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Prospects for Measuring the Stop Mixing Angle at the LHC

(work in progress)

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SUSY stop mixing

Mixing matrix in MSSM

$$L_{m_{\tilde{t}}} = -\begin{pmatrix} \tilde{t}_L^* & \tilde{t}_R^* \end{pmatrix} \mathbf{m}_{\tilde{\mathbf{t}}}^{\mathbf{2}} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

$$\mathbf{m}_{\tilde{\mathbf{t}}}^{\mathbf{2}} = \begin{pmatrix} m_{Q_3}^2 + m_t^2 + \Delta_{\tilde{u}_L} & v(A_t^* \sin\beta - \mu y_t \cos\beta) \\ v(A_t \sin\beta - \mu^* y_t \cos\beta) & m_{\bar{u}_3}^2 + m_t^2 + \Delta_{\tilde{u}_R} \end{pmatrix}$$

- Unless $A_t \neq 0$ (hinted at by Higgs mass?), lowest eigenstate is $\tilde{t}_1 \sim \tilde{t}_R$ if $\tan\beta \gg 1$.
- If off-diagonal real, rotation into eigenbasis parametrized by an angle.
- Portal for constraining models

Top polarization

To measure stop mixing angle:

Could measure $\tilde{t}_1$ decay branching ratios, combined with precise knowledge of the chargino, neutralino spectrum from an ILC
(e.g., Rolbiecki, *et al.* [arXiv:0909.3196])

Or, could directly measure polarization of top from $\tilde{t}_1 \to t\chi_n^0$ decays to determine degree of mixing

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Apart from SUSY, top polarization from top partner decays is an important handle on new physics, such as Z'

Top polarization (cont'd)

Two parton-level analyses

- Jessie Shelton [arXiv:0811.0569] – measure energy fraction $E_{W,l}/(E_{W,l}+E_b)$ of boosted daughters in collinear limit
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Strategies at detector level

- Subcluster hadronic decays oftops, measure energy fraction using reconstructed objects
- Tag and reconstruct leptonic top decays, measure energy fraction
- Observe forward/backward asymmetry in leptonic decays above combinatorics

Our initial strategy

General method

- Study one simplified model @ 14 TeV, 800 GeV stop decaying 100% to $t\chi_1^0$ ($m_{\chi_1^0} = 100$ GeV)
- Do full event generation (hadronization, ISR/FSR, MPI) with fast detector simulation including all effects (e.g., magnetic field)
- Model most prominent backgrounds
- Subcluster and reconstruct top

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Background suppression

Use new background suppression technologies:

- Plehn, Spannowsky, Takeuchi [arXiv:1205.2696]
- Kaplan, Rehermann, Stolarski [arXiv:1205.5816]

Stop templates

Must understand response of analysis (cuts, tagging, reconstruction) on parton-level polarization

Create top polarization "templates" for right, mixed and left stops w/ 10× expected signal ($= 3000\text{fb}^{-1} \times 60\text{fb}$ [PROSPINO])

Much of the signal washed out by spread in energy to due to spread in W reconstructed invariant mass.

Stop templates (cont'd)

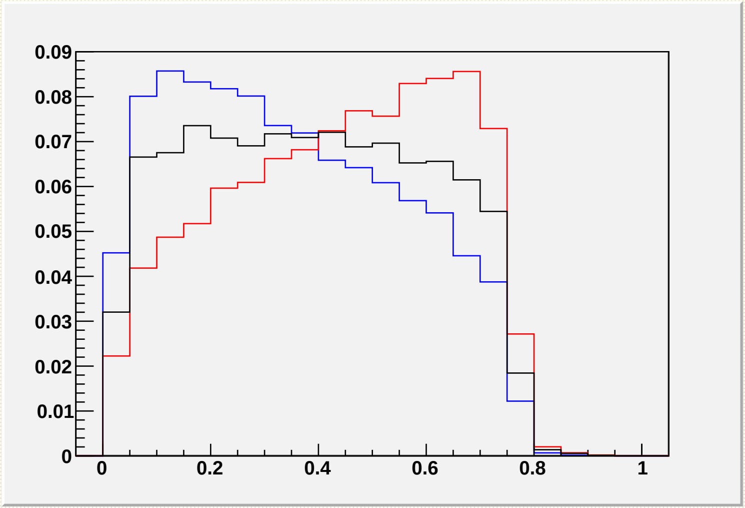


Figure : Parton level

Stop templates (cont'd)

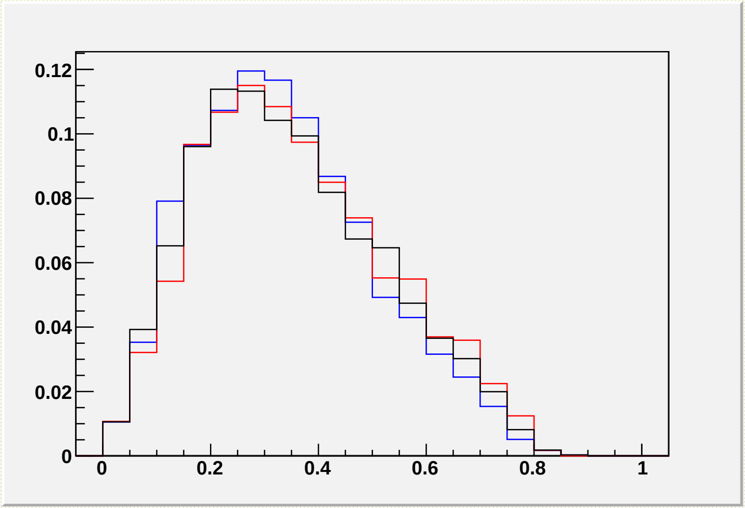


Figure : Analysis level

Simulation

Event generation, hadronization, decay

- `Herwig++ 2.5.0` with all physics effects (hadronization, ISR/FSR, MPI)
- Require `Herwig++`'s spin-correlation capabilities to see any signal at all

Fast detector simulation

- `Delphes 2.0.2` modified to use subjet capabilities of `FastJet 3.0.3`
- Detector card tuned to ATLAS, including correct calorimeter grid

Backgrounds

Top pair, W+jets and Z+jets

Analysis

(De)clustering

- Use k_T algorithm w/ $R = 1.0$ and $d_{cut} = (10\ \mathrm{GeV})^2$ to form child jets. Obtain 2 to 5 subjets with correct invariant mass.
- Cambridge/Aachen algorithm gives many soft subjets w/ hadronization; trimming gives wrong invariant mass. (Bug in FastJet?)

Tagging

Implement CMS top tagger.

- 30% tagging rate before cuts, 20% afterward
- low mistag rate (see BOOST 2010 proceedings)

Analysis (cont'd)

Basic cuts

- Only top tag jets $p_T > 300$ GeV
- Hardest two jets $|\eta| < 1.5$ since stop products unlikely to be collinear. Also ensures efficiency of high-performance b-tagger (e.g., ATLAS-CONF-2011-102).
- No Delphes electrons, muons or tau jets, to reduce contamination from top leptonic decays and suppress W+jet mistags

Analysis (cont'd)

(Severe) kinematic cuts

- $\not{E}_T > 500$ GeV — most important tunable to balance stop and top events
- $M_T > 700$ GeV for two hardest jets
- $M_{T2} > 600$ GeV (UC Davis code)

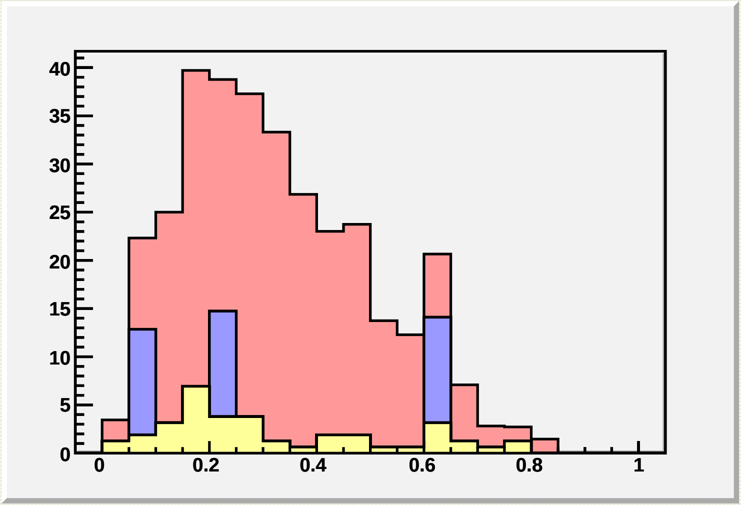
Signal no longer background limited, but statistics limited. Efficiency 1%; top pair suppression 3×10^5, W+jet 10^4, Z+jet 10^5.

Final b-tag

- If only one top tagged in event, require a b-tag on another jet to kill W+jet.
- Assume 70% efficiency with 1% mistag.

Histograms

Figure : stop right + backgrounds (320 fb^{-1})



Histograms (cont'd)

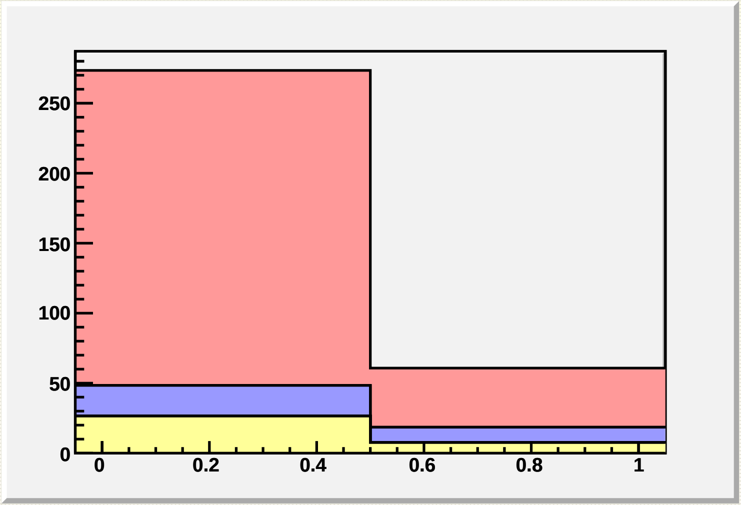


Figure : stop right + backgrounds (320 fb^{-1}; rebinned)

Excluding hypotheses

Table : p-values

	Hypothesis		
Truth	right	mixed	left
right	0.72	0.049	3.1×10^{-4}
mixed	0.019	0.37	0.080
left	3.4×10^{-3}	0.098	0.83

With this sample

- Can ascertain $\tilde{t}_1 \sim \tilde{t}_R$ if assuming mixed state at 320 fb^{-1}.
- Conversely, if assuming $\tilde{t}_1 \sim \tilde{t}_R$, can determine mixed state at 250 $\text{fb}^{-1} \Rightarrow A_t > 0$?
- Exact luminosity required depends on sample and its fluctuations

Conclusion

Demosntrated

- There is a (small) polarization signal in (moderately) boosted top substructure
- Can distinguish stop mixing hypotheses at $\sim 300\ \mathrm{fb}^{-1}$ @ 14 TeV for 800 GeV stop

Immediate improvements

- Include NLO top pair, single top backgrounds; also $t\bar{t} + Z$, multijet
- In case light stop found this year, reoptimize for different simplifed model points
- Experiment with more aggressive tagger

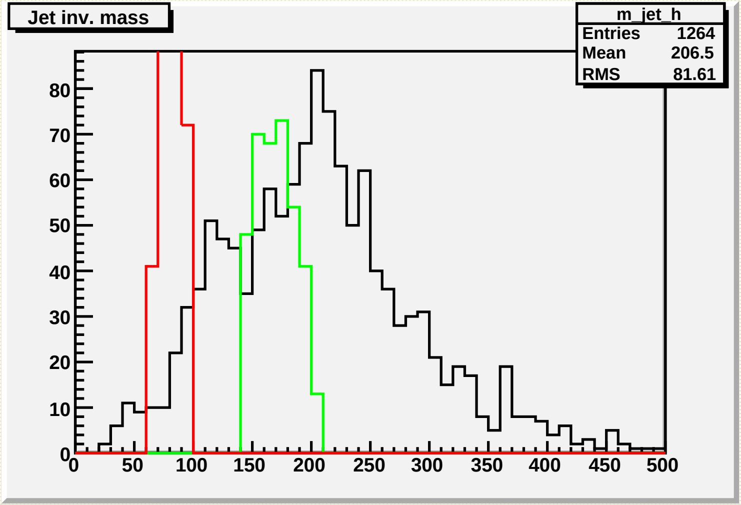
Conclusion (cont'd)

Distant improvements

- Ameliorate washout, require (significantly less) luminosity?
- Try to get C/A jet clustering to work?
- Try selecting on semi-leptonic events, kill more backgrounds?
- Try to observe lepton polarization signals (energy fraction, asymmetry)?

Will be fun to explore!

Jet invariant mass



Jet invariant mass (partons)