 0.042	-3.90 ± 0.05	-1.37 ± 0.33	-5.36 ± 0.40
$G_{LR}(R)$	-1.51 ± 0.04	-4.98 ± 0.05	-2.14 ± 0.32	-6.53 ± 0.37
$G_{LR}(Y)$	-0.938 ± 0.042	-3.58 ± 0.05	-1.40 ± 0.33	-5.05 ± 0.38
$G_{SM}(SM)$	0.802 ± 0.042	2.71 ± 0.05	1.16 ± 0.32	3.79 ± 0.38
$G_{SM}(T_{3L})$	1.90 ± 0.04	4.80 ± 0.05	2.70 ± 0.31	6.36 ± 0.38
$M_{Z'} = 2.0$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV
SM	-0.011 ± 0.088	-0.012 ± 0.10	-0.020 ± 0.73	-0.020 ± 1.04
$G_{LR}(LR)$	-1.38 ± 0.07	-4.38 ± 0.08	-1.91 ± 0.66	-5.81 ± 0.75
$G_{LR}(R)$	-2.09 ± 0.07	-5.49 ± 0.08	-2.91 ± 0.64	-6.97 ± 0.69
$G_{LR}(Y)$	-1.34 ± 0.07	-4.05 ± 0.08	-1.99 ± 0.65	-5.54 ± 0.71
$G_{SM}(SM)$	1.12 ± 0.07	3.01 ± 0.08	1.59 ± 0.65	4.07 ± 0.71
$G_{SM}(T_{3L})$	2.55 ± 0.07	5.21 ± 0.08	3.53 ± 0.62	6.74 ± 0.71

Generalised models: A_{RFB}



- Performed best among charge asymmetries
- Clearly visible above SM

Significance

- Significance s of A_L and A_{RFB} between models, $M_{Z'}$=1.7[2] TeV in upper[lower] triangles, invariant mass window $\Delta M_{t\bar{t}}$=100(500) GeV, LHC at 14 TeV L=100fb^{-1}

A_L	SM	$G_{LR}(LR)$	$G_{LR}(R)$	$G_{LR}(Y)$	$G_{SM}(SM)$	$G_{SM}(T_{3L})$
SM	–	50.0(22.8)	63.9(37.3)	45.9(22.0)	35.0(19.2)	61.8(47.4)
$G_{LR}(LR)$	34.1(12.2)	–	15.3(9.3)	4.5(0.6)	93.5(29.9)	123.0(49.5)
$G_{LR}(R)$	42.8(18.5)	9.8(7.2)	–	19.8(9.9)	108.8(39.9)	123.0(60.3)
$G_{LR}(Y)$	31.5(11.8)	2.9(0.4)	12.7(7.6)	–	89.0(29.3)	118.5(48.9)
$G_{SM}(SM)$	23.6(10.1)	65.3(25.3)	75.1(32.4)	62.4(24.8)	–	29.5(18.9)
$G_{SM}(T_{3L})$	40.8(22.8)	84.8(39.7)	84.8(46.9)	81.8(39.3)	19.4(14.4)	–

A_{RFB}	SM	$G_{LR}(LR)$	$G_{LR}(R)$	$G_{LR}(Y)$	$G_{SM}(SM)$	$G_{SM}(T_{3L})$
SM	–	13.6(4.0)	19.0(7.2)	13.1(4.2)	7.8(2.7)	18.5(9.1)
$G_{LR}(LR)$	8.9(3.2)	–	6.4(3.2)	0.6(0.2)	6.9(1.4)	5.8(5.2)
$G_{LR}(R)$	12.6(5.6)	4.0(2.4)	–	7.1(3.0)	13.4(4.6)	0.6(2.0)
$G_{LR}(Y)$	8.6(3.4)	0.6(0.1)	4.8(2.3)	–	6.3(1.6)	6.4(5.0)
$G_{SM}(SM)$	5.0(2.1)	4.6(1.2)	8.9(3.6)	4.1(1.3)	–	12.7(6.6)
$G_{SM}(T_{3L})$	11.8(7.0)	3.3(3.8)	0.7(1.4)	4.0(3.7)	8.0(5.1)	–

Luminosity dependence

- Required integrated luminosity to achieve s=3 between models
  - Measure of the power of an asymmetry variable

$A_L \searrow A_{LL}$	SM	$E_6(\chi)$	$E_6(\eta)$	$E_6(\psi)$	$E_6(N)$	$E_6(S)$	$G_{LR}(B-L)$	$G_{LR}(LR)$	$G_{LR}(R)$	$G_{LR}(Y)$	$G_{SM}(SM)$	$G_{SM}(T_{3L})$
SM	–	62.6	5.1	10.6	38.7	>300	77.5	3.8	2.7	3.9	4.0	3.0
$E_6(\chi)$		–	10.2	32.7	>300	90.7	>300	7.1	4.6	7.5	7.7	5.2
$E_6(\eta)$			–	48.4	13.1	5.6	9.5	>300	45.3	>300	>300	70.7
$E_6(\psi)$				–	51.7	12.3	28.2	24.2	11.1	26.8	28.2	13.7
$E_6(N)$					–	51.6	>300	8.8	5.4	9.3	9.5	6.2
$E_6(S)$						–	117.8	4.2	3.0	4.3	4.4	3.3
$G_{LR}(B-L)$							–	6.6	4.3	6.9	7.1	4.9
$G_{LR}(LR)$	0.8							–	95.9	>300	>300	200.0
$G_{LR}(R)$	0.5							9.3	–	78.9	72.0	>300
$G_{LR}(Y)$	0.9							105.8	5.6	–	>300	151.7
$G_{SM}(SM)$	1.6							0.2	0.2	0.2	–	133.9
$G_{SM}(T_{3L})$	0.5							0.1	0.1	0.1	2.4	–

Spatial	SM	$G_{LR}(LR)$	$G_{LR}(R)$	$G_{LR}(Y)$	$G_{SM}(SM)$	$G_{SM}(T_{3L})$
SM	–	11.4(14.0)	5.6(6.6)	12.2(14.8)	35.7(42.6)	6.4(7.5)
$G_{LR}(LR)$	13.2(30.9)	–	55.0(59.1)	>300(>300)	42.6(55.1)	83.5(94.0)
$G_{LR}(R)$	7.1(14.3)	61.2(118.8)	–	38.7(51.7)	11.3(13.4)	>300(>300)
$G_{LR}(Y)$	13.7(33.0)	>300(>300)	55.3(98.4)	–	52.3(63.0)	56.1(79.6)
$G_{SM}(SM)$	40.0(97.6)	40.9(122.5)	11.8(28.9)	44.4(144.5)	–	14.0(16.6)
$G_{SM}(T_{3L})$	7.8(16.7)	94.0(204.9)	>300(>300)	82.8(161.5)	14.0(37.5)	–

Conclusion

- Overview of a phenomenological study of spin and spatial asymmetries from a set of benchmark Z' models in $t\bar{t}$ channel
- Quantified the ability to distinguish these models from the SM and among themselves
- Clear that the such models will be visible in the relatively early stages of LHC running (<100 fb^{-1})
- Spin asymmetries depend strongly on the chiral couplings of the Z' and in some cases can disentangle models which would not be by cross section measurements

Outlook

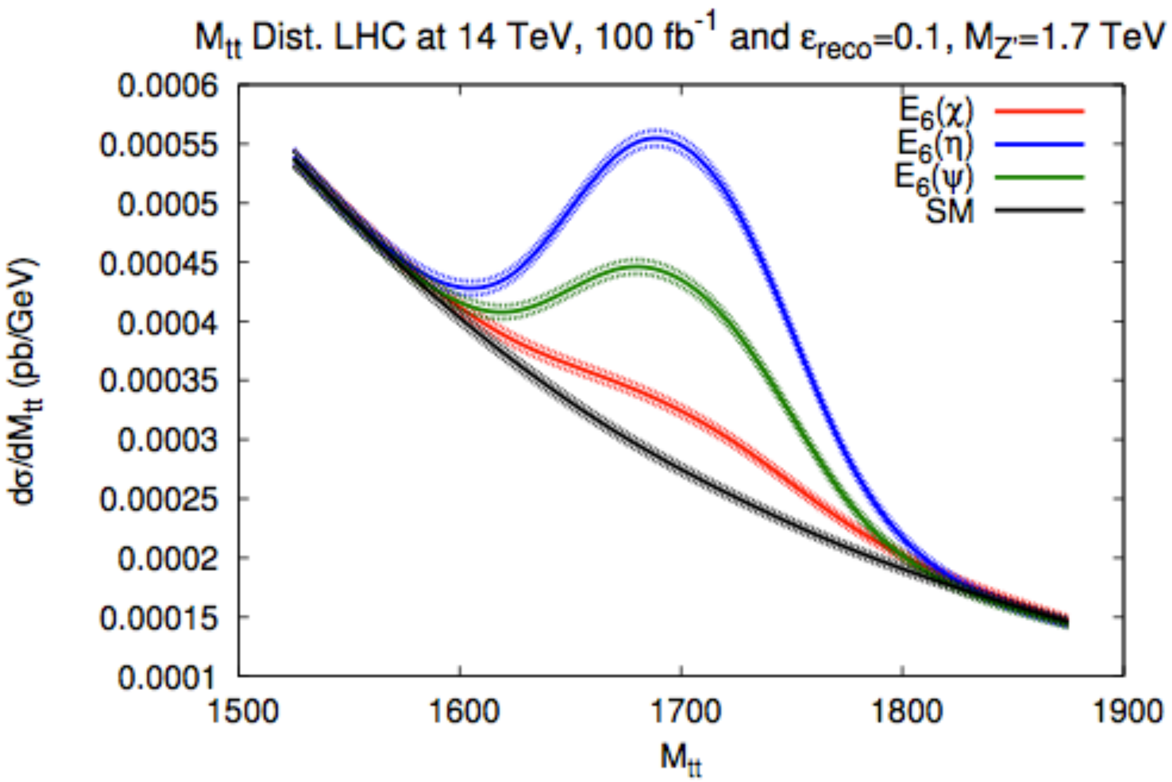
- The set of benchmark models considered lend themselves to di-lepton searches
  - $t\bar{t}$ can complement but not compete
- Other BSM scenarios with Z′s naturally have preferential couplings to the top or are leptophobic
  - Dynamical EWSB / composite Higgs
  - Extra dimensions
  - etc.
- Apply this kind of study to such models in which the $t\bar{t}$ channel is a competitive discovery mode
- Investigate the complementarity of asymmetries in $t\bar{t}$, $b\bar{b}$ and $l^+ l^-$ channels to fully probe parameter space of Z′ models

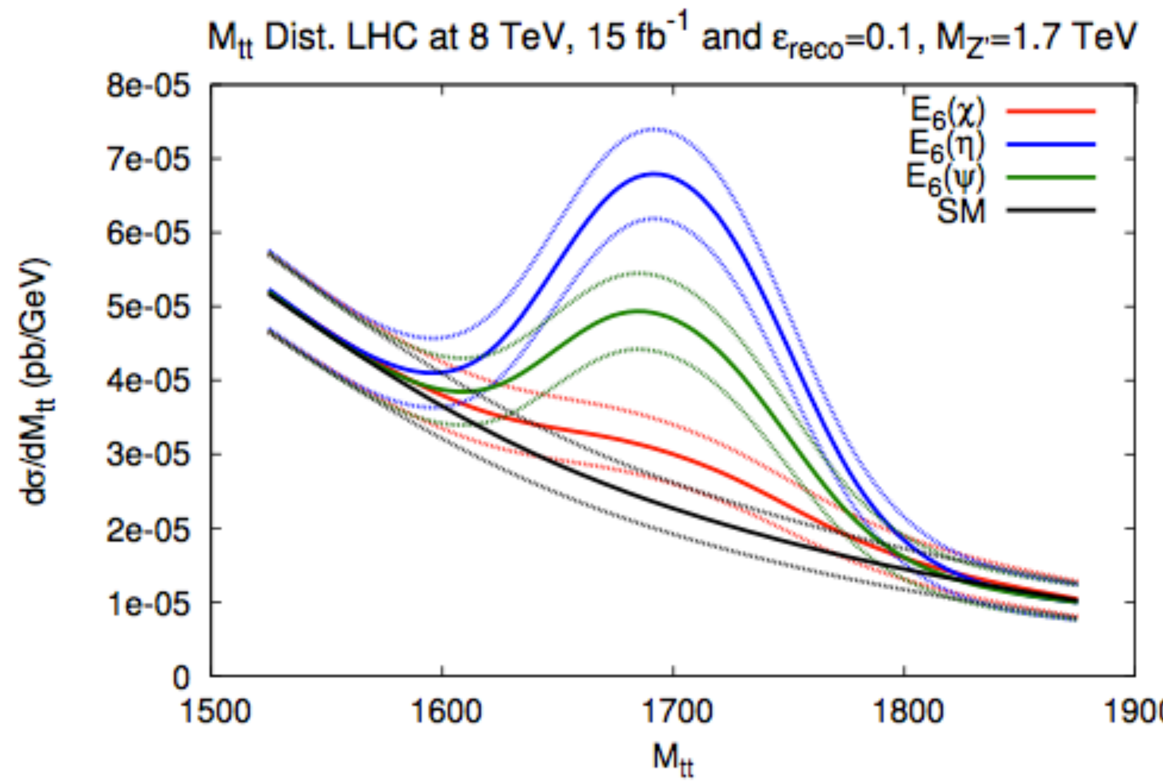
BACKUP

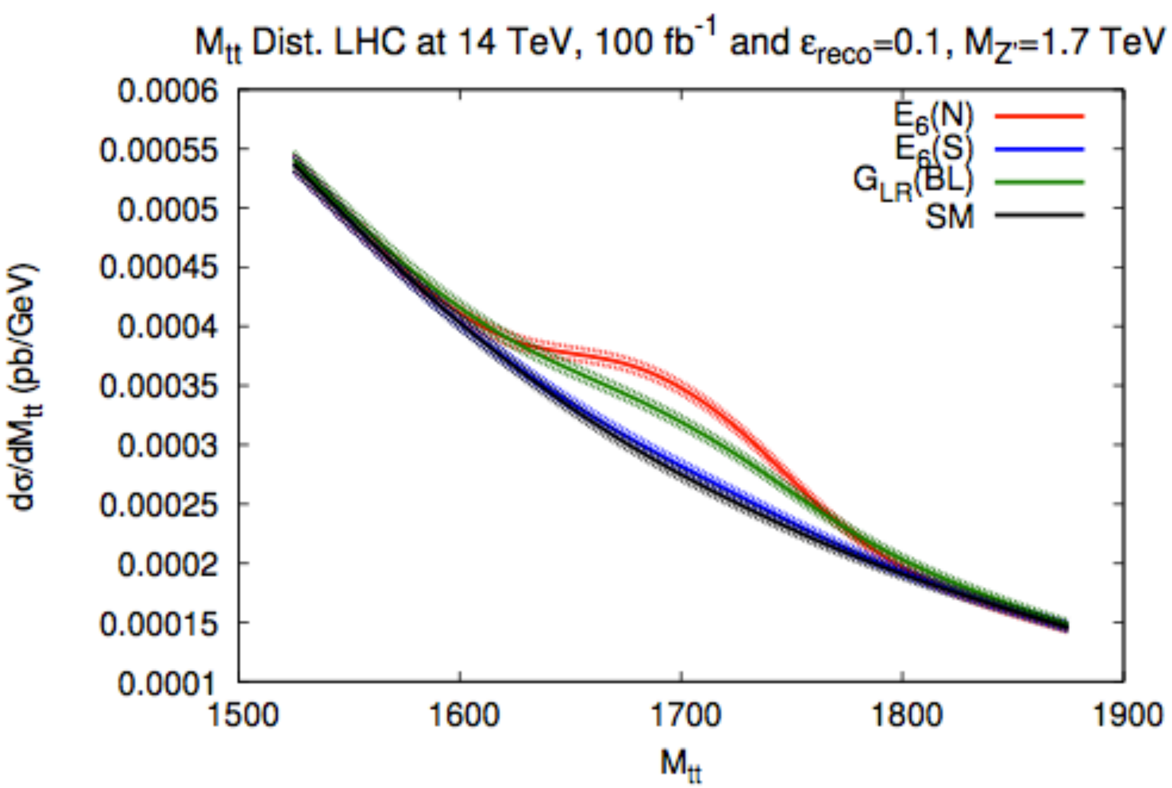
Z': Models

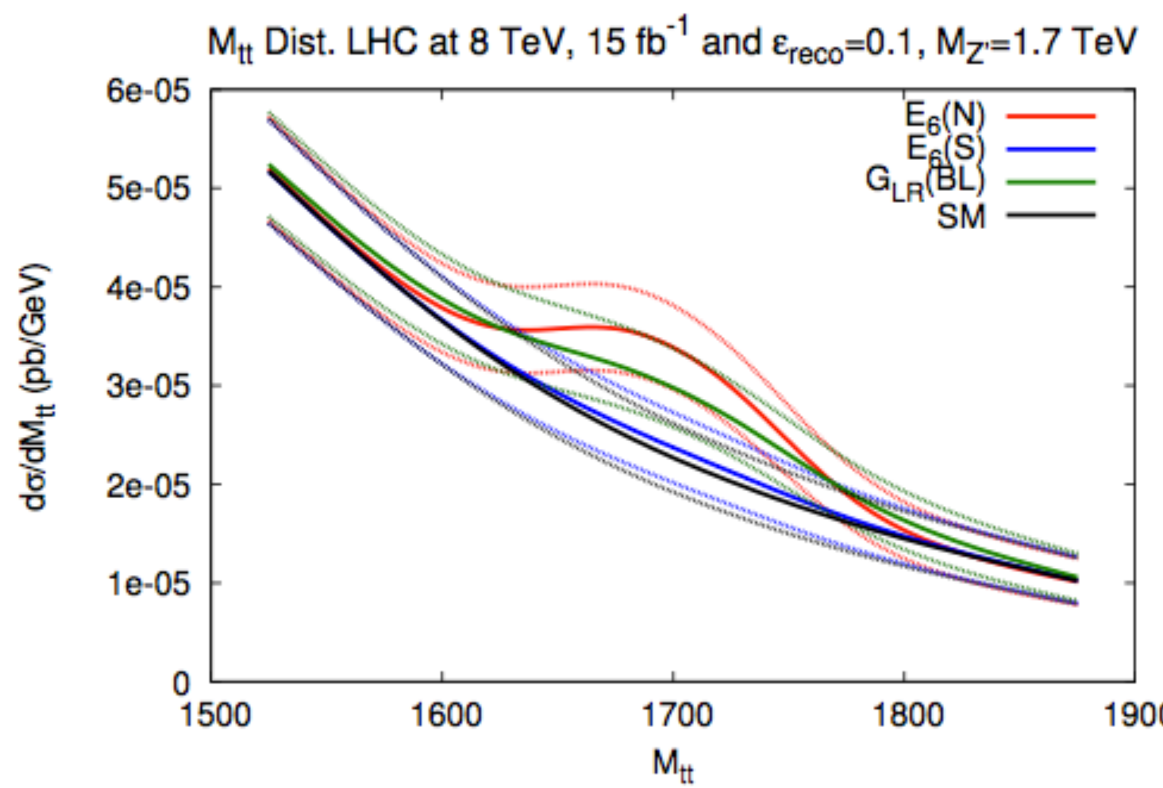
- E_6 models
  - Two additional U(1)'s from GUT group breaking pattern
  - $E_6 \rightarrow SO(10) \otimes U(1)_\psi \rightarrow SU(5) \otimes U(1)_\psi \otimes U(1)_\chi \rightarrow SM \otimes U(1)_\psi \otimes U(1)_\chi$
  - Linear combination survives down to TeV scale
  - $Q(E_6) = \cos\theta \, T_\chi + \sin\theta \, T_\psi$
- Left-Right symmetric
  - $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \rightarrow SU(2)_L \otimes U(1)_Y$
  - $U(1)_R \otimes U(1)_{B-L} \rightarrow U(1)_Y$
  - $Q(G_{LR}) = \cos\phi \, T_{3R} + \sin\phi \, T_{B-L}$
- Generalised sequential SM
  - Sequential = SM couplings : Standard candle in experimental searches
  - $Q(G_{SM}) = \cos\alpha \, T_{3L} + \sin\alpha \, Q_{EM}$

Results: E_6 type models

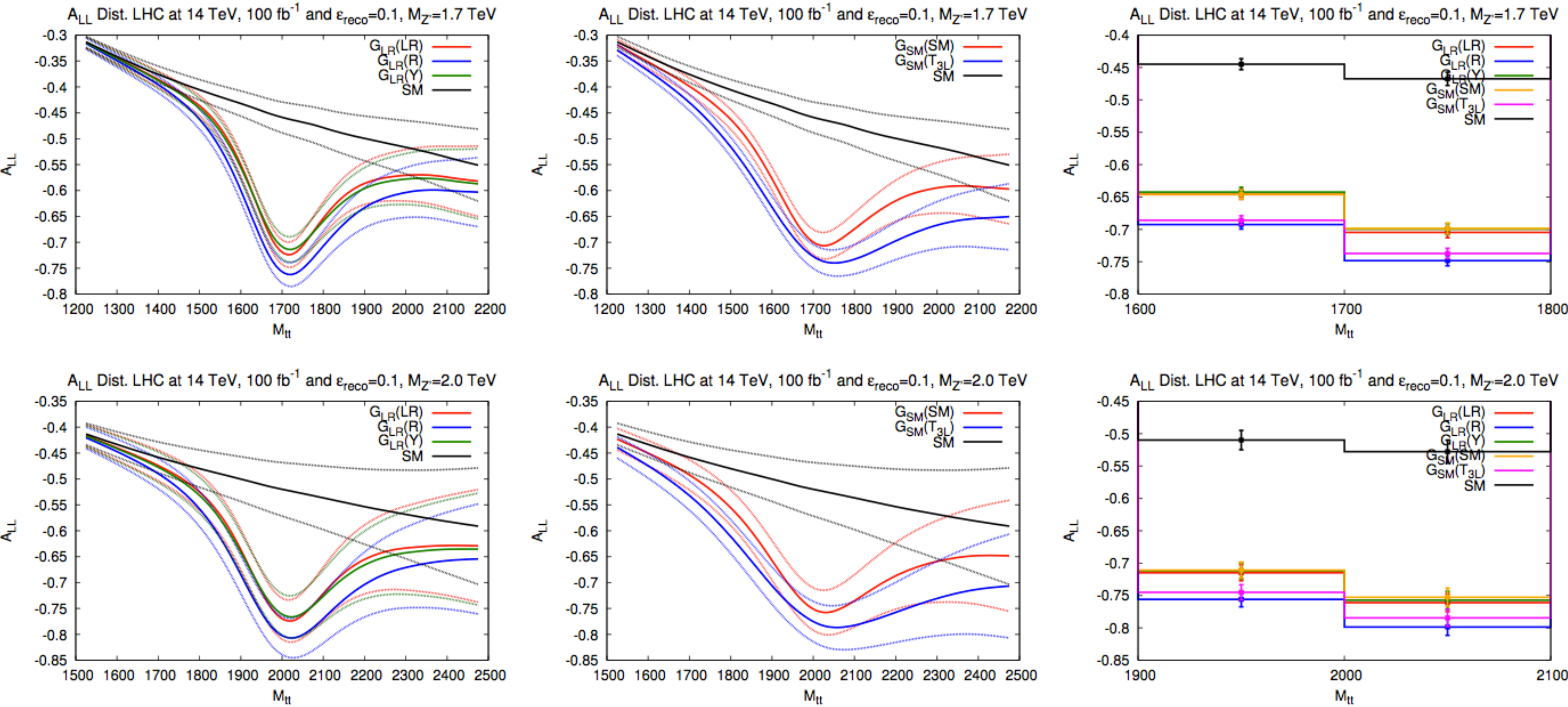








Generalised models: A_{LL}



- Larger couplings contribute to more visible effects, increased width
- Performs much worse that total cross section measurements
- Almost all models can clearly be discriminated from the SM but not between each other, G_{LR} and G_{SM} can be separated in the two bin plots

Generalised models: A_{LL}

- Some distinction is obtained in the integrated values from reduced statistical uncertainty and increased central values

$A_{LL}(\times 10)$	$\sqrt{s} = 14$ TeV	$\mathcal{L}_{int} = 100$ fb^{-1}	$\sqrt{s} = 8$ TeV	$\mathcal{L}_{int} = 15$ fb^{-1}
$M_{Z'} = 1.7$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV
SM	-3.79 ± 0.05	-4.54 ± 0.07	-4.75 ± 0.39	-5.65 ± 0.61
$G_{LR}(LR)$	-4.41 ± 0.05	-6.72 ± 0.06	-5.48 ± 0.37	-8.03 ± 0.45
$G_{LR}(R)$	-4.70 ± 0.05	-7.18 ± 0.05	-5.83 ± 0.36	-8.38 ± 0.41
$G_{LR}(Y)$	-4.43 ± 0.05	-6.68 ± 0.05	-5.55 ± 0.37	-8.02 ± 0.44
$G_{SM}(SM)$	-4.52 ± 0.05	-6.69 ± 0.06	-5.64 ± 0.37	-8.04 ± 0.45
$G_{SM}(T_{3L})$	-4.94 ± 0.04	-7.09 ± 0.05	-6.12 ± 0.35	-8.31 ± 0.41
$M_{Z'} = 2.0$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV	$\Delta M_{t\bar{t}} < 0.5$ TeV	$\Delta M_{t\bar{t}} < 0.1$ TeV
SM	-4.66 ± 0.09	-5.17 ± 0.11	-5.68 ± 0.84	-6.32 ± 1.23
$G_{LR}(LR)$	-5.41 ± 0.08	-7.36 ± 0.09	-6.53 ± 0.78	-8.51 ± 0.85
$G_{LR}(R)$	-5.74 ± 0.08	-7.75 ± 0.09	-6.90 ± 0.75	-8.79 ± 0.76
$G_{LR}(Y)$	-5.44 ± 0.08	-7.32 ± 0.09	-6.62 ± 0.77	-8.53 ± 0.82
$G_{SM}(SM)$	-5.53 ± 0.08	-7.30 ± 0.09	-6.69 ± 0.77	-8.51 ± 0.86
$G_{SM}(T_{3L})$	-5.99 ± 0.08	-7.63 ± 0.09	-7.16 ± 0.72	-8.72 ± 0.78

Complementarity

- Collaboration with Lorenzo Basso focusing on complementarity of $t\bar{t}$, $b\bar{b}$ and $l^+ l^-$ channels to fully probe parameter space of a minimal Z' model
- Gauged $U(1)_{B-L}$:
  - $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$
  - Two gauge couplings (kinetic mixing, B-L): $g_E Y_E = \tilde{g}\tilde{Y} + g' Y_{B-L}$
  - Benchmark models can be recovered by appropriate coupling definitions
  - Heavy right-handed neutrinos minimally extend fermion sector
  - Mass mixing heavily constrained by EWPT
- Investigate effect of heavy neutrinos on observables via Z' width

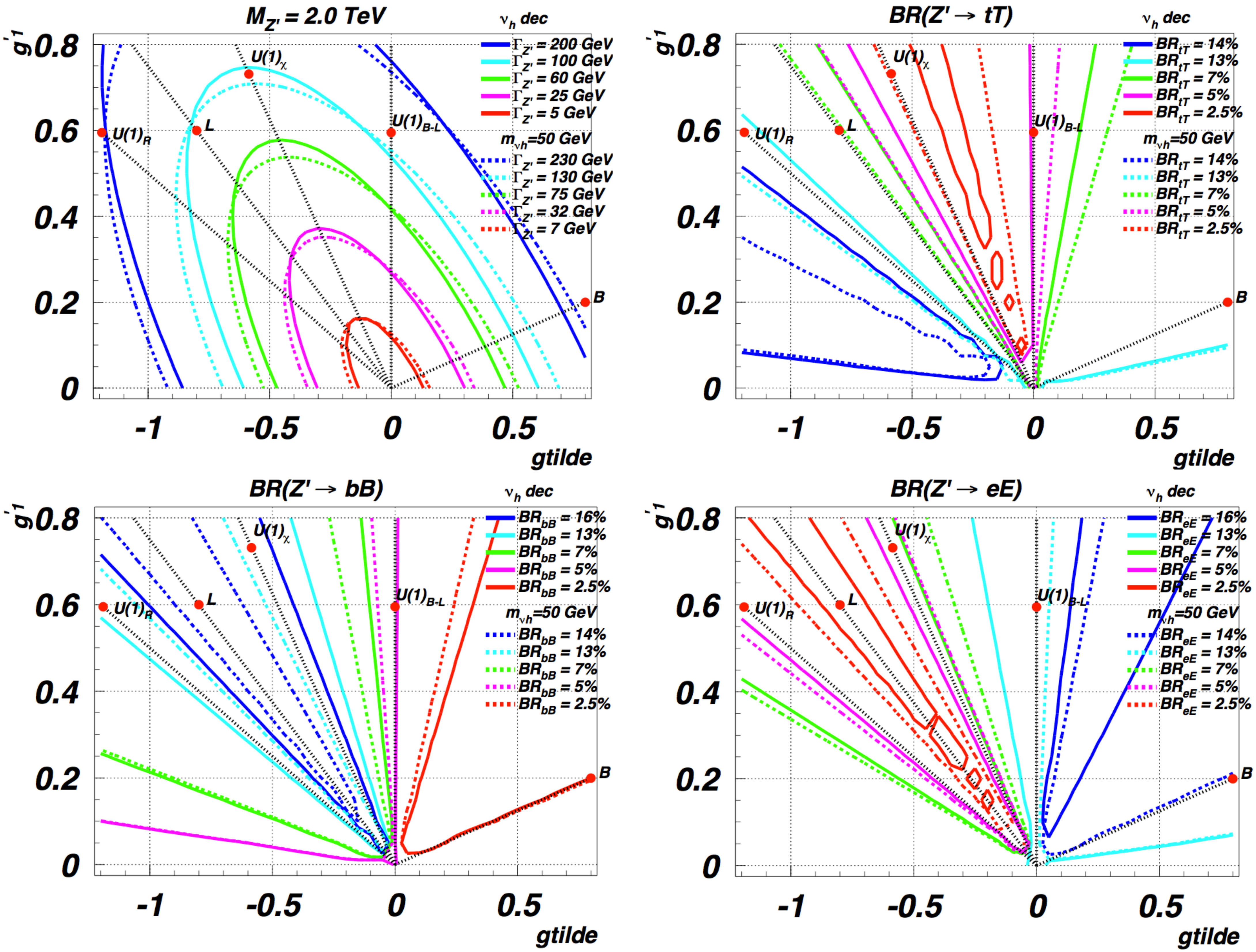
Minimal B-L study

- Performed a scan over parameter space between allowed values of $\tilde{g}$ and g' for masses above current bounds for all 3 final states
- Considered using previously defined asymmetries to disentangle various benchmark points using a combination of channels
  - Recover $U(1)_R$ [$g_V=g_a$], $U(1)_{B-L}$ [$\tilde{g}=0$], $U(1)_\chi$ [$g_V{}^u=0$]
  - New benchmarks 'B' and 'L' where vector couplings to down-type quarks and leptons are zero respectively
- RH neutrinos 50 GeV, decoupled (>$M_{Z'}/2$)

$$C_V^d(g_1',\widetilde{g}) = \frac{C'\,C_W\,(-4g_1'+\widetilde{g})\,S_W + e\,S'\,(-3+4\,S_W^2)}{12\,C_W\,S_W}, \quad C_V^u(g_1',\widetilde{g}) = \frac{-C'\,C_W\,(4g_1'+5\widetilde{g})\,S_W + e\,S'\,(3-8\,S_W^2)}{12\,C_W\,S_W}, \quad C_V^\ell(g_1',\widetilde{g}) = \frac{-C'\,C_W\,(4g_1'+3\widetilde{g})\,S_W + e\,S'\,(1-4\,S_W^2)}{4\,C_W\,S_W},$$

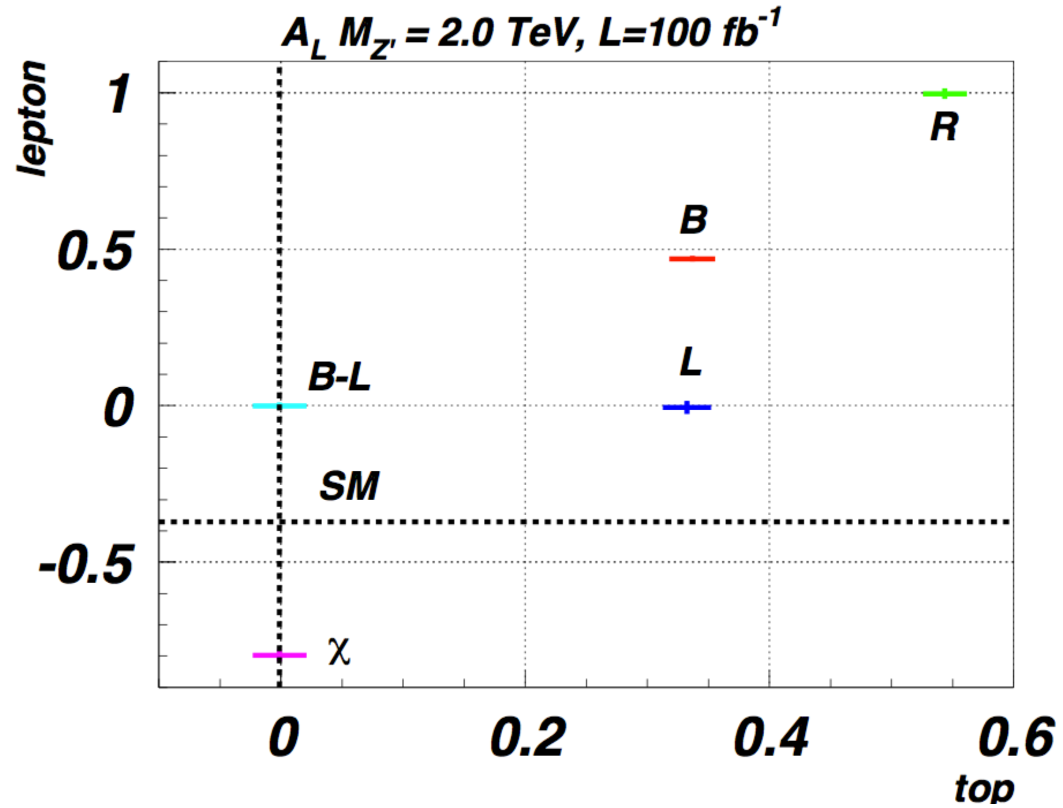
$$C_A^d(g_1',\widetilde{g}) = \frac{C'\,\widetilde{g}\,C_W\,S_W + e\,S'}{4\,C_W\,S_W}. \quad C_A^u(g_1',\widetilde{g}) = -\frac{e\,S' + C'\,C_W\,\widetilde{g}\,S_W}{4\,C_W\,S_W}. \quad C_A^\ell(g_1',\widetilde{g}) = -\frac{e\,S' + C'\,C_W\,\widetilde{g}\,S_W}{4\,C_W\,S_W}.$$

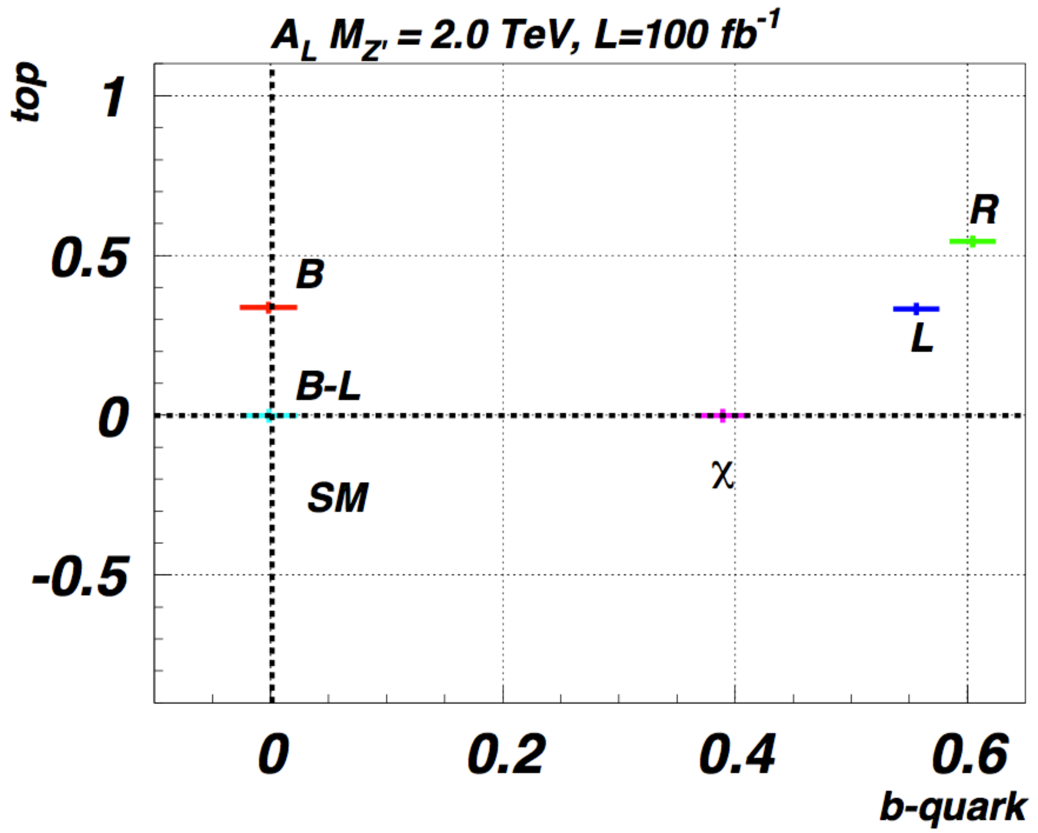
Preliminary results: Γ_T,BRs

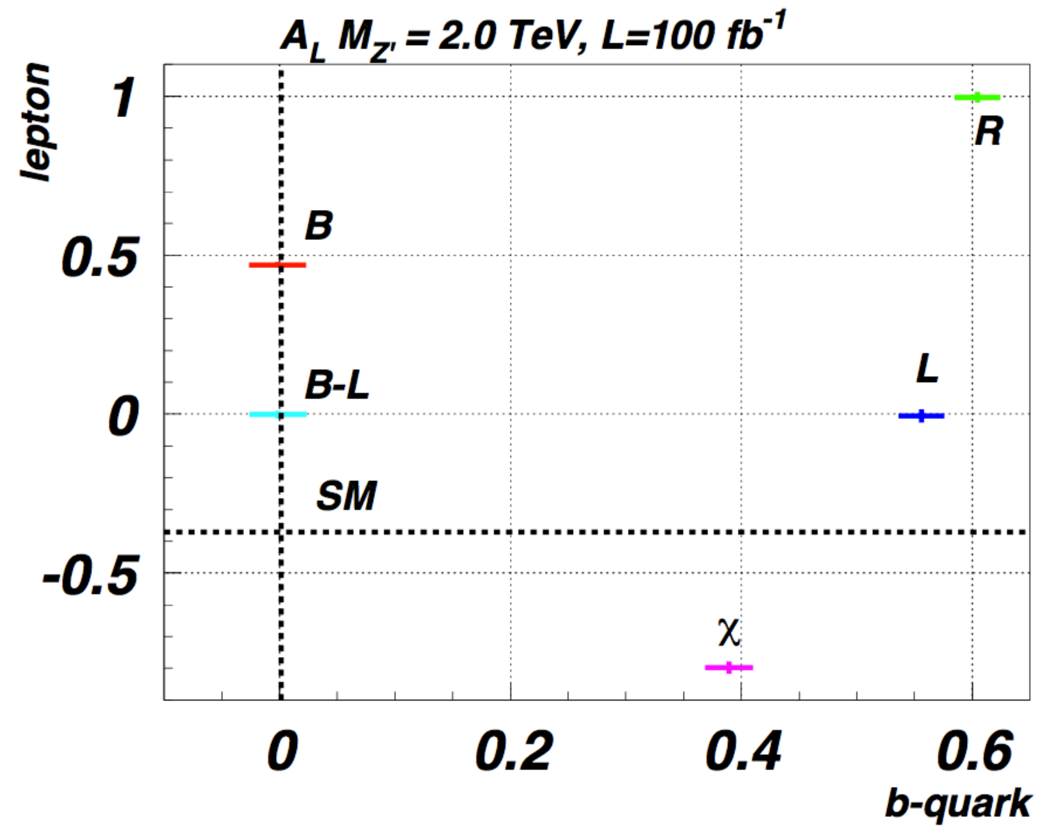


Disentanglement

- Single spin asymmetry for LHC at 14 TeV assuming 10(90)% efficiency for tt/bb(ll)
- Combination of channels allows for complete differentiation of benchmark points within statistical uncertainty
- More to come...







'Top friendly' models

- Collaboration with Elena Accomando on investigating top phenomenology of leptophobic/quark-philic AADD model of extra dimensions
  [Accomando, Antoniadis, Benakli. arXiv: hep-ph/9912287]
- Full SM embedded into one extra dimension with colour sector (quarks + gluons) localised on a brane while EW sector (leptons + gauge bosons) propagates in bulk
  - Towers of Kaluza-Klein excitations of Z and photon (leptons)
  - Loop suppressed couplings to SM leptons (survives EWPT)
  - Enhanced couplings to quarks
- Multiple levels of quasi-degenerate Z′s preferentially coupling to tops