Search for scalar top quark pair production in the dilepton final state at $\sqrt{s} = 13$ TeV

Intermediate thesis presentation

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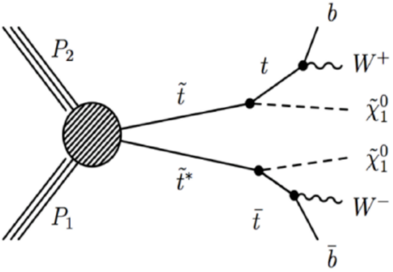
- Extension to the SM, symmetry between fermions and bosons
- Gives a solution to the hierarchy problem (Higgs mass near electroweak scale by cancellation of loop corrections)
- R-parity, $R = (-1)^{3(B-L)+2s}$, is a multiplicative quantum number, $+1$ for SM particles, -1 for SUSY particles
- In R-parity conserving models:
  - SUSY particles can only be produced in pairs
  - SUSY particle can not decay exclusively to SM particles
  - Lightest Supersymmetric Particle (LSP) is stable $\rightarrow$ DM candidate

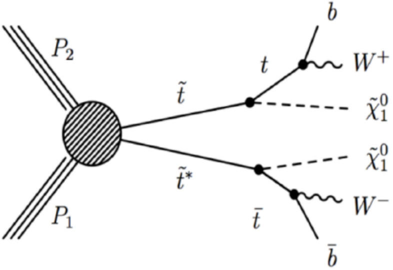
Supersymmetry

Search for scalar top production



- $\tilde{t}\tilde{t}^*$ (stop-antistop), decay to $t\bar{t}$ and $\tilde{\chi}_1^0\tilde{\chi}_1^0$ (neutralino's, LSP $\rightarrow$ MET)
- $t\bar{t}$ decays to $b\bar{b}$ and W^+W^-

Event selection



Require events to have:

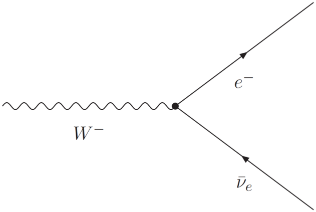
- 2 jets of which at least one b-tagged from the $t\bar{t}$ decay
- 2 opposite sign leptons from the W^+W^- decay

Problem: huge Standard Model $t\bar{t}$ background

Transverse mass

Definition

$$
\begin{aligned}
(M_T)^2 &= (\mathbf{p}_{l,T} + \mathbf{p}_{T,\nu})^2 \\
&= \mathbf{p}_{l,T}^2 + \mathbf{p}_{T,\nu}^2 + 2\,\mathbf{p}_{T,l} \cdot \mathbf{p}_{T,\nu} \\
&= 2E_{l,T}E_{T,\nu}(1 - cos(\Delta\phi)) \\
&= 2E_{l,T}E_T^{miss}(1 - cos(\Delta\phi)) \\
&\leq (M_W)^2
\end{aligned}
$$



- Introduce new variable, $M_{T2}(ll)$
- Generalization of transverse mass
- $\mathbf{p}_T^{miss} = \mathbf{p}_{T1}^{miss} + \mathbf{p}_{T2}^{miss}$
- $M_{T2}^2(ll) = \min_{\mathbf{p}_{T1}^{miss} + \mathbf{p}_{T2}^{miss} = \mathbf{p}_T^{miss}} \left(\max \left[M_T^2(\mathbf{p}_T^{l1}, \mathbf{p}_{T1}^{miss}), M_T^2(\mathbf{p}_T^{l2}, \mathbf{p}_{T2}^{miss}) \right] \right)$
- $M_{T2}^2(ll) \leq (M_W)^2$

Stransverse mass

Standard Model top production vs. SUSY stop production

$$pp \to t + \bar{t} + X \to bW^+ + \bar{b}W^- + X \to b\bar{l}\nu_l + \bar{b}l\bar{\nu}_l + X$$

- Assume contributions of X to E_T^{miss} are relatively small
- Assumptions in definition of $M_{T2}(ll)$ hold
- $M_{T2}(ll) \leq M_W$

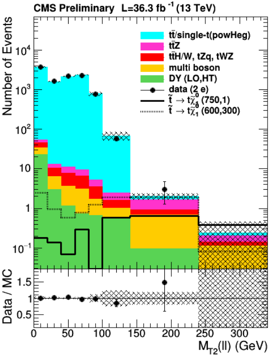
$$pp \to \tilde{t} + \bar{\tilde{t}} + X \to \bar{\tilde{\chi}}_1^0 bW^+ + \tilde{\chi}_1^0 \bar{b}W^- + X \to \bar{\tilde{\chi}}_1^0 b\bar{l}\nu_l + \tilde{\chi}_1^0 \bar{b}l\bar{\nu}_l + X$$

- At least 4 invisible particles
- Assumptions in definition of $M_{T2}(ll)$ do not hold
- $M_{T2}(ll) \not\leq M_W$

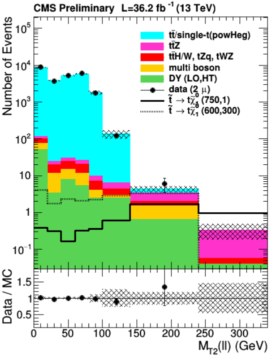
$\Rightarrow$ We can use $M_{T2}(ll)$ to distinguish signal from background

$M_{T2}(ll)$ plots

ee



$\mu\mu$



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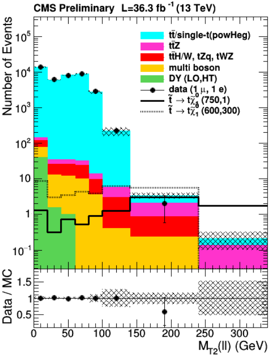


$t\bar{t}$ (lightblue) almost completely removed for $M_{T2}(ll) > 140\text{GeV}$

Need a way of verifying how well MC models the tails of the $M_{T2}(ll)$ distributions, since these are the signal regions

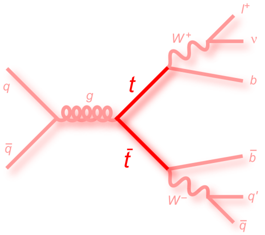
- Problem: very low statistics in these regions
- Proposed solution: look at $M_{T2}(ll)$ in other events with a similar topology with more statistics

For example:

- Take $W +$ jets events from MC, combine them with single lepton $t\bar{t}$ MC events, calculate the $M_{T2}(ll)$ using 1 lepton from $W +$ jets, 1 lepton from single lepton $t\bar{t}$ and the vectorially combined MET
- Do the same for data and compare

W + jets combined with single lepton $t\bar{t}$

Closure test



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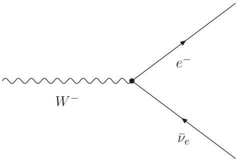

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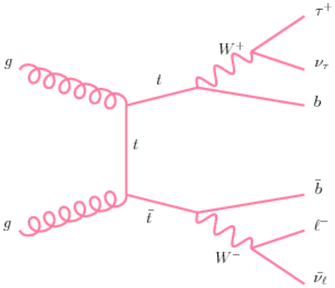
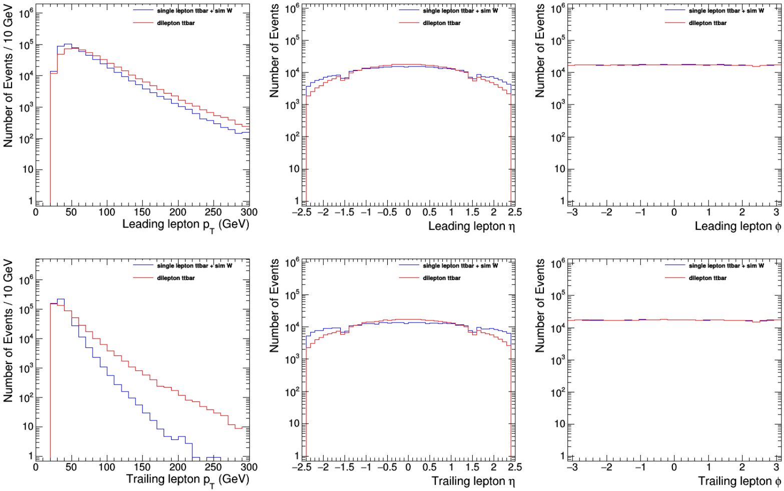


Comparing the kinematics: leptons

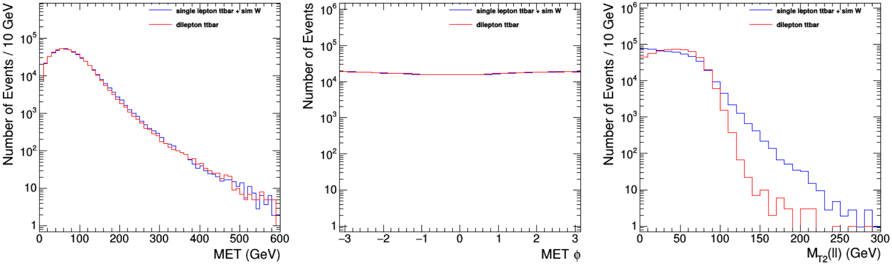
Dileptonic $t\bar{t}$ (red) vs single lepton $t\bar{t}$ and W + jets (blue)



→ Differences in trailing lepton p_T, slight difference in leading/trailing η

Comparing the kinematics: MET and $M_{T2}(ll)$

Dileptonic $t\bar{t}$ (red) vs single lepton $t\bar{t}$ and W + jets (blue)

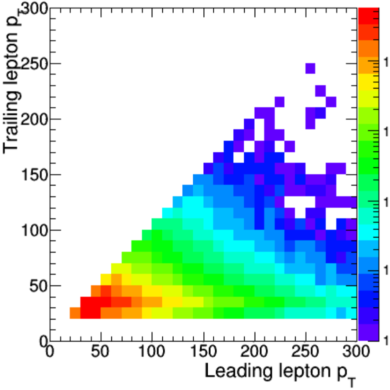


- Both the MET and MET ϕ distributions match nicely
- $M_{T2}(ll)$ distributions are very different (log plot)

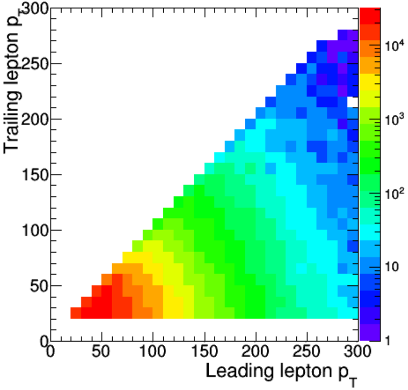
$M_{T2}(ll)$ mismatch

Lepton p_T correlation

Single lepton $t\bar{t}$ and W + jets



Dilepton $t\bar{t}$

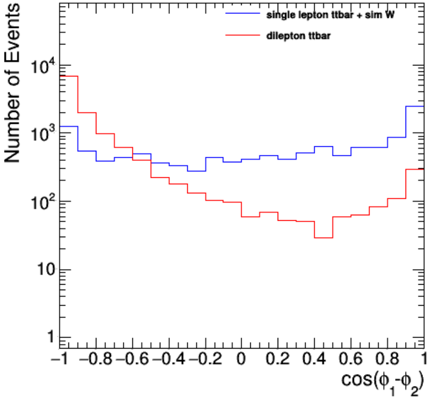


Main difference: lower trailing lepton p_T, also seen in the 1D plot, but difference is most pronounced at high leading lepton p_T

$M_{T2}(ll)$ mismatch
Lepton p_T correlation

- In dileptonic $t\bar{t}$, high leading p_T is compensated by high trailing p_T
- In single lepton $t\bar{t}$ and $W+$ jets, the two leptons are uncorrelated since the events are combined randomly

  This can be seen in a $\cos(\phi_{leading} - \phi_{trailing})$ plot, where we require $p_{T,leading}$ and $p_{T,trailing} > 100\,\text{GeV}$

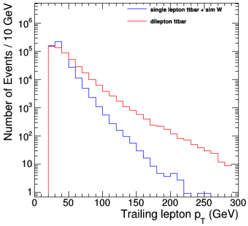


- Single lepton is distributed as cosine of a uniform variable
- Dilepton has more events at $\phi_{leading} - \phi_{trailing} = \pi$, these are back to back leptons

$M_{T2}(ll)$ mismatch

Reweighing the events

- The biggest difference seems to be in trailing lepton p_T
- Try reweighing based on the ratio in trailing lepton p_T:



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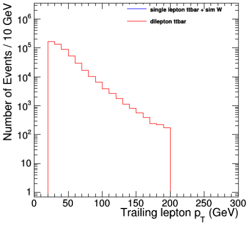
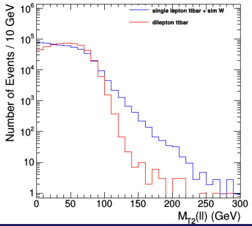


Cut at leading $p_T < 200$ GeV since almost no events here, this plot confirms correct reweighing



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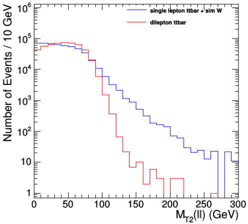

No improvement on $M_{T2}(ll)$ distributions, seems to have made it even worse

In terms of $M_{T2}(ll)$, dileptonic $t\bar{t}$ and single lepton $t\bar{t}$ combined with W + jets are not equivalent:

- $M_{T2}(ll)$ distributions do not match
- Difficult to pinpoint exact cause, recalling definition:

$$M_{T2}^2(ll) = \min_{\mathbf{p}_{T1}^{miss}+\mathbf{p}_{T2}^{miss}=\mathbf{p}_T^{miss}} \left(\max\left[M_T^2(\mathbf{p}_T^{l1}, \mathbf{p}_{T1}^{miss}), M_T^2(\mathbf{p}_T^{l2}, \mathbf{p}_{T2}^{miss})\right]\right),$$

  interplay between p_T, η and ϕ of the leptons and the MET not straightforward

However, we can still compare MC to data to check how well the $M_{T2}(ll)$ tail is modeled, giving an indirect measurement of how accurate the MC is in this region.

Moving forward

To do list

- Investigate further why the two $M_{T2}(ll)$ distributions do not match and if possible try to improve the correspondence, although they will never completely match due to the difference in lepton correlation
- Everything so far has been run on MC samples, need to run on data to compare
- Aside from combining single lepton $t\bar{t}$ and $W +$ jets, try different processes and combinations as well, one example being using $W +$ jets from data and MC and adding a random W decaying leptonically both in data and MC and comparing the two $M_{T2}(ll)$ distributions