The Recursive Jigsaw Reconstruction

SUSY15 Lake Tahoe

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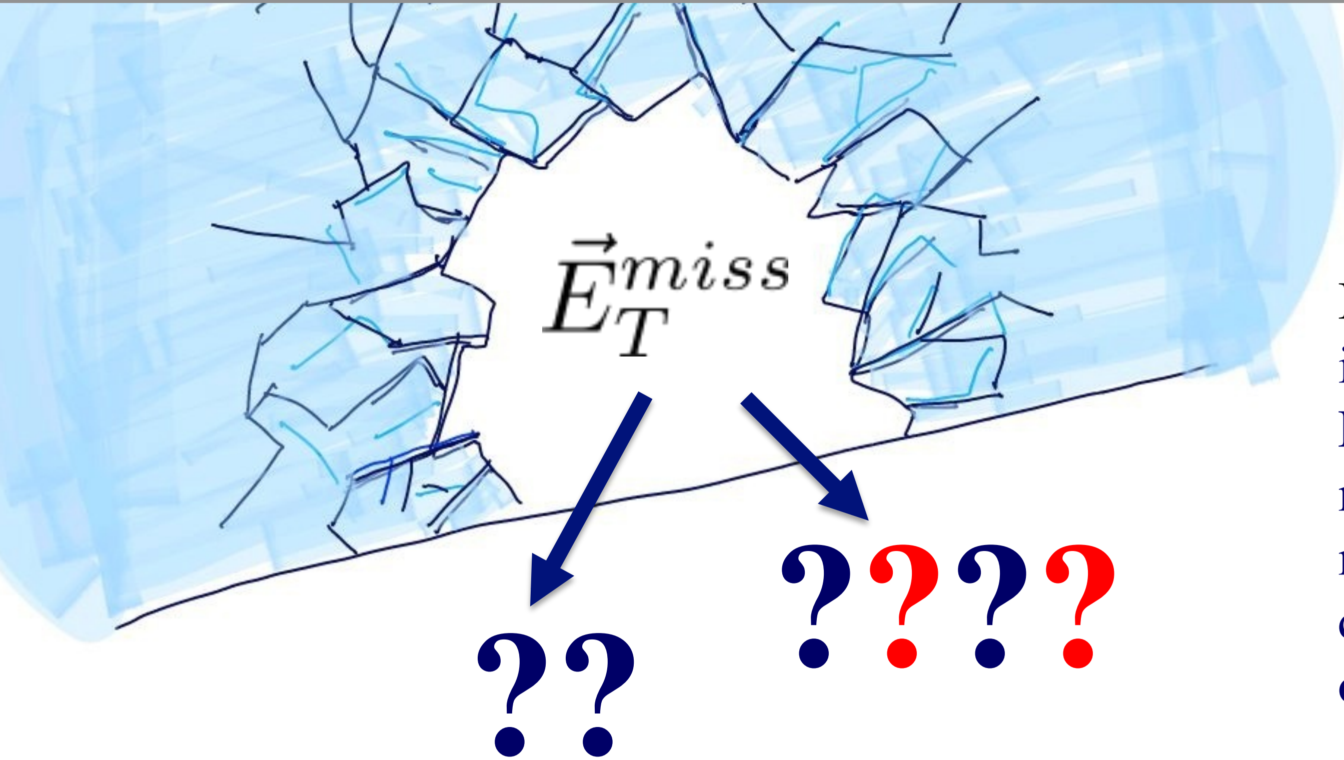
CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

- Weakly interacting particles and open final states – what and why?
- Recursive Jigsaw reconstruction: towards a kinematic basis for open final states
- Examples:
  - SM ttbar
  - stop pair production
  - gluino pair production (see L. Lee talk Monday)
- Outlook



$$\vec{E}_T^{miss} \equiv - \sum_i^{calo} \vec{E}_T^{\,i}$$

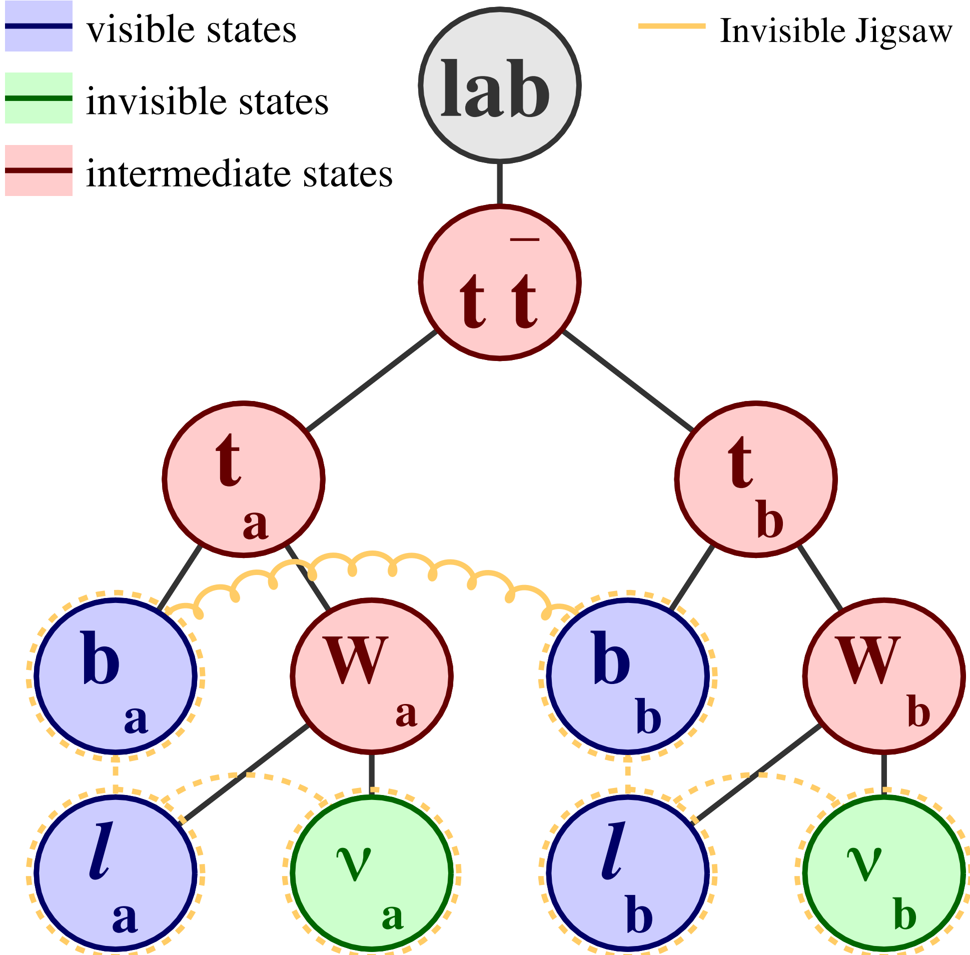
Infer presence of weakly interacting particles in LHC events by looking for missing transverse momentum…..may be composed of one or more objects, which may differ

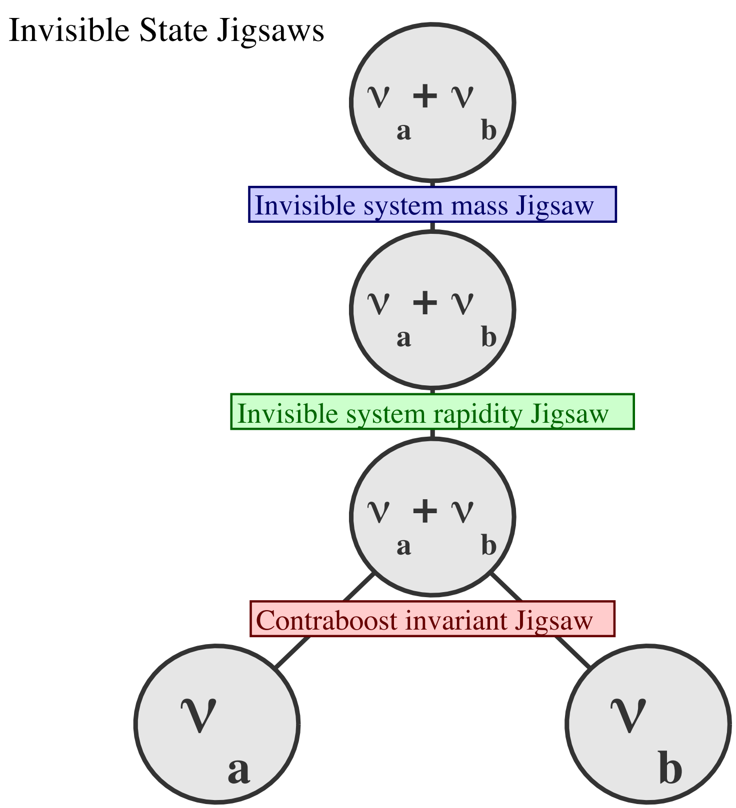
We can learn more by using other information in an event to contextualize the missing transverse momentum ⇒
multiple weakly interacting particles?

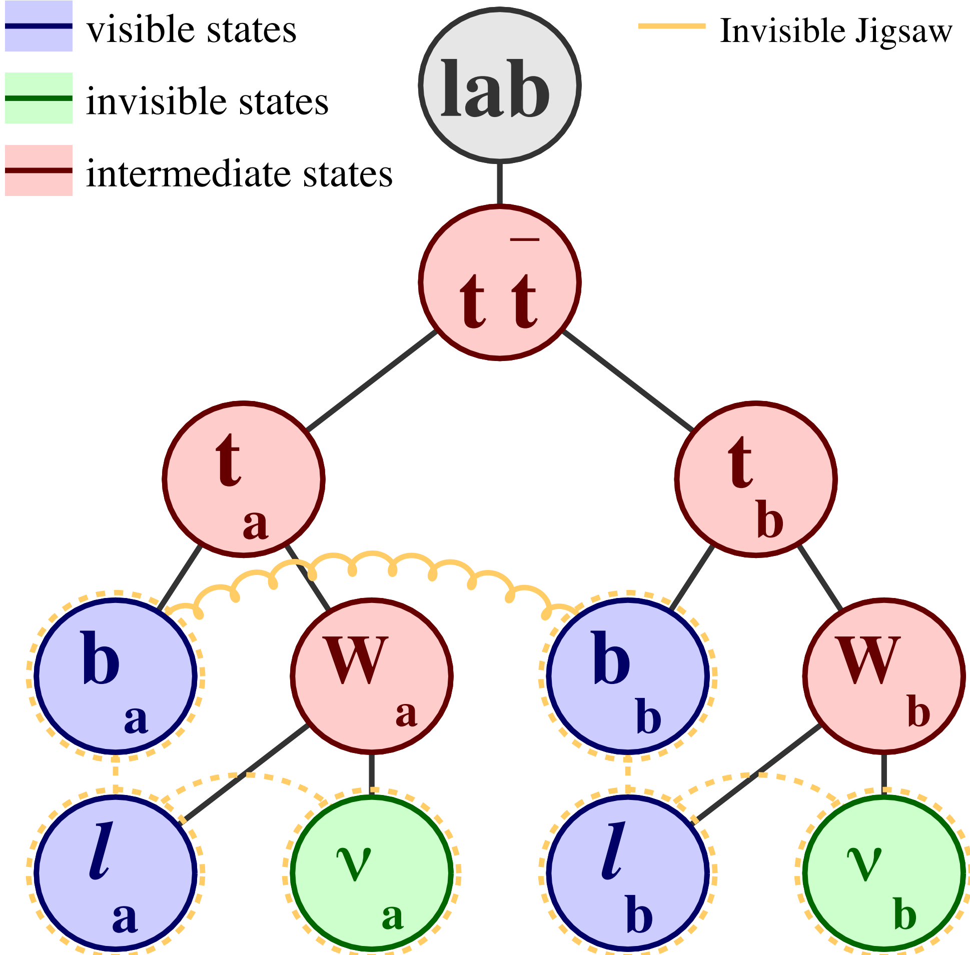
New approach to reconstructing open final states:

- The strategy is to transform observable momenta iteratively ***reference-frame to reference-frame***, traveling through each of the reference frames relevant to the topology
- At each step, ***extremize only the relevant d.o.f. related to that transformation***
- Repeat procedure recursively according to particular rules defined for each topology (the topology relevant to each reference frame)

See talk by Larry Lee on Monday for example applications of the approach


visible states
invisible states
intermediate states
Invisible Jigsaw
lab
t t̄
t a
t b
b a
W a
b b
W b
l a
ν a
l b
ν b


Invisible State Jigsaws
ν a + ν b
Invisible system mass Jigsaw
ν a + ν b
Invisible system rapidity Jigsaw
ν a + ν b
Contraboost invariant Jigsaw
ν a
ν b

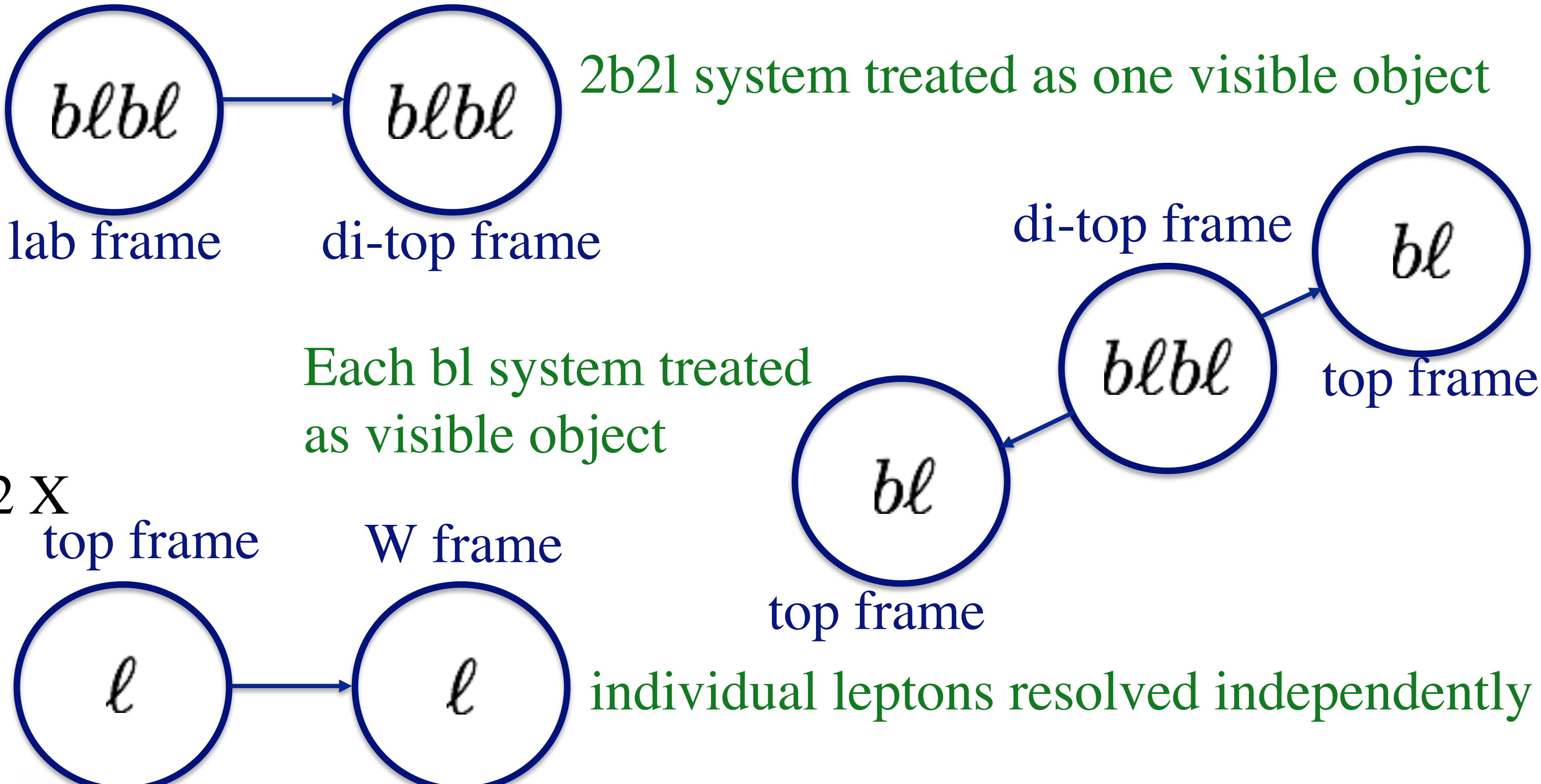


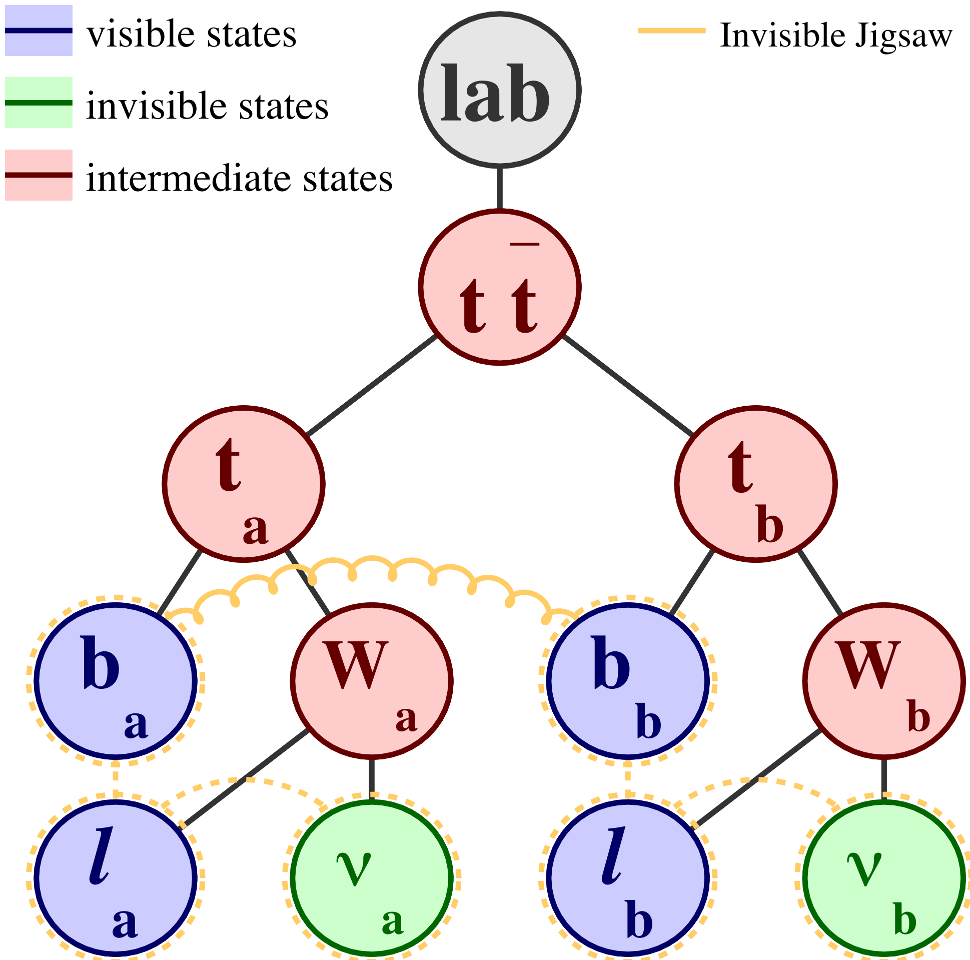
$$\sqrt{\hat{s}} \equiv 2\gamma M_t$$

$$E_b \equiv \frac{M_t^2 - M_W^2}{2M_t}$$

$$E_{\text{lep}} \equiv \frac{M_W^2 - M_\nu^2}{2M_W}$$

Move through each reference frame of interest in the event, specifying only d.o.f. relevant to each transformation:





$$M_{t\bar{t}},\ \vec{p}_{t\bar{t}}, \cos\theta_{TT}$$

$$\Delta\phi_{T1,T2}$$

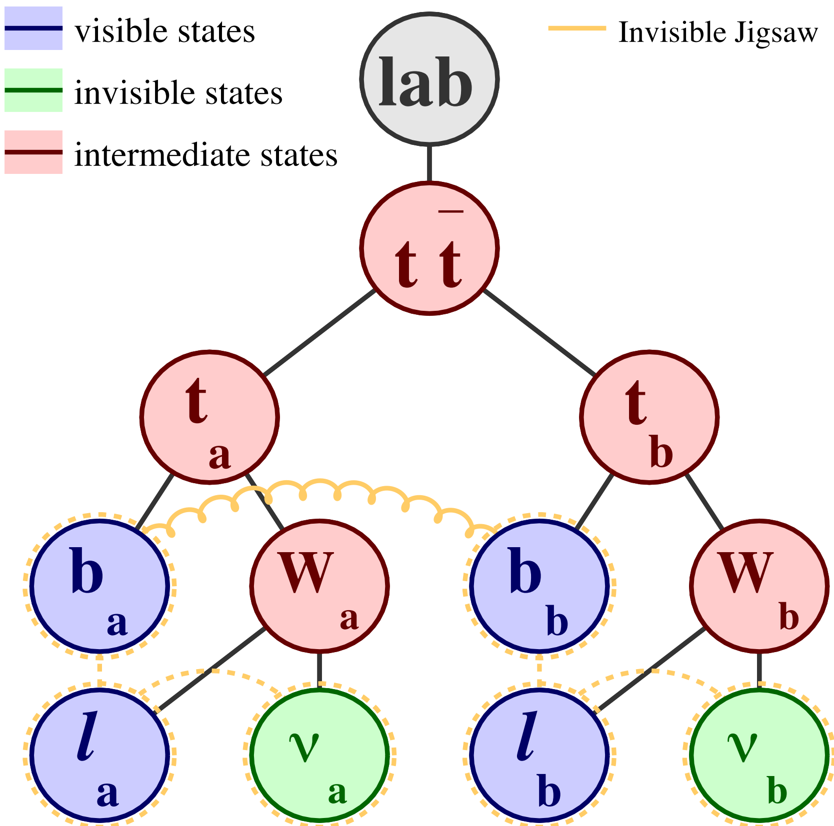
2 X

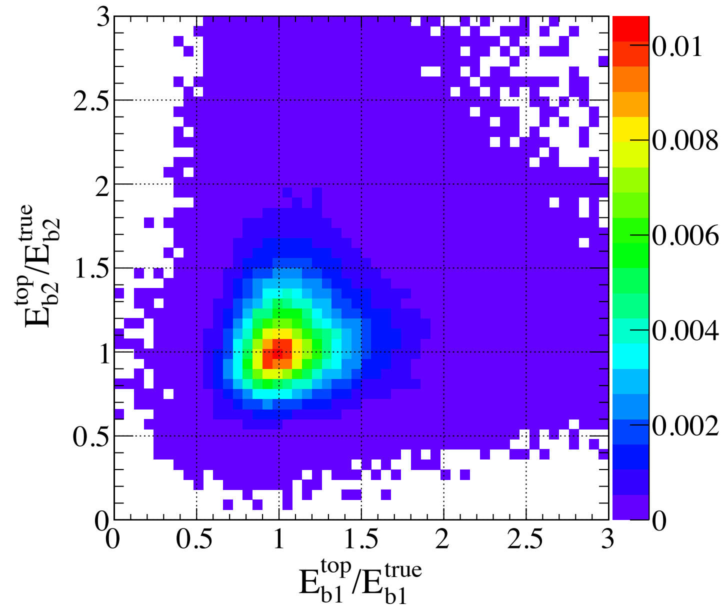
$$E_b^{\mathrm{top-frame}}, \cos\theta_T$$

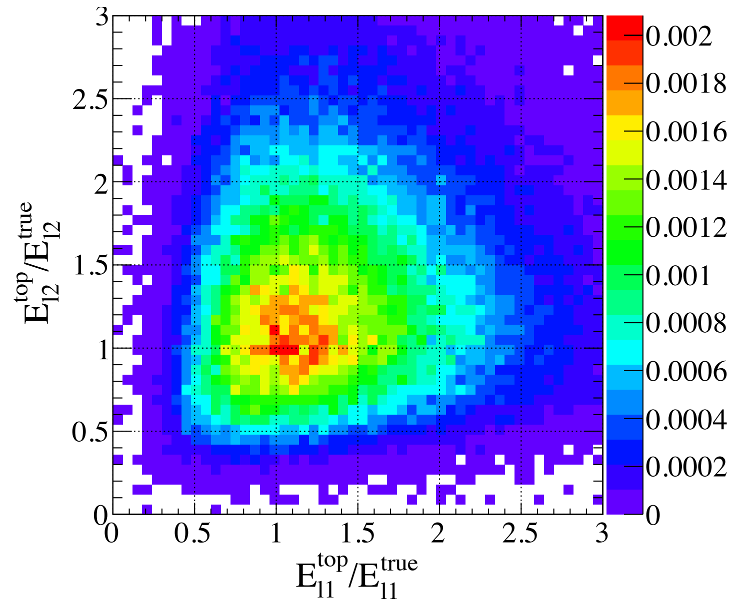
$$\Delta\phi_{T,W}$$

$$E_\ell^{\mathrm{W-frame}}, \cos\theta_W$$

The Recursive Jigsaw Reconstruction

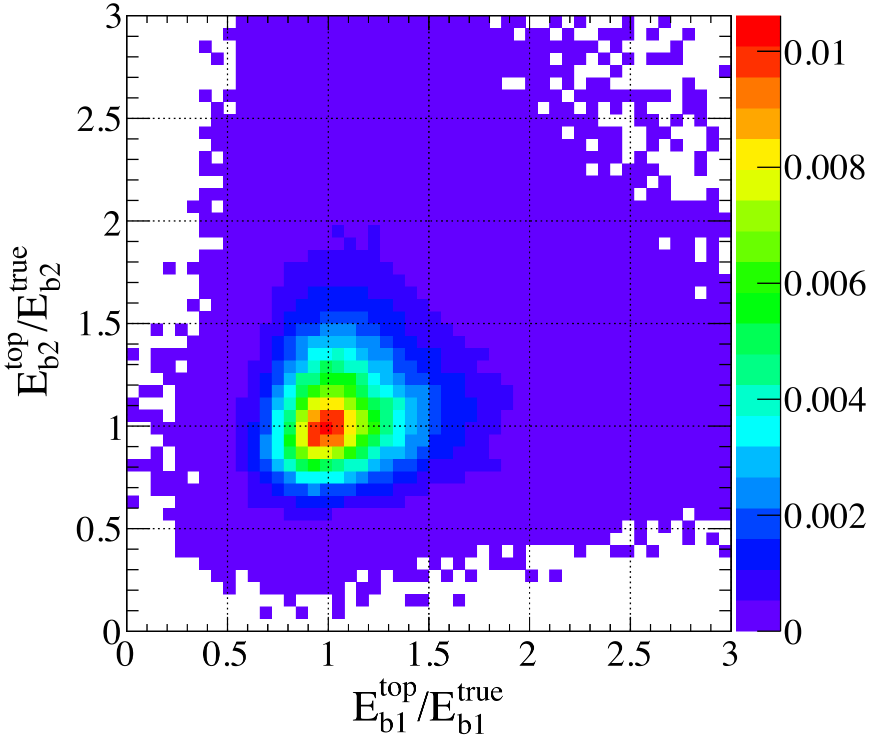


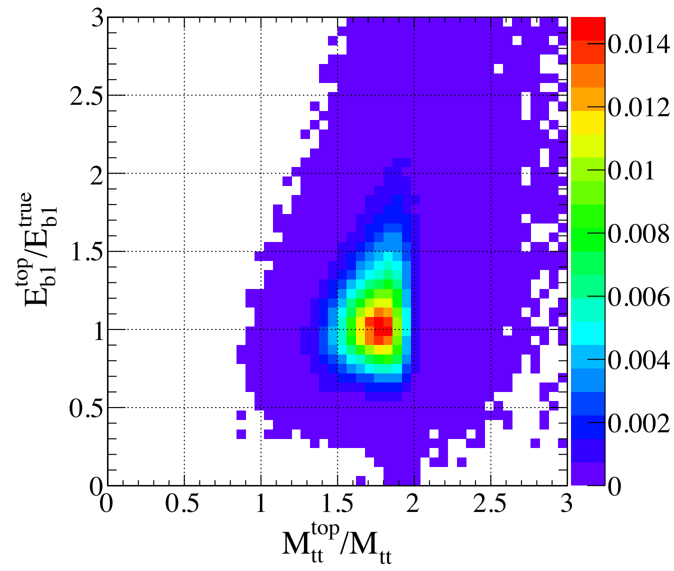




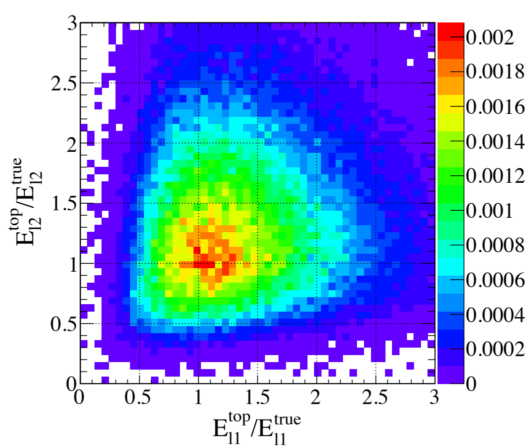
The scales can be extracted ~independently

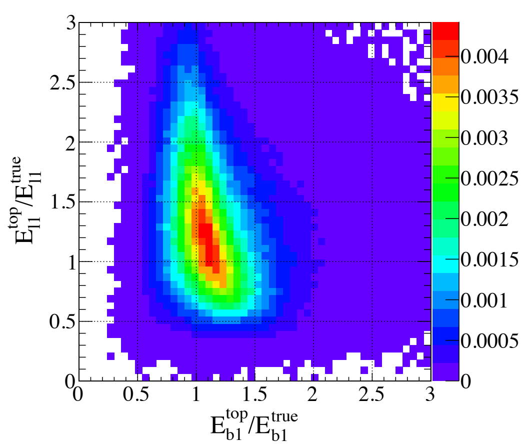
The dileptonic top basis

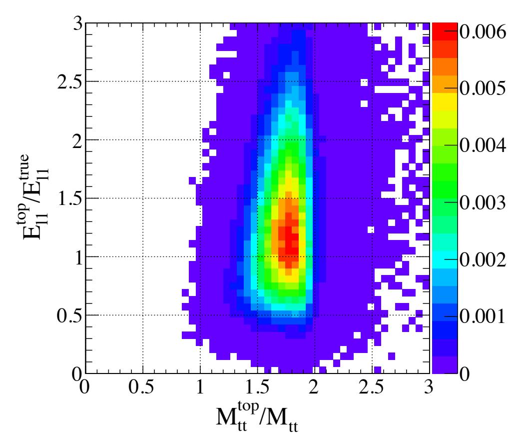




largely independent information about five different masses

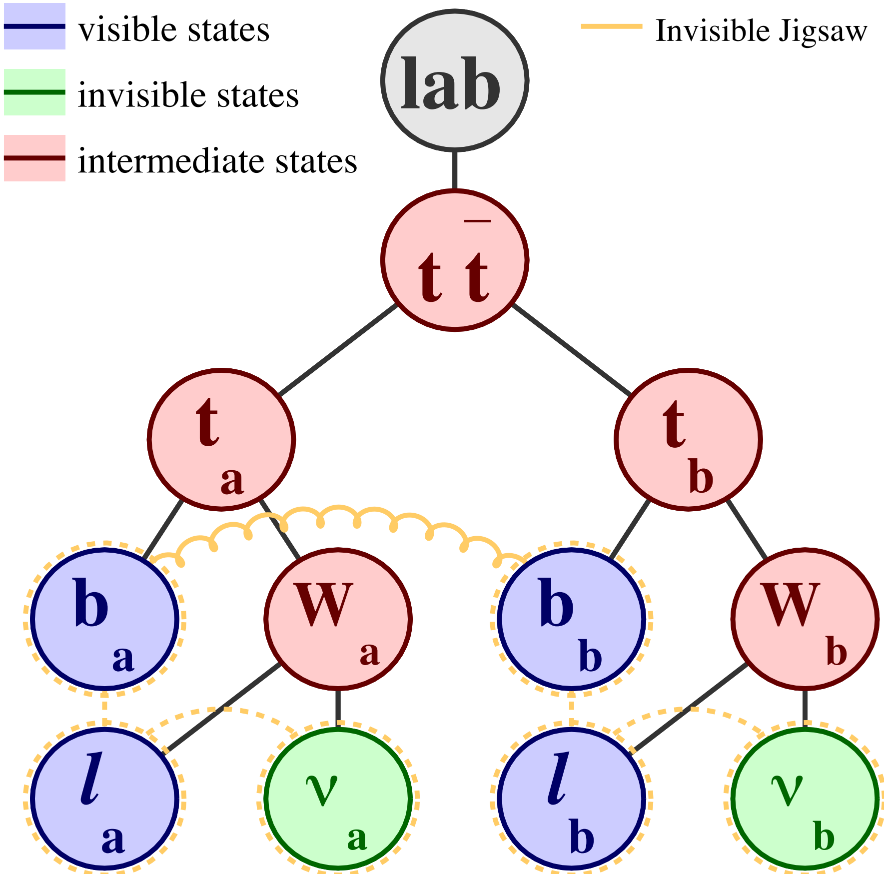


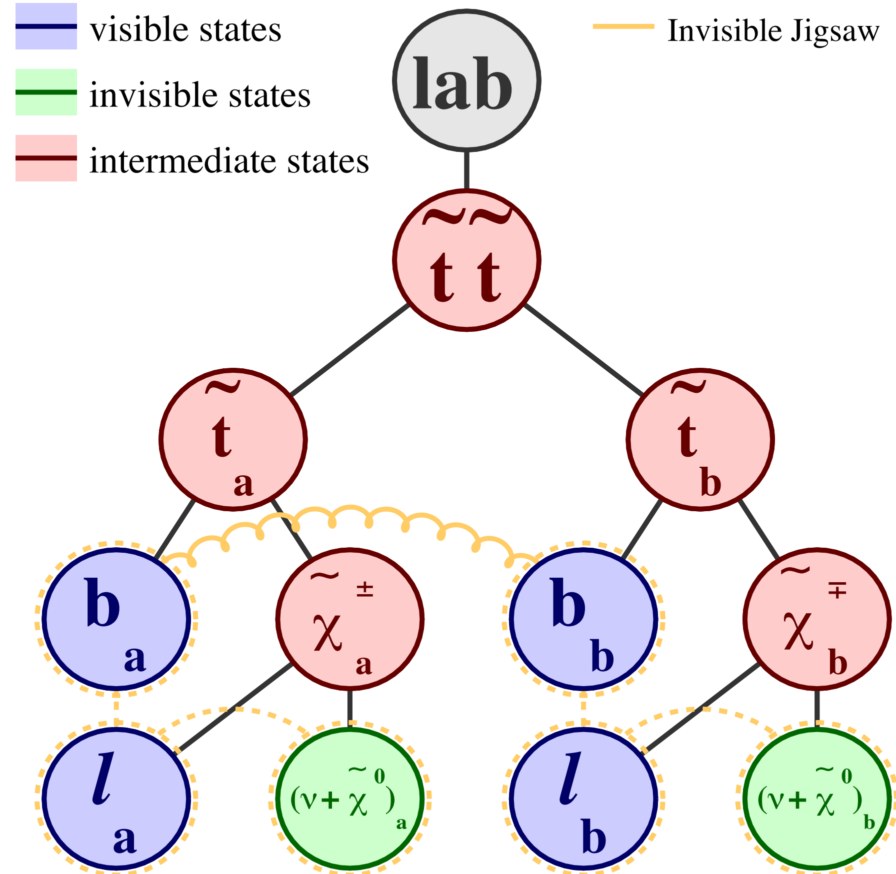




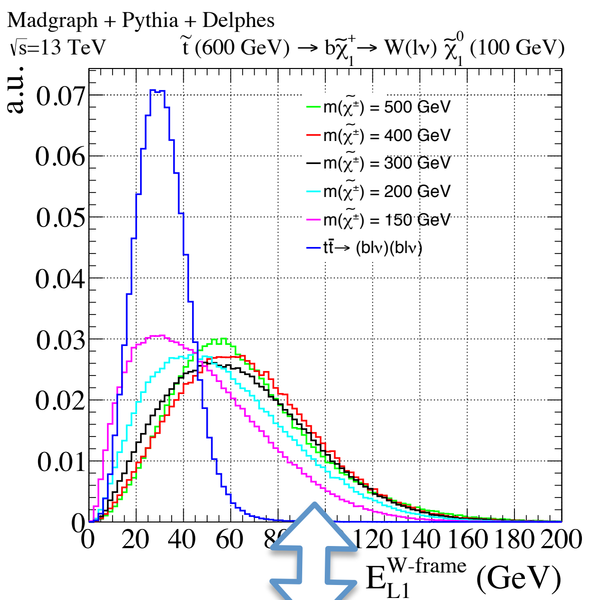
The di-leptonic top basis vs Stops

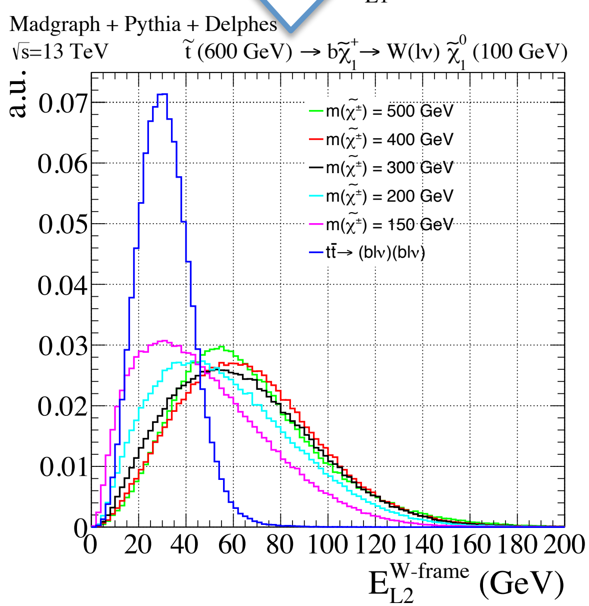
SUSY stops decaying through charginos

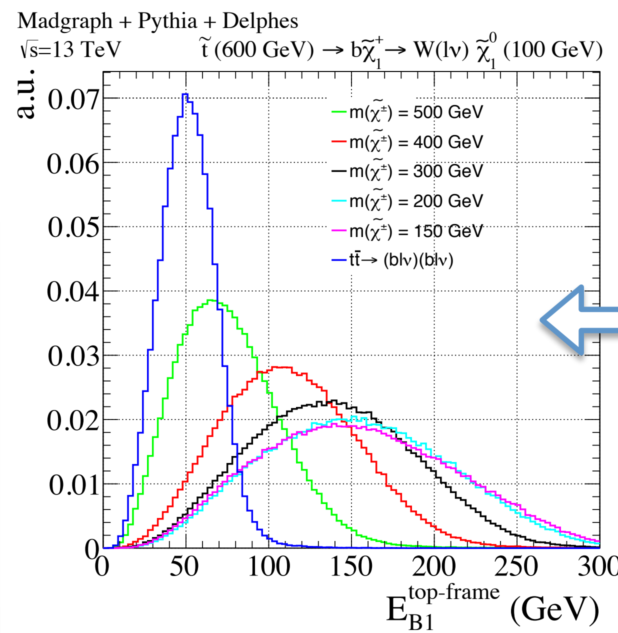


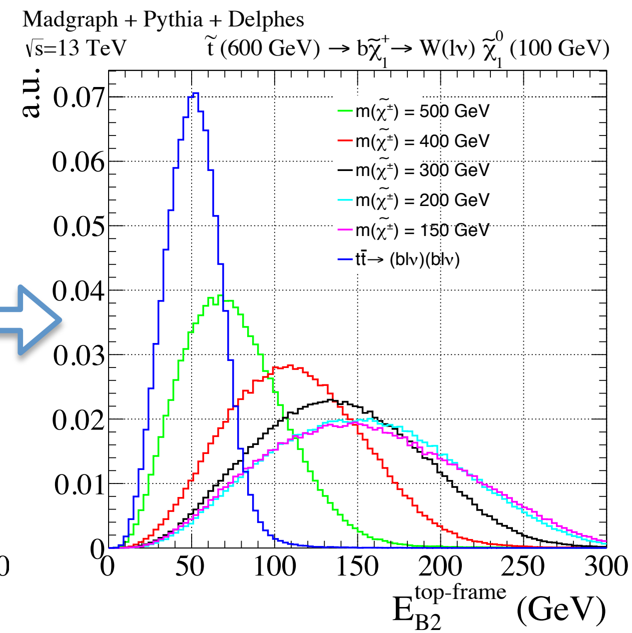


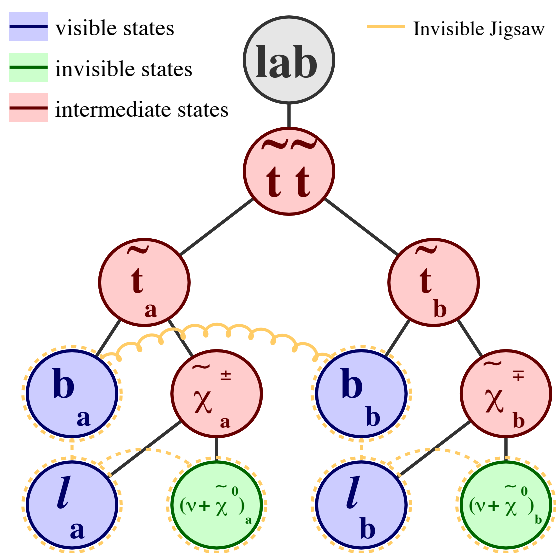
The di-leptonic top basis vs Stops







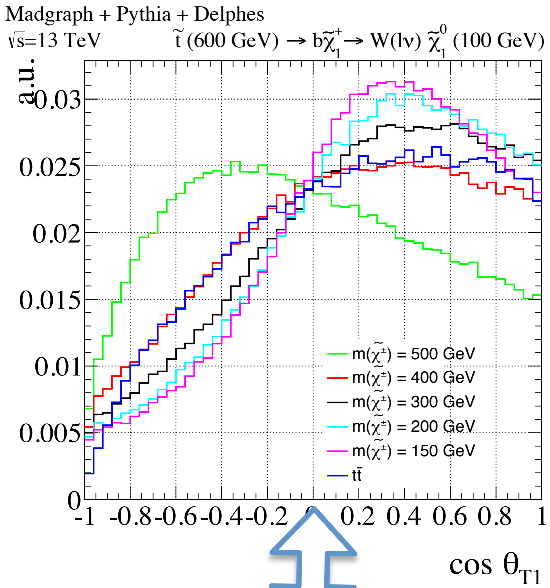


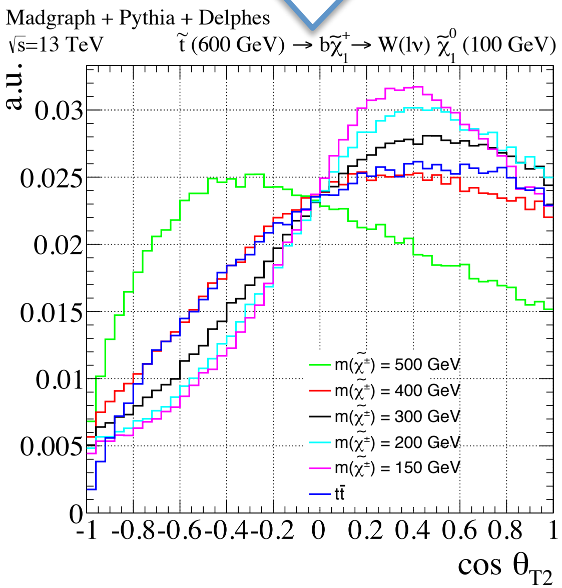


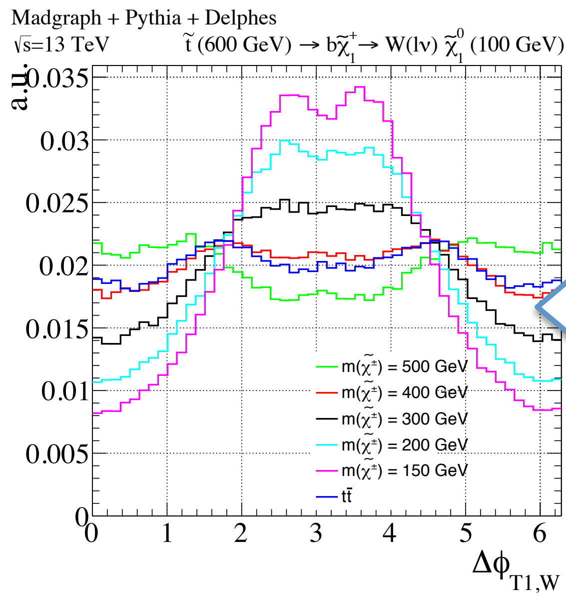
Mass-splitting-sensitive observables can be used to distinguish presence of signals.

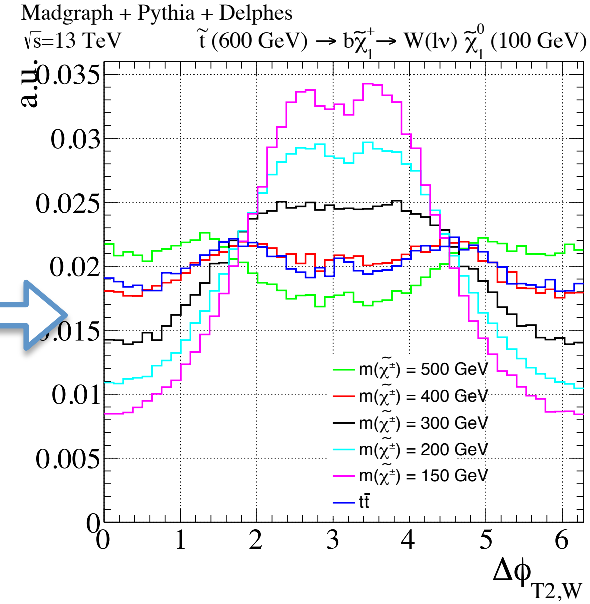
With a variable for each hemisphere and for each mass splitting

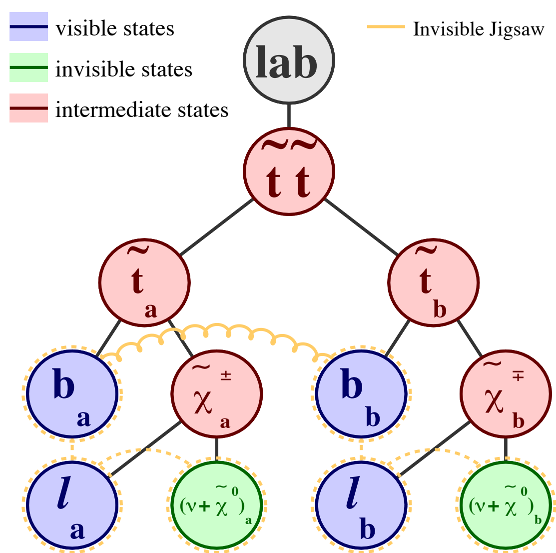
The di-leptonic top basis vs Stops







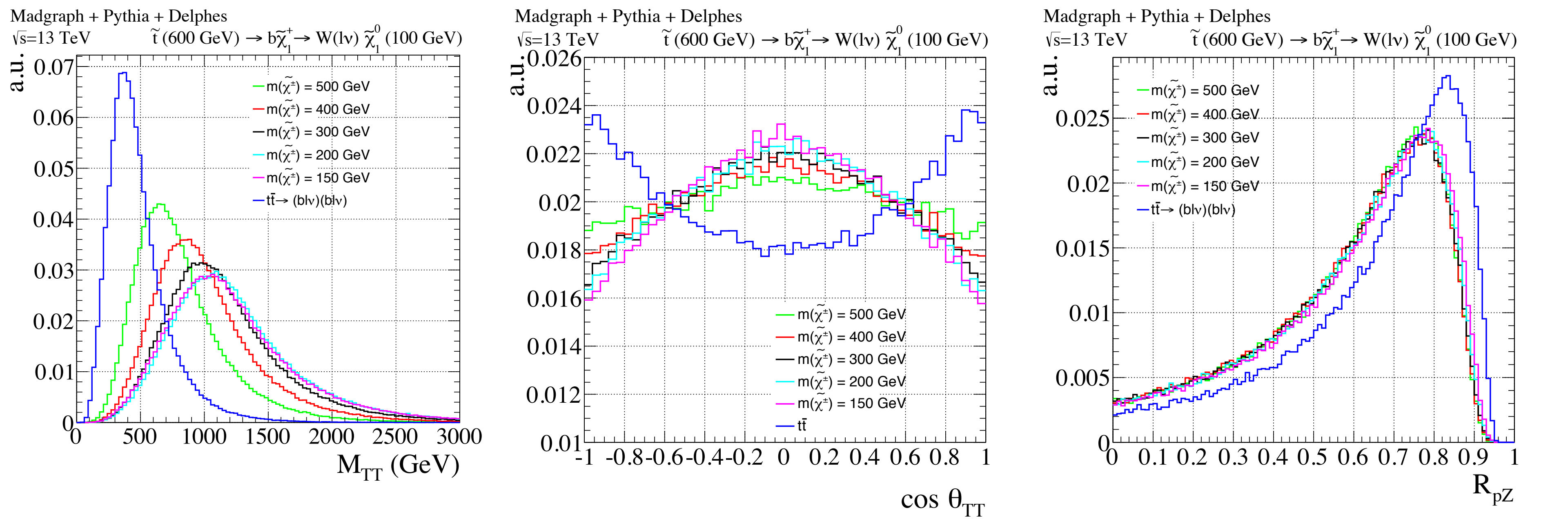




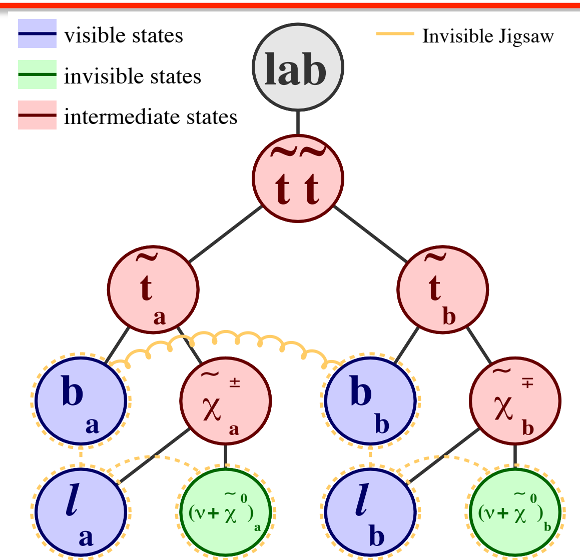
Angular observables can be sensitive to mass-splitting and properties

With variables for each hemisphere

The di-leptonic top basis vs Stops

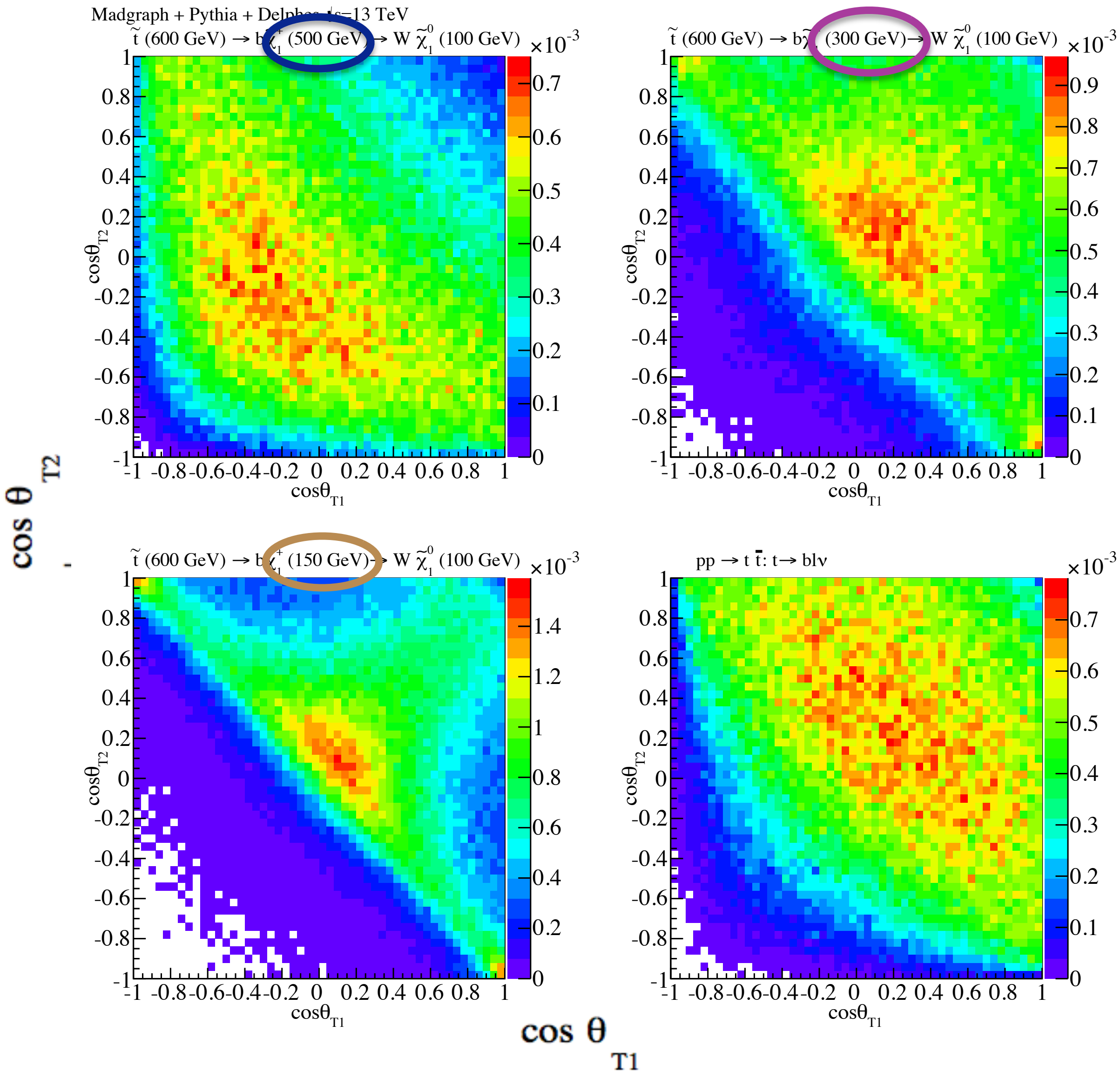


$M_{TT}, cos\theta_{TT},$



Decay angles are also sensitive to differences between stop signals and ttbar background

The di-leptonic top basis vs Stops

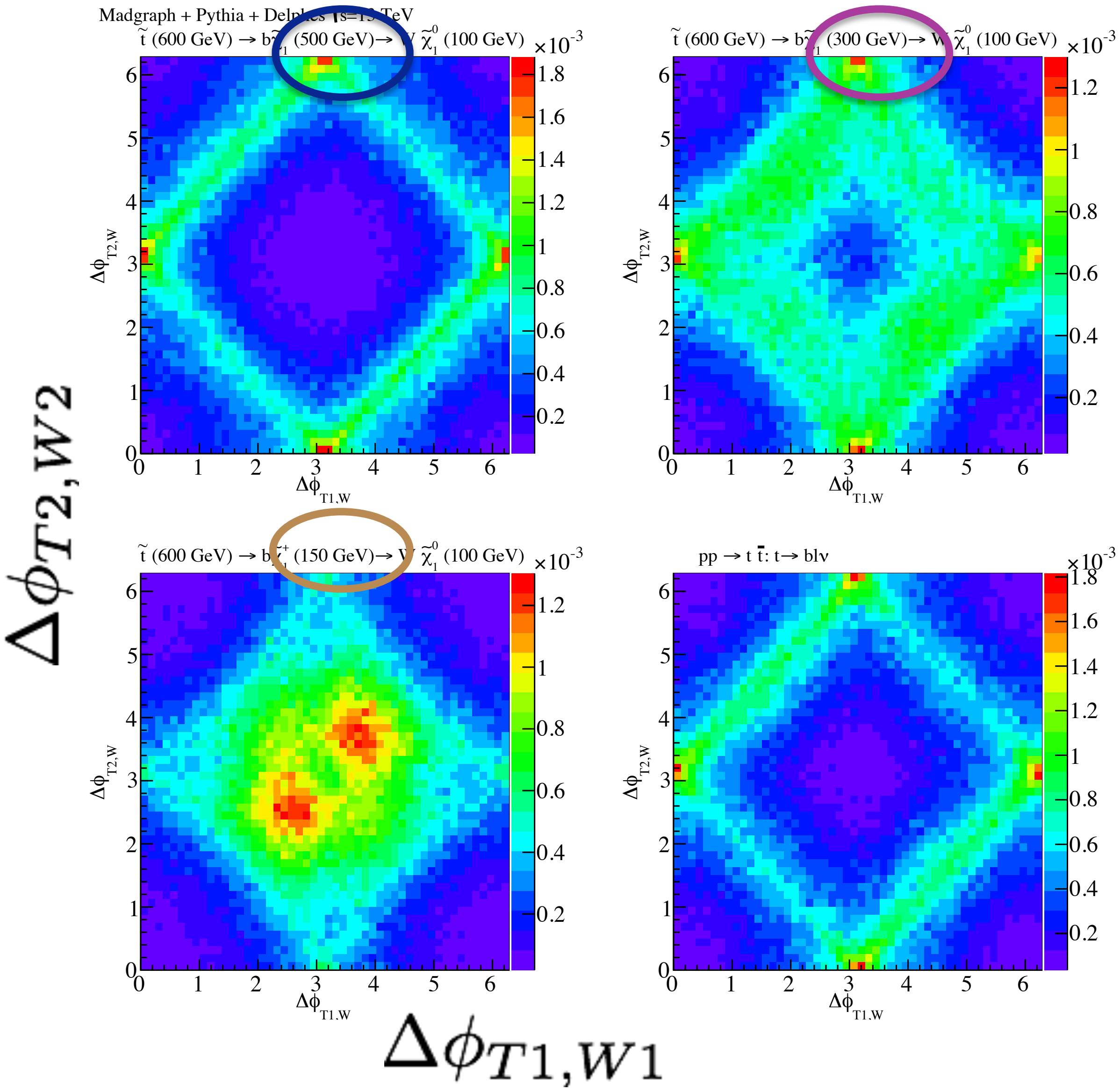


$$m_{\tilde{t}_1} = 600 \text{ GeV}$$

$$m_{\tilde{\chi}^\pm} = \begin{matrix} 500 \\ 300 \\ 150 \end{matrix} \text{ GeV}$$

$$m_{\tilde{\chi}_1^0} = 100 \text{ GeV}$$

Decay angles are sensitive to differences in stop signals and ttbar background



$$m_{\tilde{t}_1} = 600 \text{ GeV}$$

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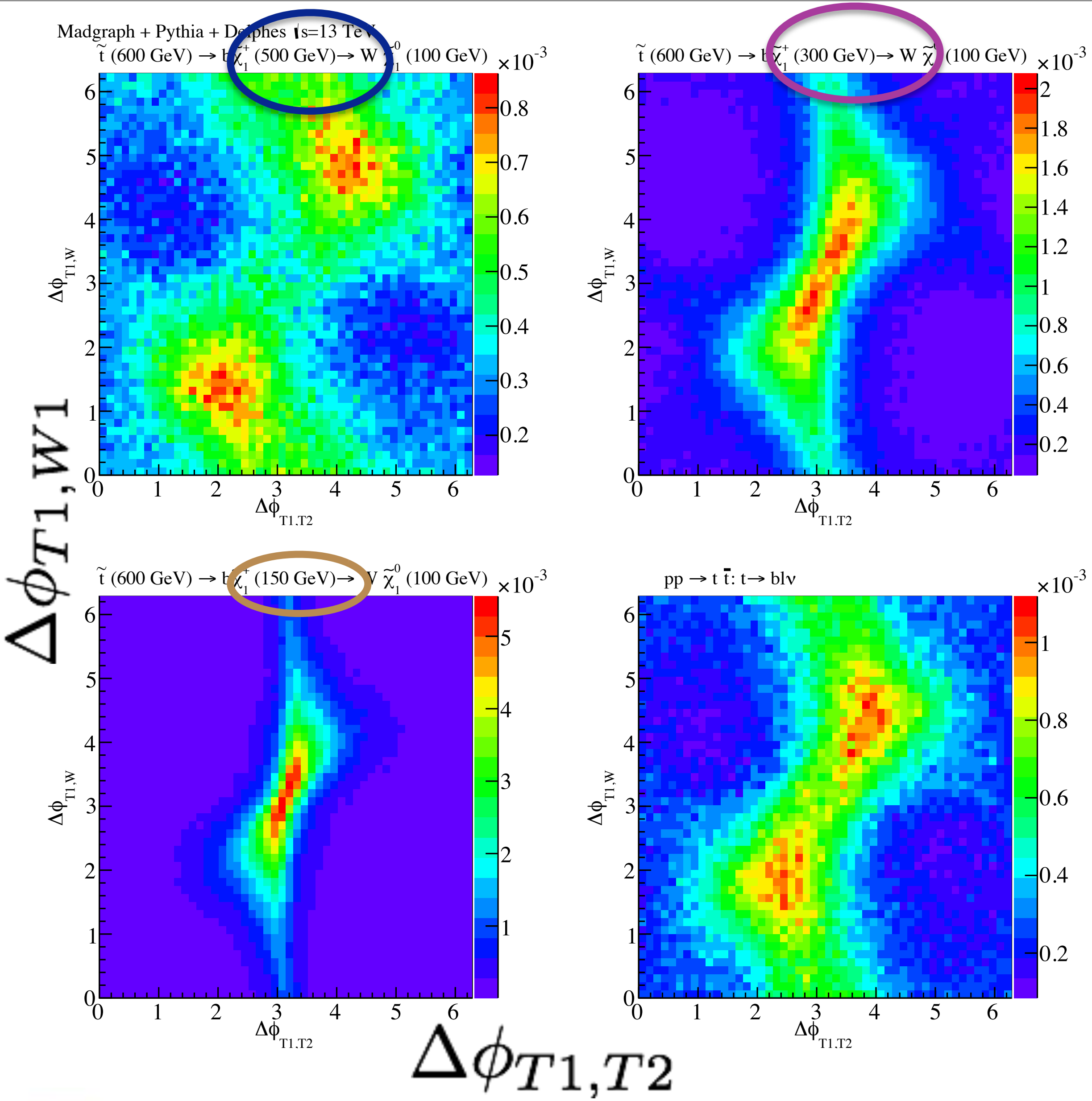
The azimuthal angle between the the top and W decay planes from each hemisphere

The di-leptonic top basis vs Stops



$$m_{\tilde{t}_1} = 600 \text{ GeV}$$

$$m_{\tilde{\chi}^\pm} = \begin{matrix} 500 \\ 300 \\ 150 \end{matrix} \text{ GeV}$$

$$m_{\tilde{\chi}_1^0} = 100 \text{ GeV}$$

The azimuthal angle between the the top and W decay planes and the angle between the two top decay planes

Recursive Jigsaw Reconstruction – in practice

To study the tractability of applying this approach to an analysis at the LHC we studied samples generated as part of the Snowmass study in mid/late 2013

They comprise samples of all major Standard Model backgrounds, simulated at 14TeV (see arXiv:1308.1636 and 1309.1057 for details) with additional jets. All samples are generated/simulated using Madgraph+Pythia+Delphes

To compare, signal samples studied at 14TeV (same version of MG5, Pythia and Delphes)

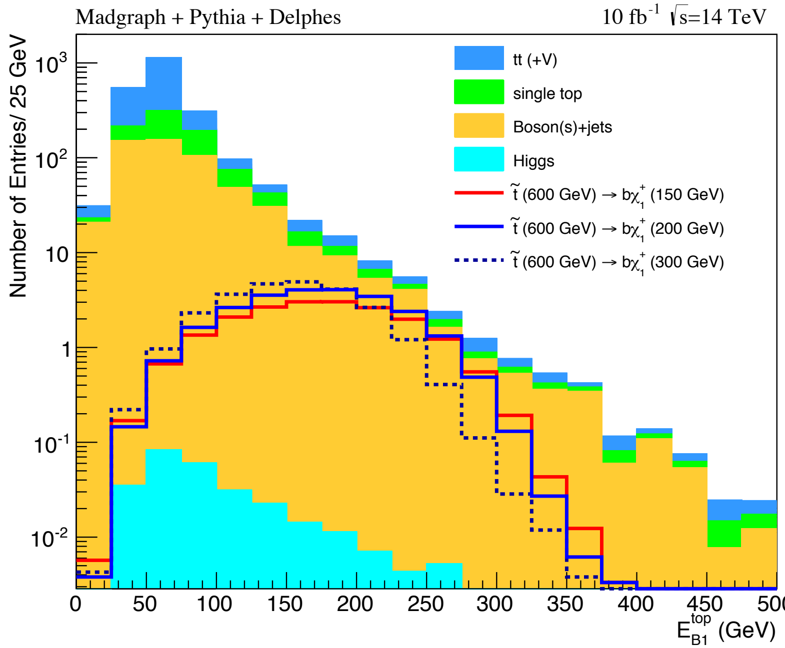
Touch on only three signal topologies based on the size of the mass splittings:

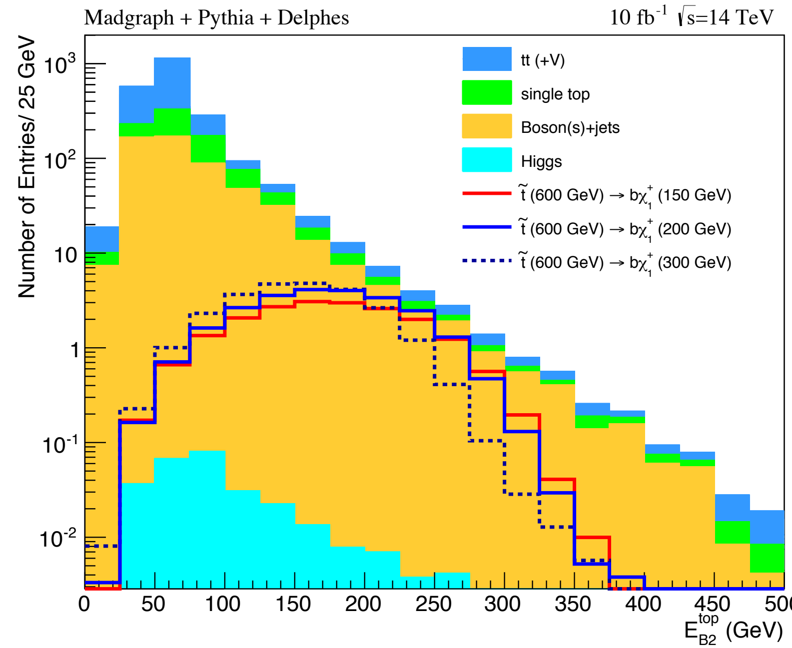
- Fix two masses-> m(stop)=600GeV and m(neutralino)=100GeV
- Vary one -> m(chargino) = 300GeV, 200GeV, 150GeV

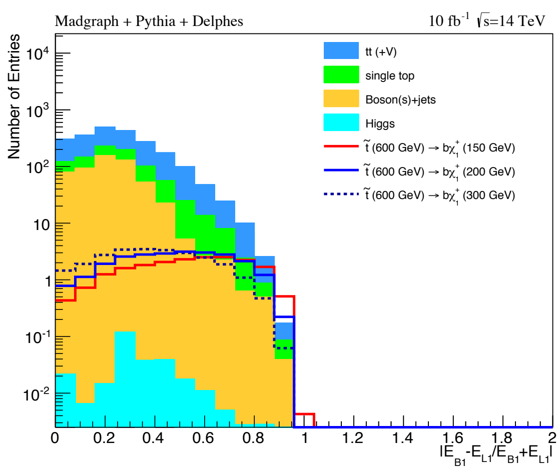
In each case the Recursive Jigsaw reconstruction is applied to calculate the variable basis and we plot the normalised distributions to study the shapes and yields.

All samples are scaled to a projection of 10 fb^{-1}

The Recursive Jigsaw Reconstruction







To target the case with a large first mass splitting we can cut on the difference in scale between the first and second mass splitting sensitive variables

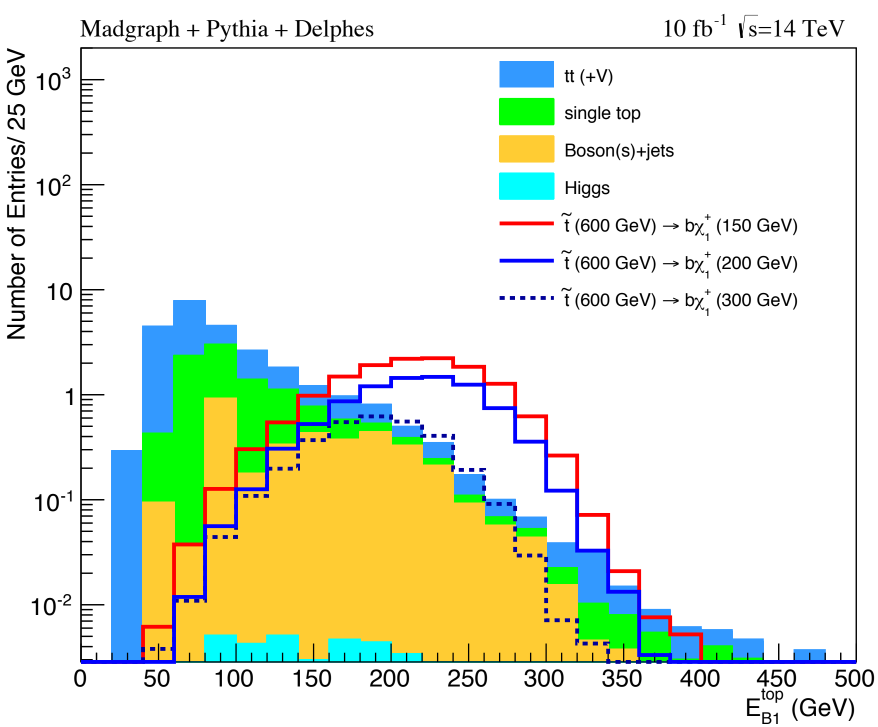
n.b. There is another copy of this

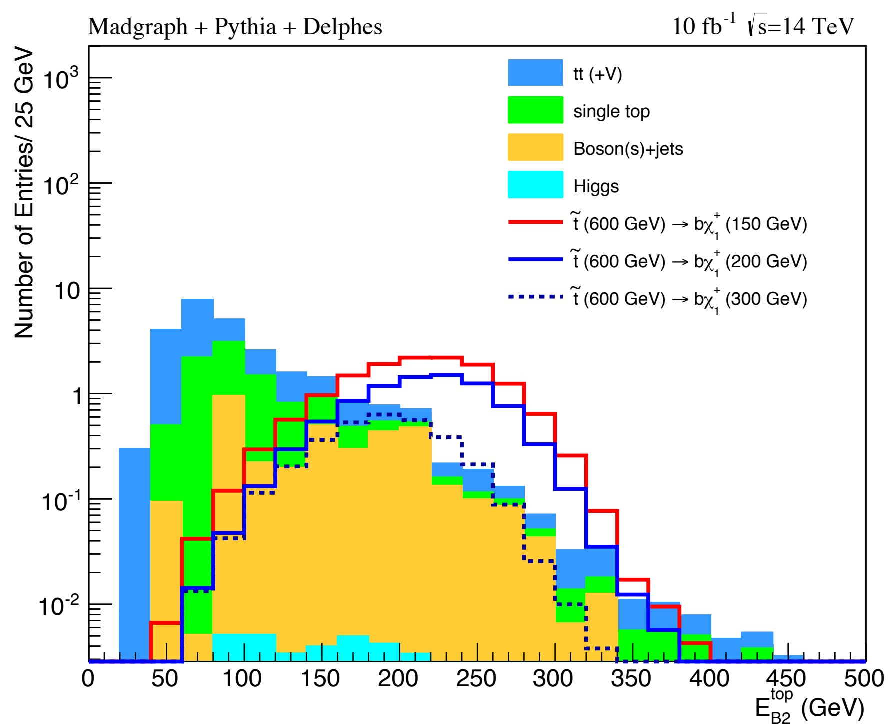
Two-dimensional peak at characteristic mass scale

Apply some simple selection criteria:

Jet_pt1(2)>60GeV && Lep_pt1(2)>12GeV && 2 b-tagged jets

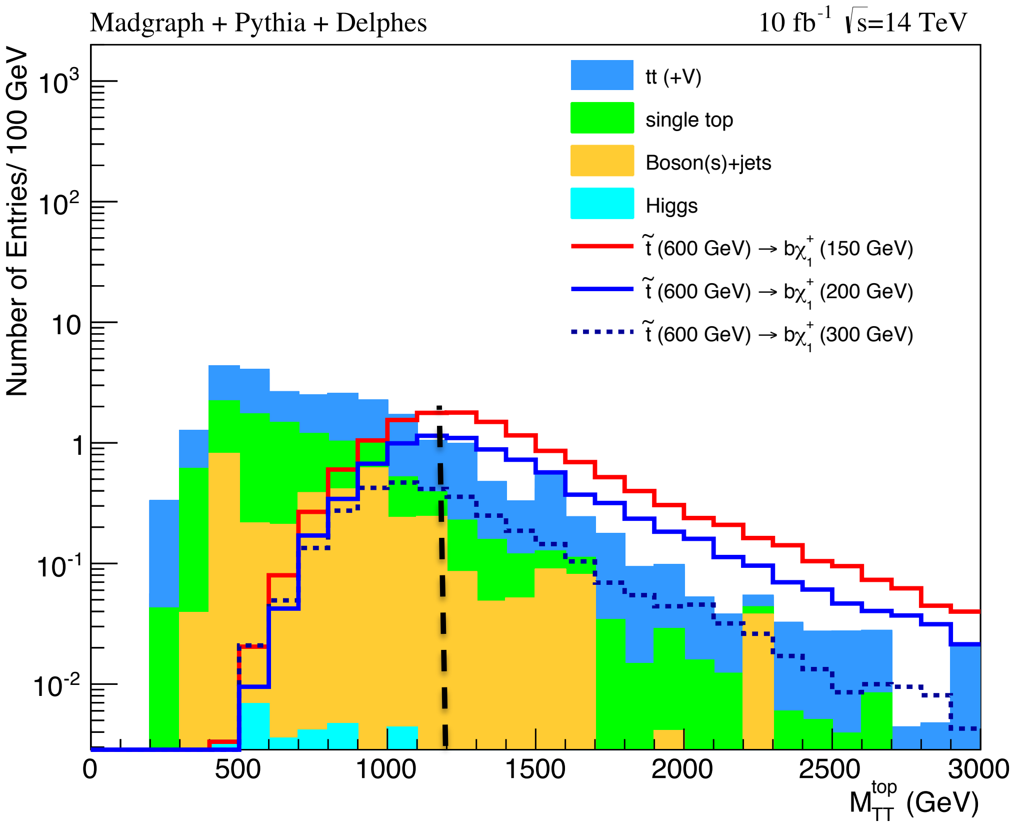
$E_{b1(2)} - E_{L1(2)}/E_{b1(2)} + E_{L1(2)} > 0.55$



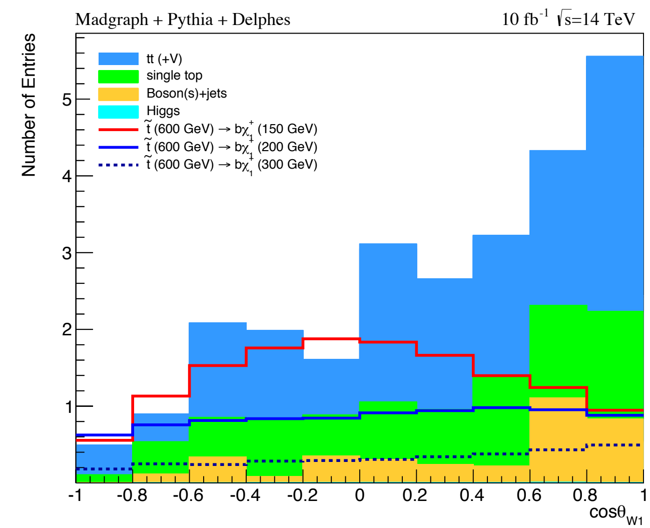


The Recursive Jigsaw Reconstruction

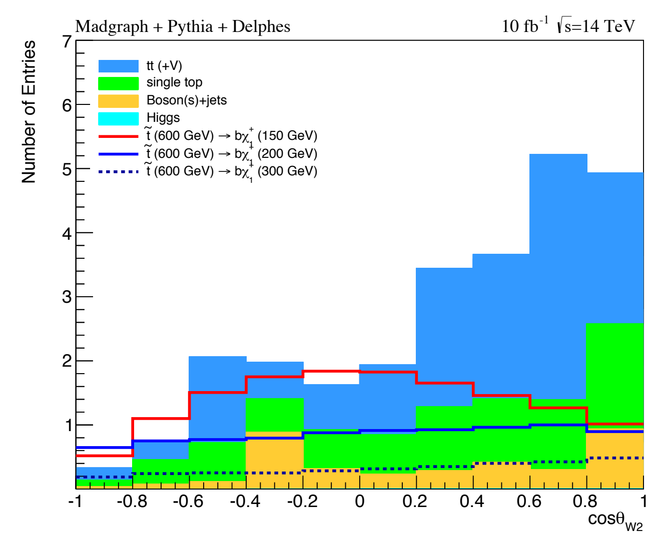
There are still variables we haven't touched….



Overall mass scale peaks at roughly di-gluino mass



Decay angles from each hemisphere differ in shape to backgrounds



- The strategy is to not only develop ‘good’ mass estimator variables, but to decompose each event into a ***basis of kinematic variables***
- Through the recursive procedure, each variable is (as much as possible***) independent of the others***
- The interpretation of variables is straightforward; they each correspond to an ***actual, well-defined, quantity in the event***
- For more complicated topologies (like di-leptonic top) the two hemispheres are ***largely decoupled***, i.e., ***the decay chains can be reconstructed independently*** → no need to assume/require symmetry between the heavy particle decays (appealing method to interrogate mixed decays)
- Work to be summarised in forthcoming papers

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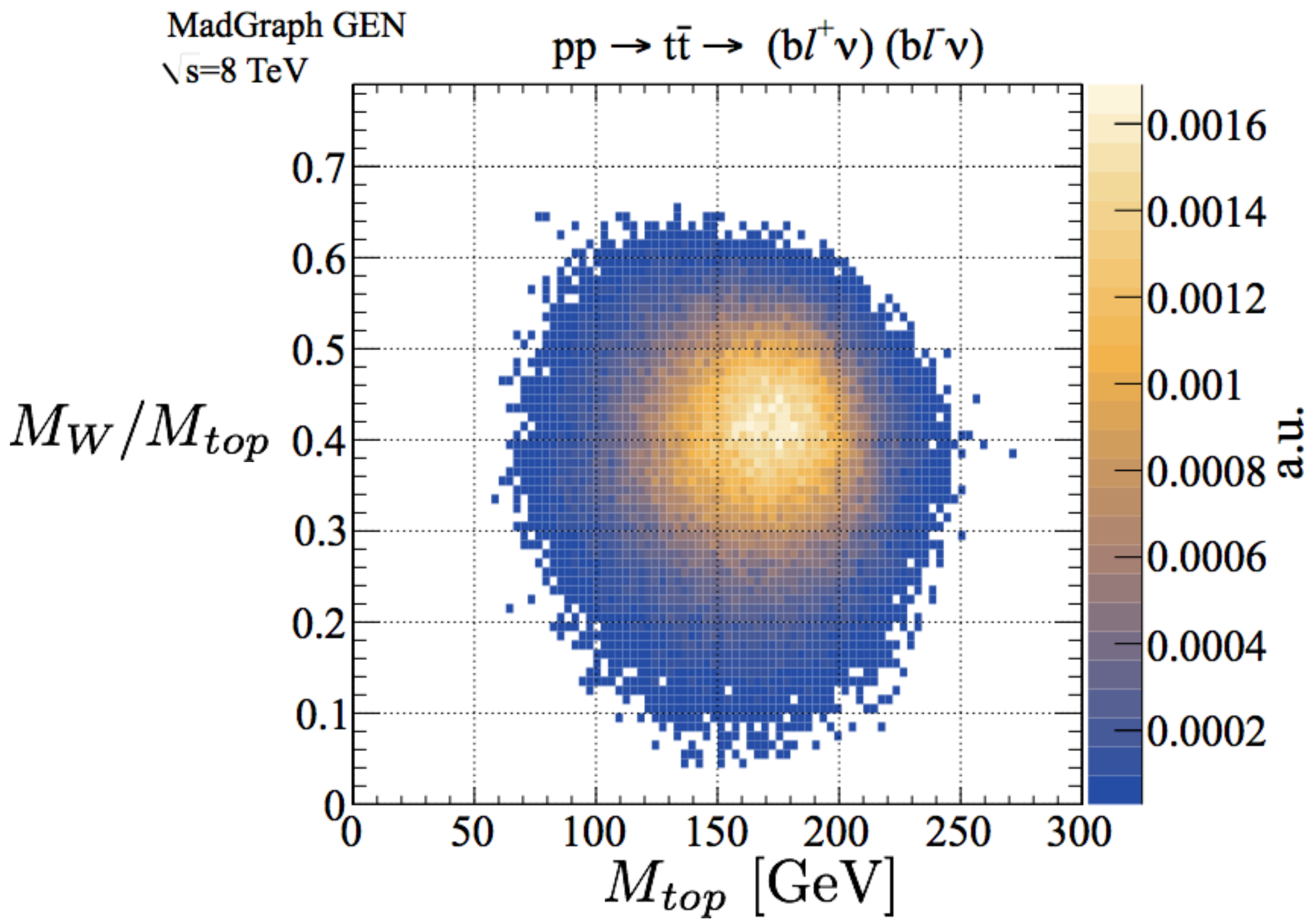
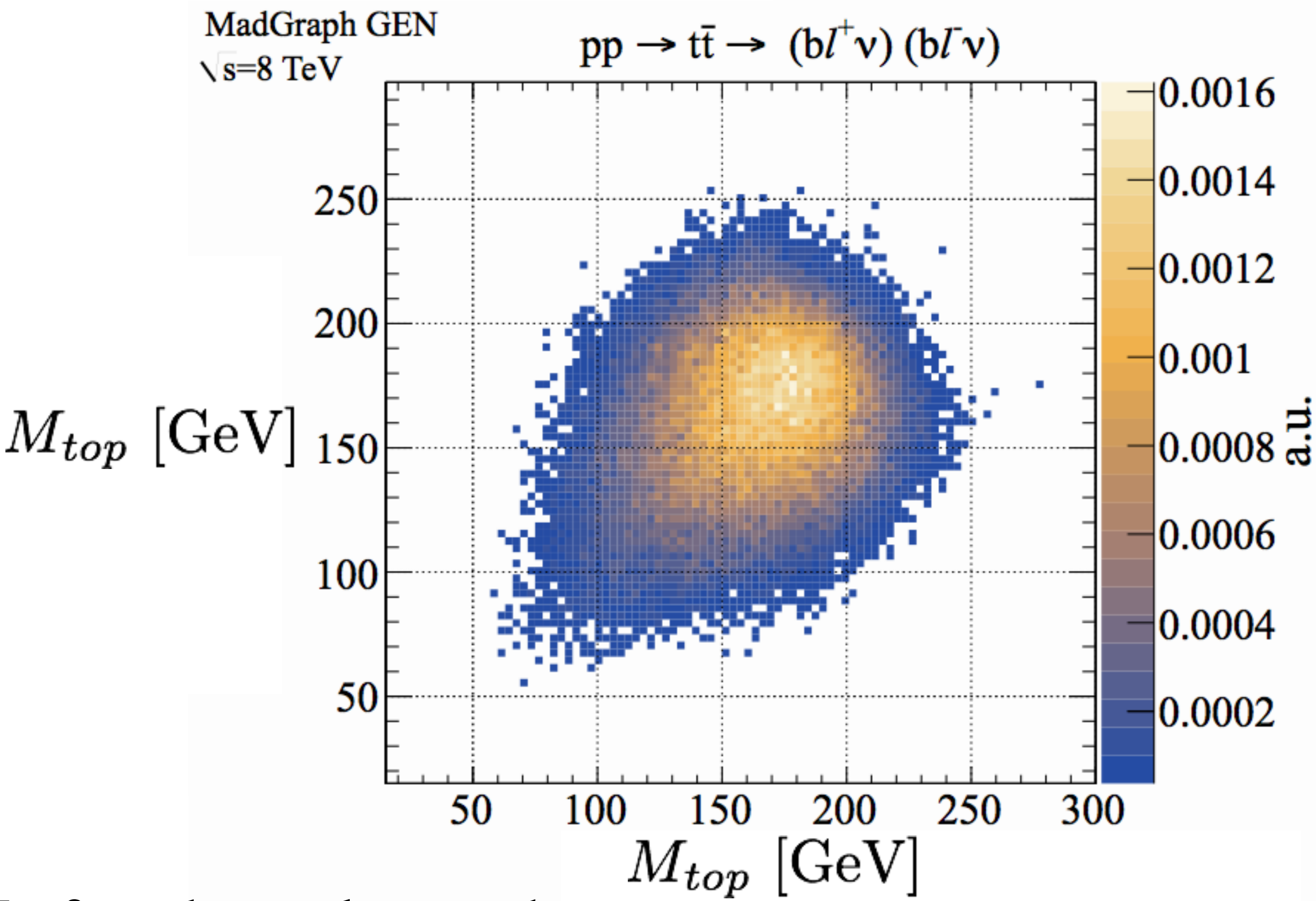
The Recursive Jigsaw Reconstruction



The scales can be extracted independently

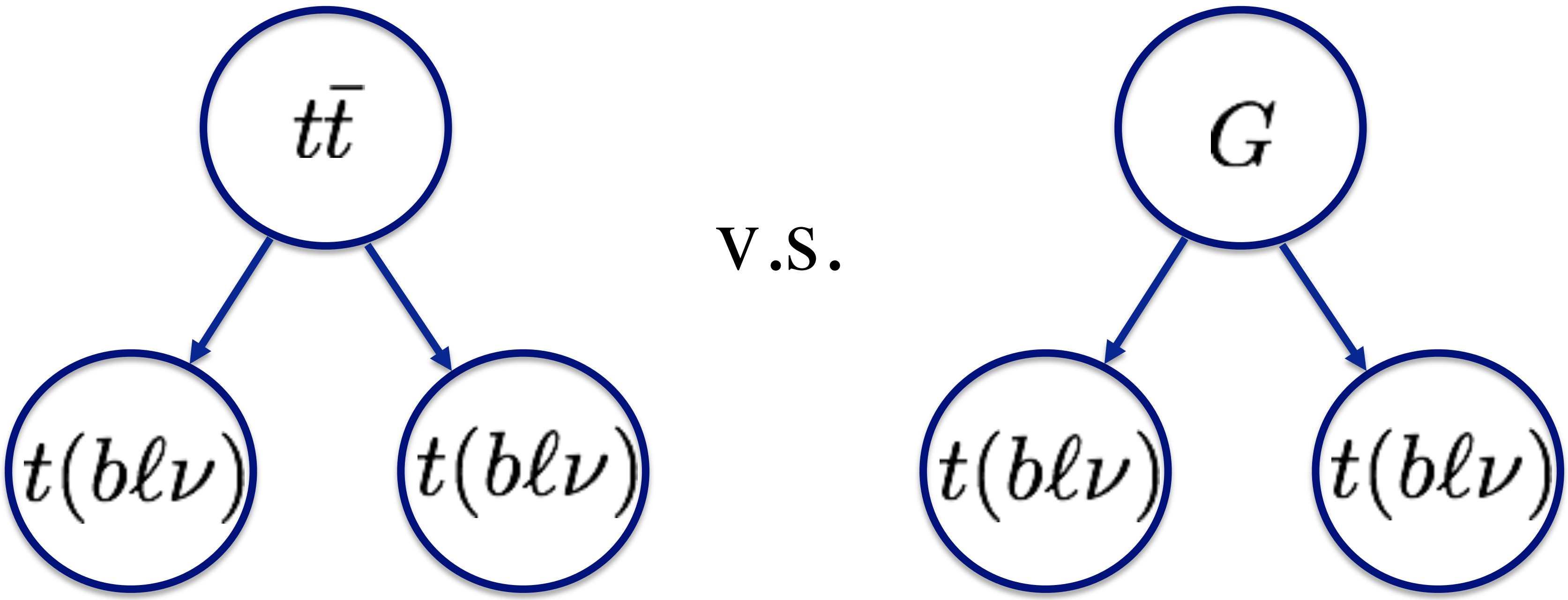
The Recursive Jigsaw Reconstruction



In fact the scales can be extracted independently for each top – the reconstruction chains are ***decoupled***

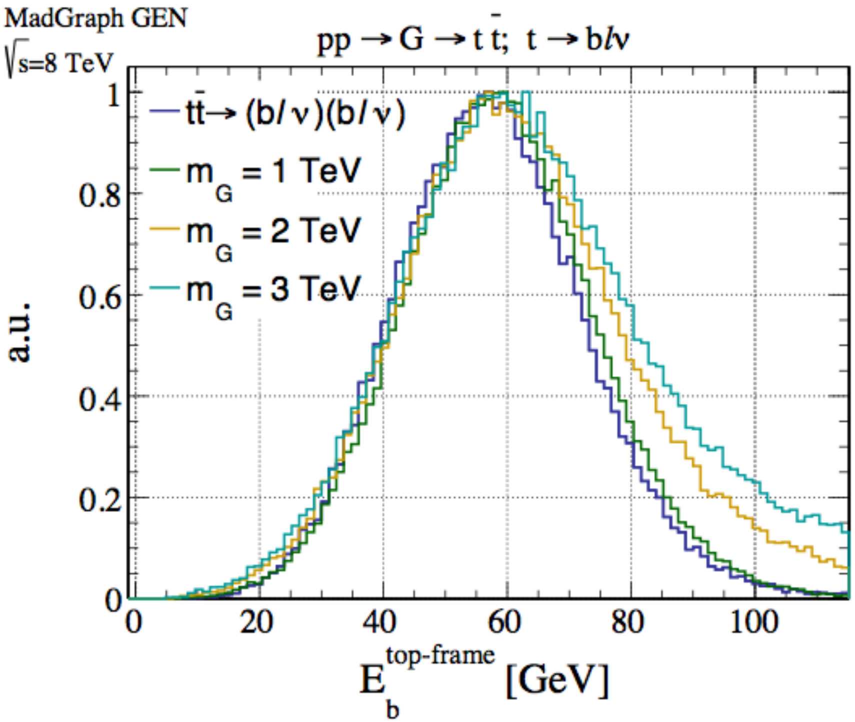
Resonance decaying to dileptonic top

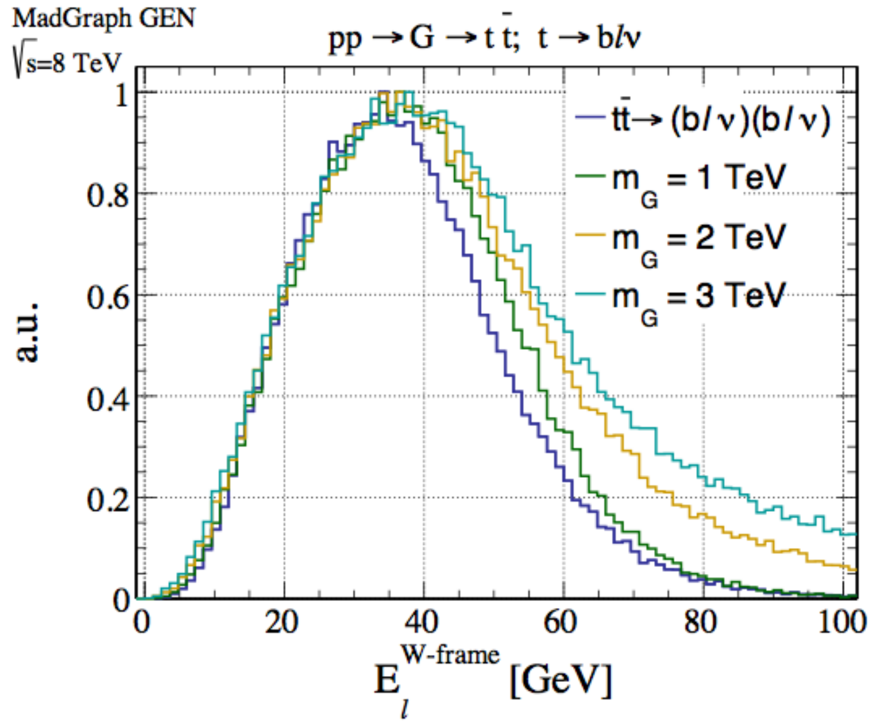
Different variables in the basis are useful for different signals



First, we consider resonant ttbar production through a graviton

Different variables in the basis are useful for different signals

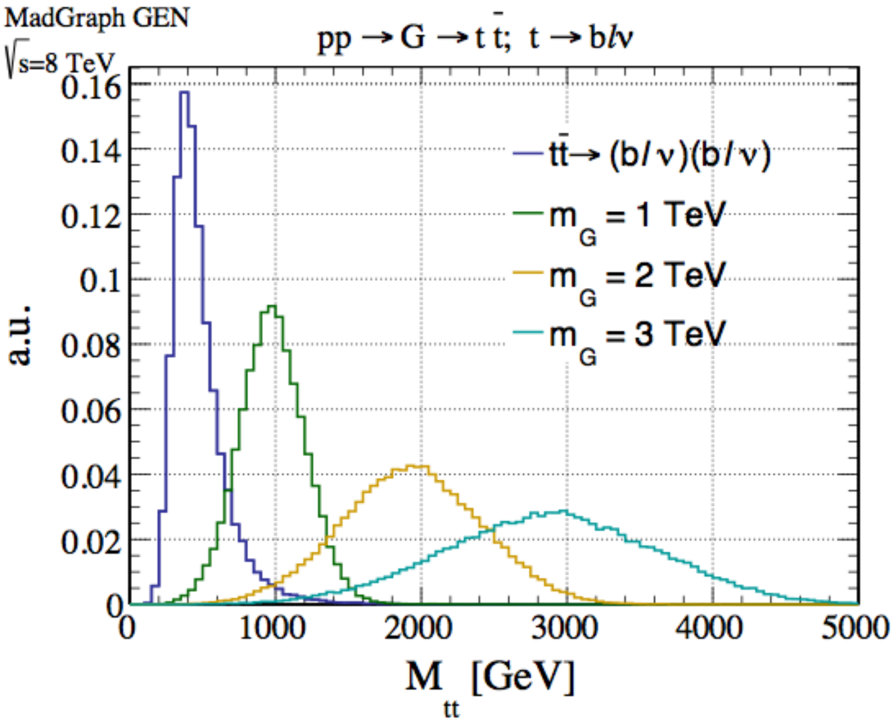


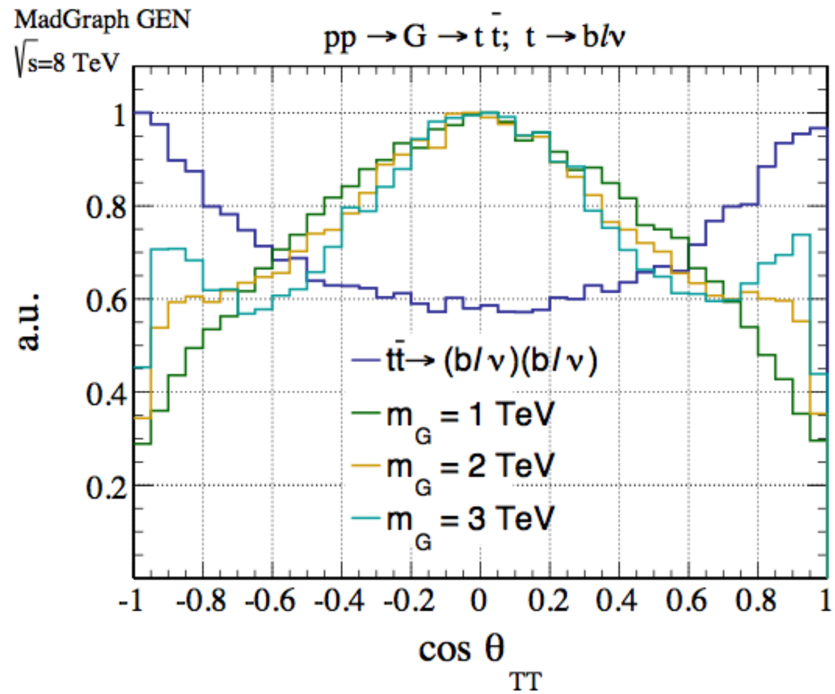


distributions of top/W/neutrino mass-splitting-sensitive observables are nearly identical since graviton signal and non-resonant background both contain on-shell tops

The di-leptonic top basis vs Gravitons

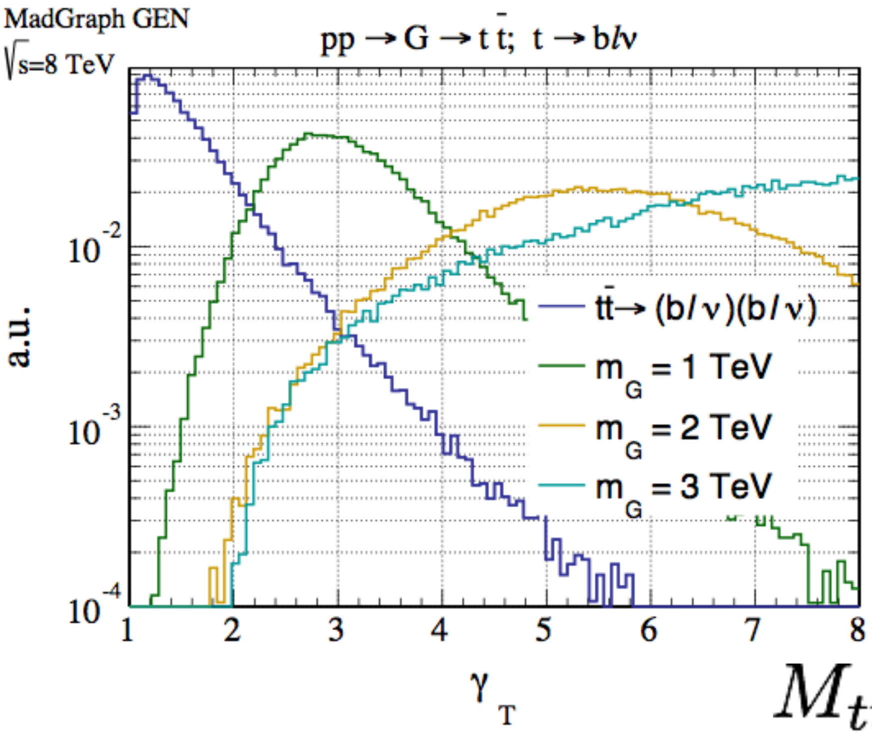
Different variables in the basis are useful for different signals

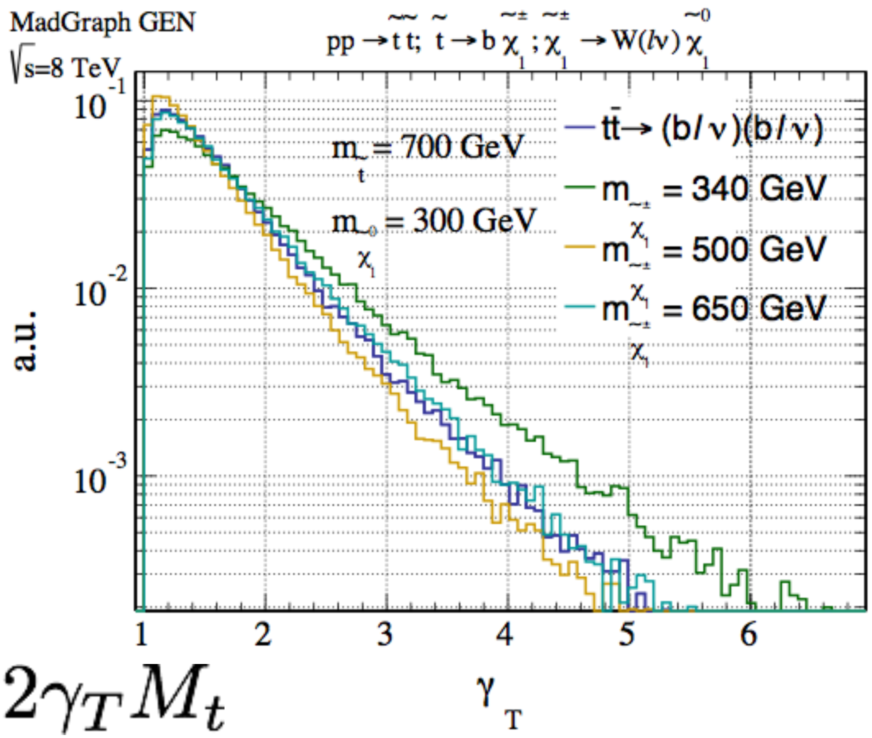




Instead, observables related to the production of the two tops are sensitive to the intermediate resonance

The di-leptonic top basis vs Stops

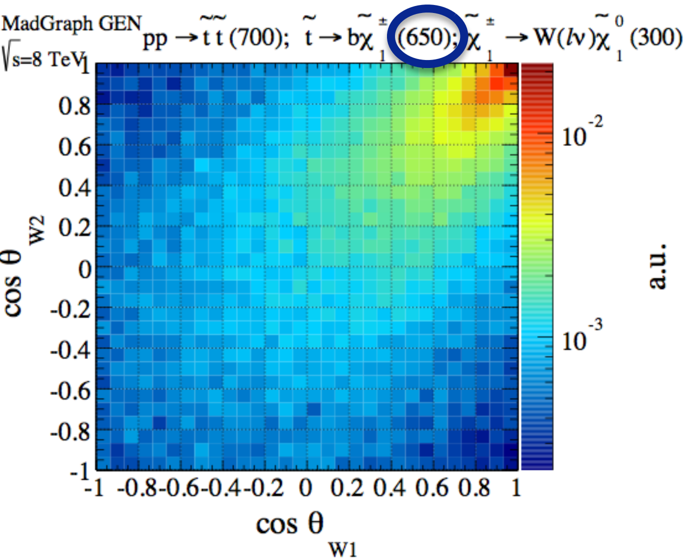


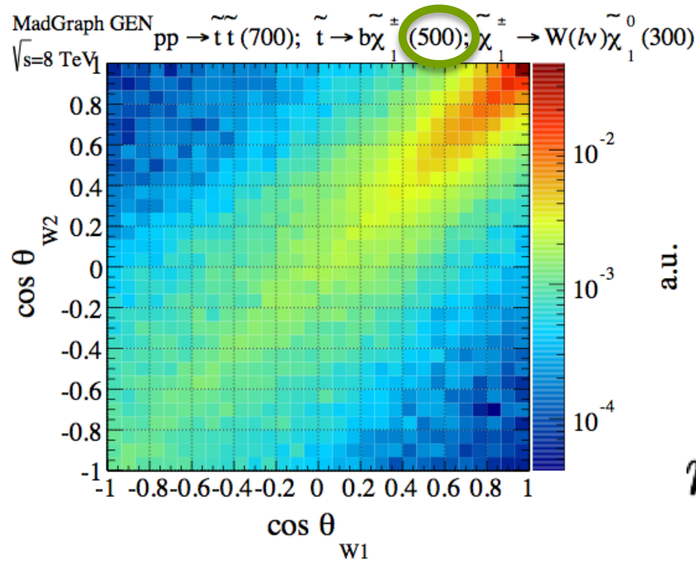


$$M_{tt} = 2\gamma_T M_t$$

Observables sensitive to intermediate resonances cannot distinguish between non-resonant signals and background

The di-leptonic top basis vs Stops

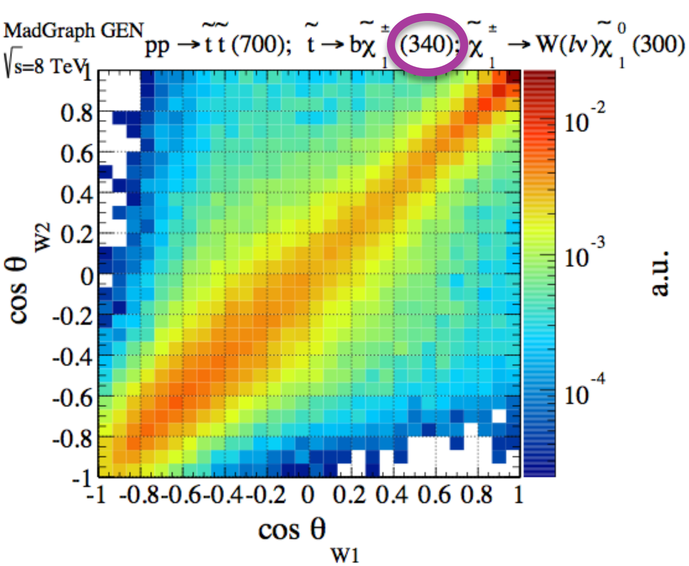


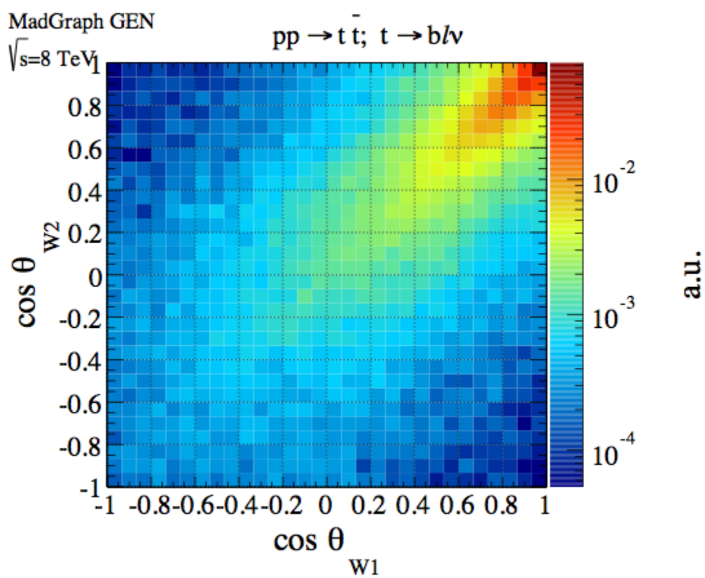


$$m_{\tilde{t}} = 700 \text{ GeV}$$

$$n_{\tilde{\chi}^{\pm}} = \begin{matrix} 650 \\ 500 \\ 340 \end{matrix} \text{ GeV}$$

$$m_{\tilde{\chi}^0_1} = 300 \text{ GeV}$$





Decay angles are also sensitive to differences between stop signals and ttbar background