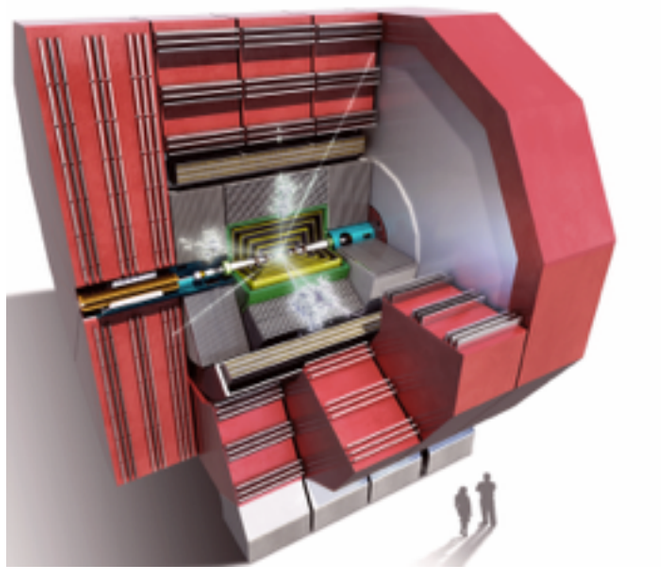
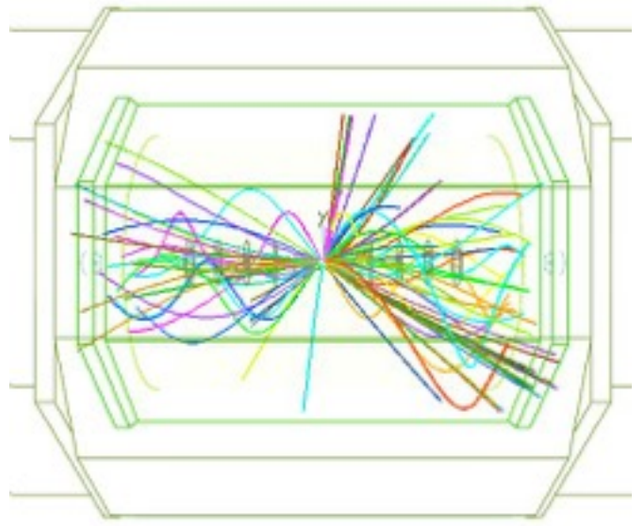




Update on Top Squarks at 3TeV

Alan Taylor

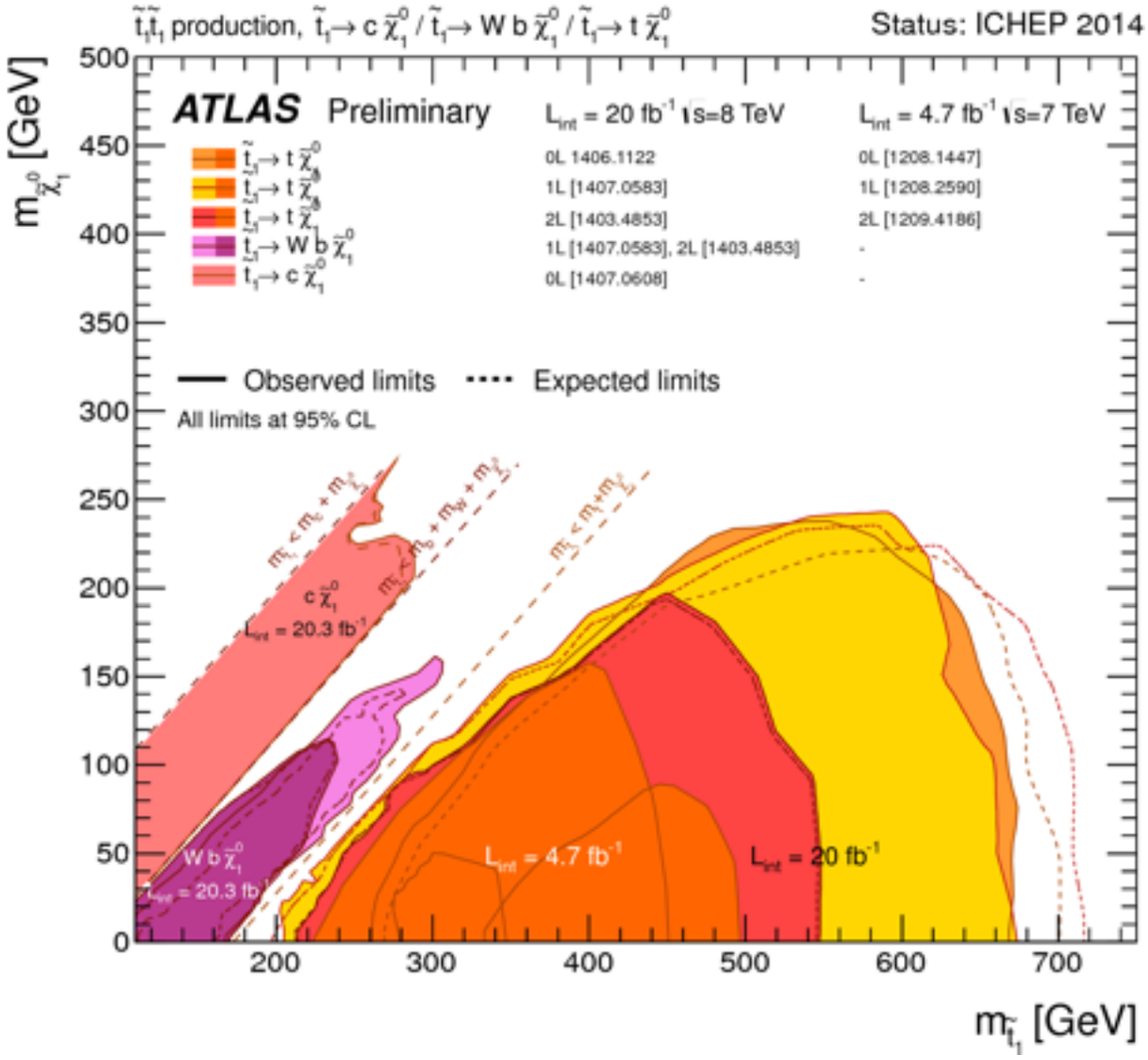
Overview

- Previous talk given at CLIC Workshop. Some of the same slides included.
- Motivations:
  —> Aim of study is to measure the top squark mass.

  —> Benchmark study for boosted top quarks at CLIC.
- SUSY model and top squark being studied.
- Overview of current analysis strategy.
- TMVA approach to event selection **NEW**
- Template fit to find top squark mass **NEW**

Top squark details

- Supersymmetry model selected is CLIC CDR Model 3.
- Mass of stop = 844GeV. Stop being studied still compatible with LHC results.
- Process $e^+e^- \to \tilde{t}_1\tilde{t}_1$ Cross section 1.65fb. ProdID = 4195
  $e^+e^- \to t\bar{t}$ 59fb
- Top squarks are pair produced in EW interactions so have to be at 3TeV.
- Study assumes an integrated luminosity of $2ab^{-1}$



SUSY model details

- In the model the stop has several decay modes.
  Main ones are:

$$BR(\tilde{t}_1 \to t\tilde{\chi}_1^0) = 52.4\% \qquad BR(\tilde{t}_1 \to \chi_1^{\pm} b) = 34.1\%$$
$$BR(\tilde{t}_1 \to t\tilde{\chi}_2^0) = 13.2\%$$

- Decay modes of SUSY particles:

$$BR(\chi_1^{\pm} \to W\chi_1^0) = 99.7\%$$
$$BR(\tilde{\chi}_2^0 \to h^0\tilde{\chi}_1^0) = 94.6\%$$

- Masses in SUSY model:

$$M(\chi_1^{\pm}) = 487GeV$$
$$M(\tilde{\chi}_2^0) = 487GeV$$
$$M(\tilde{\chi}_1^0) = 357GeV$$
$$M(h^0) = 117.8GeV$$

Top squark and top quark details

- Different decay modes of the stop leads to many final states.
- BR (t → Wb) ~ 100%
- The channels are further characterised by the decays of the W boson.

$$\tilde{t}_1\bar{\tilde{t}}_1 \to t\tilde{\chi}_1^0\chi_1^{\pm}b \to W^+W^-b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad (35.8\%)$$

$$\tilde{t}_1\bar{\tilde{t}}_1 \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad (27.4\%)$$

$$\tilde{t}_1\bar{\tilde{t}}_1 \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_2^0 \to W^+W^-b\bar{b}h^0\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad (13.7\%)$$

$$\tilde{t}_1\bar{\tilde{t}}_1 \to \chi_1^+\chi_1^-b\bar{b} \to W^+W^-b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad (11.6\%)$$

$$\tilde{t}_1\bar{\tilde{t}}_1 \to t\tilde{\chi}_2^0\chi_1^{\pm}b \to W^+W^-b\bar{b}h^0\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad (9.0\%)$$

Analysis Strategy

- Aim is to reconstruct stop mass as well as possible.

- To do this, reconstruct as many top quarks as possible. Channel currently being investigated is:

$$e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1 \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WWb\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to qqqqb\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

ANALYSIS

FastJet ⇒ Force events into 6 jets using the kt algorithm, TightPFOs, R = 0.7.

LCFIPlus

Preselection Cuts

Multivariable Selection ⇒ Boosted Decision Tree

Template Fit

Mass Measurement

W and top quark reconstruction

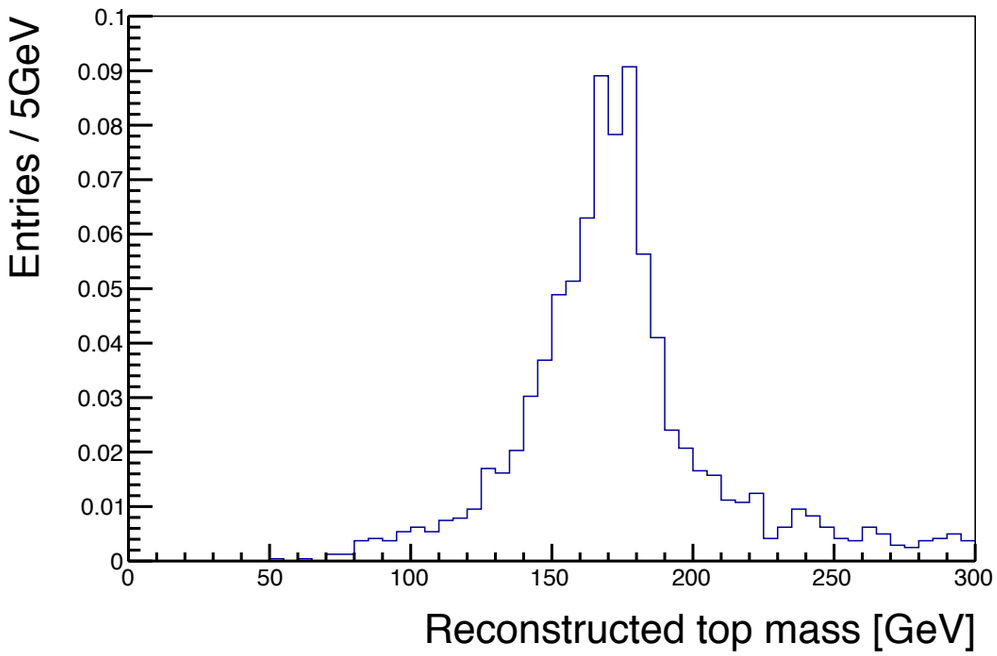
- Channel being investigated is:

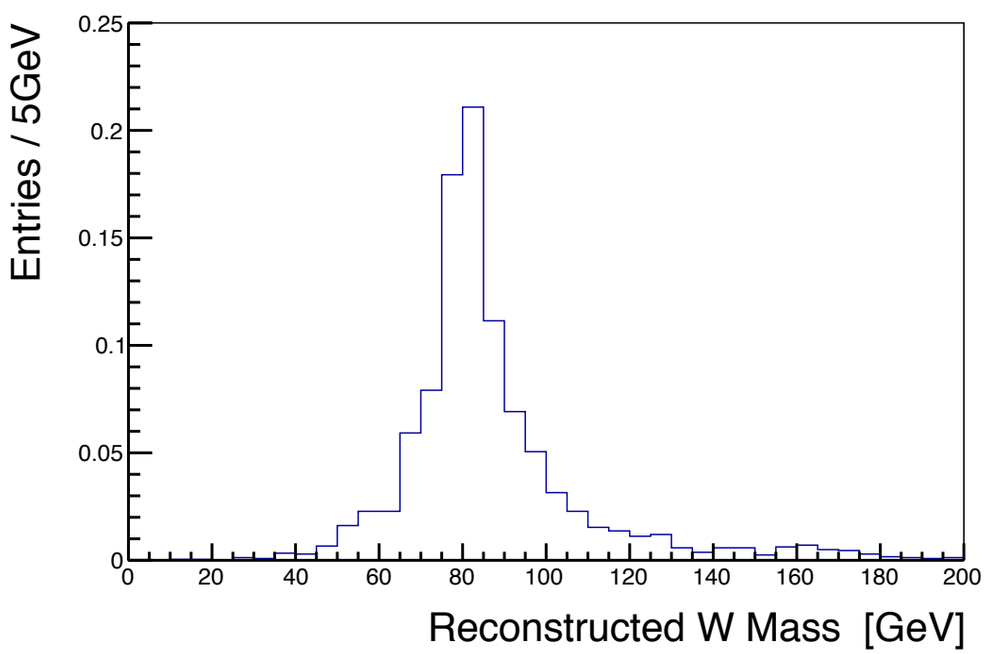
$$e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1 \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WWb\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to qqqqb\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

- 6 jets in final state with the neutralinos escaping detector.

- Choose the jets which came from each W and top by minimising the quantity:

$$\chi^2 = \frac{(m_{j_1j_2} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_1j_2j_3} - m_t)^2}{\sigma_t^2} + \frac{(m_{j_4j_5} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_4j_5j_6} - m_t)^2}{\sigma_t^2}$$





Energy of reconstructed top

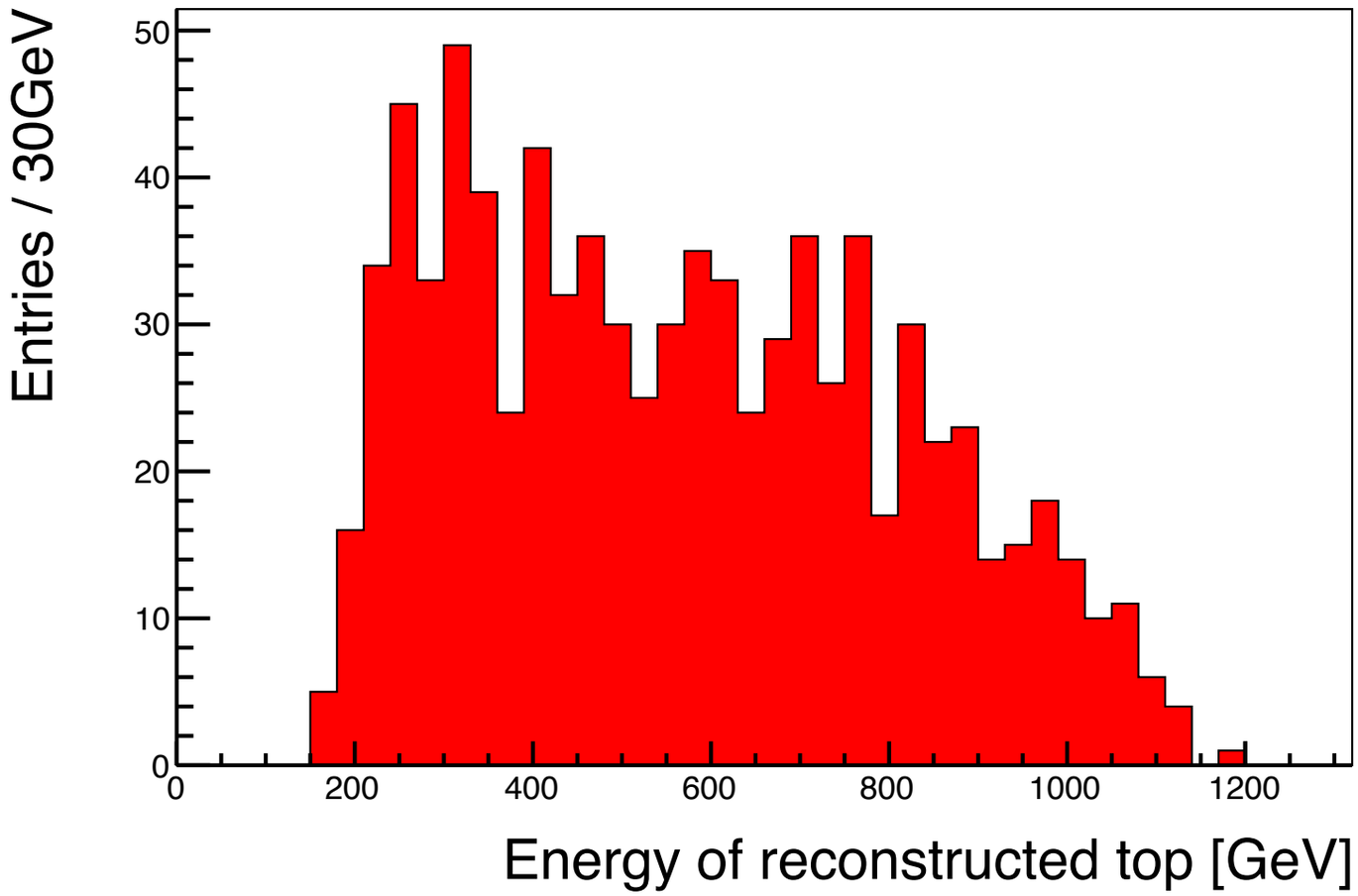
- The mass of the stop is sensitive to the energy spectrum of the top quarks that have decayed from a stop.

  actual result is: $m_{\tilde{t}_1} = \frac{\sqrt{s}}{2}\sqrt{1 - \frac{(E_{t_{max}} - E_{t_{min}})^2}{(E_{t_{max}} + E_{t_{min}})^2}}$

- Signal events = 422

- Histogram scaled to $2ab^{-1}$. Corresponds to running CLIC at 3TeV for ~4 years.

- Beamstrahlung and ISR distort energy distribution. More statistics towards the minimum energy —> Makes fitting the end points challenging.



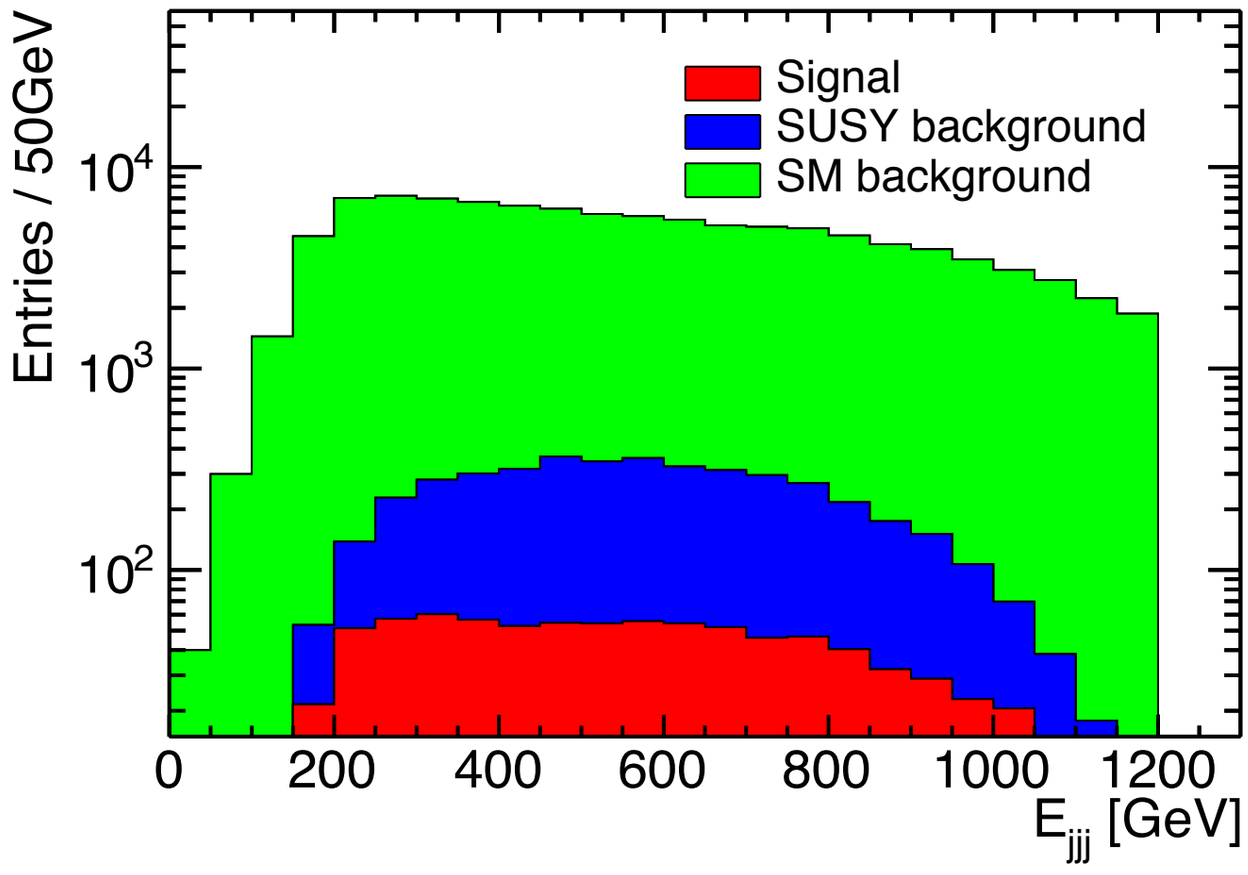
Background + Preselection cuts

- Backgrounds currently being considered are $e^+e^- \to t\bar{t}$ and stop events other than

$$\tilde{t}_1\bar{\tilde{t}}_1 \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WWb\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to qqqqb\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

- Current preselection cuts:
  —> No isolated leptons found using Isolated Lepton processor
  —> Visible energy in jets less than 2TeV
  —> Both Ejjj < 1.2TeV.

- Energy spectrum of top quark with backgrounds:



- 98% of signal events surviving and 26% of background events surviving.

- Histograms are stacked and normalised to 2ab.

Event Selection

NEW

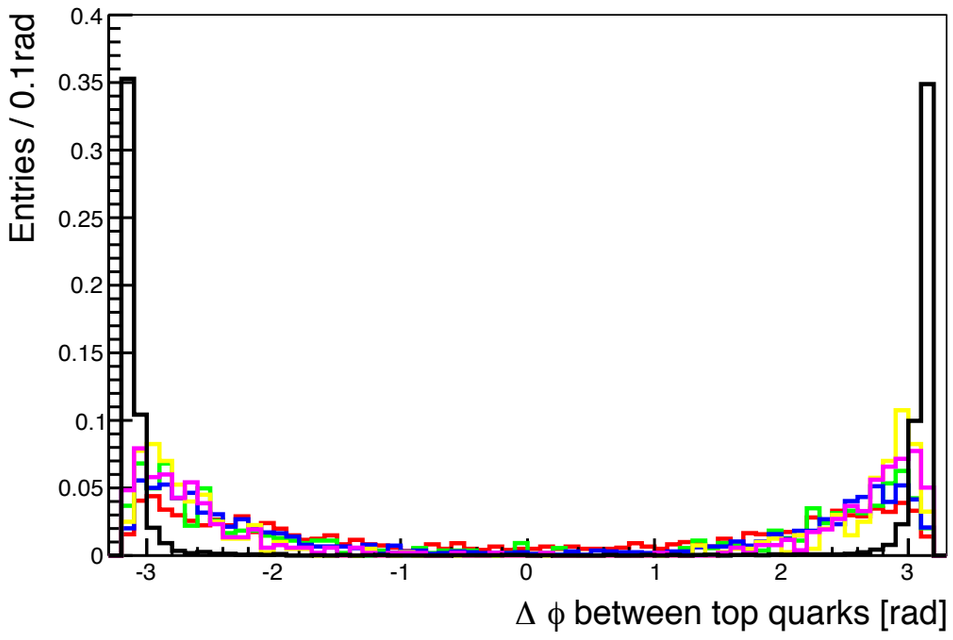
- Boosted Decision Tree in TMVA used for event selection. BDT trained with 10,000 $e^+e^- \to \tilde{t}_1\tilde{t}_1$ and 30,000 $e^+e^- \to t\bar{t}$ events.

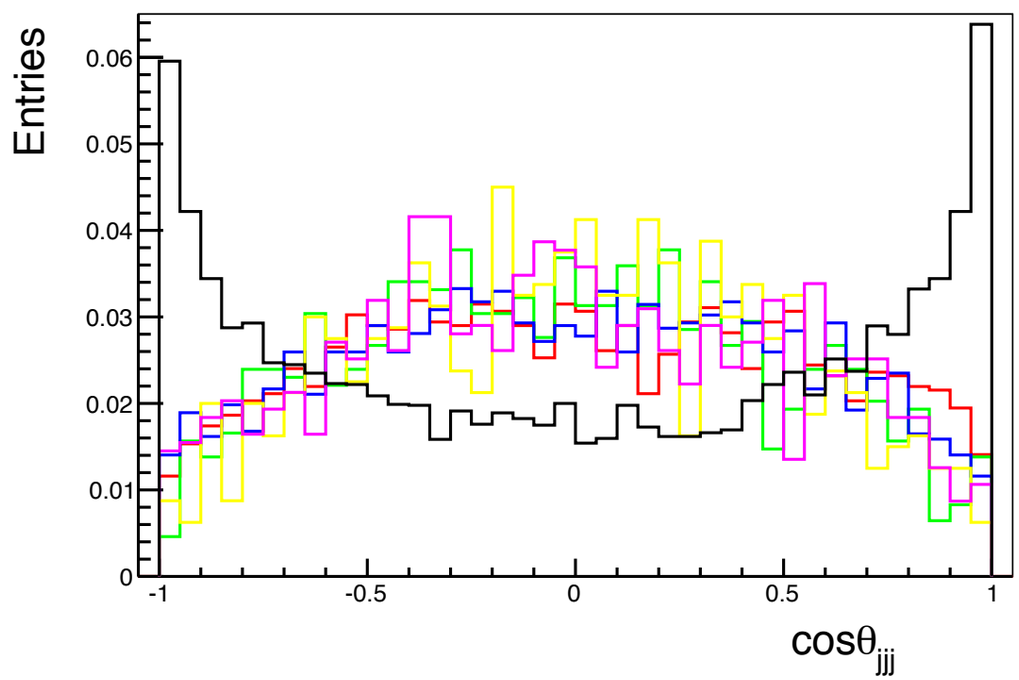
- 27 variables used in training of BDT. List of variables:

  $E_{visible}$, P_T, Masses of top and W candidates, θ^{miss}, $cos\theta_{j_1j_2j_3}$, $cos\theta_{j_4j_5j_6}$, $\Delta\phi$ between top candidates, Thrust, Oblateness, Acoplanarity, no. of tight pros in event, ΔR between W candidates and b jets, jet transition values $y_{34}, y_{45}, y_{56}, y_{67}, y_{78}$, three highest b-tag and c-tag values

- 5 leading discriminating variables : $P_T, \theta^{miss}, cos\theta_{jjj}, \Delta\phi, E_{visible}$

  Two plotted below. Histograms normalised to unit area.



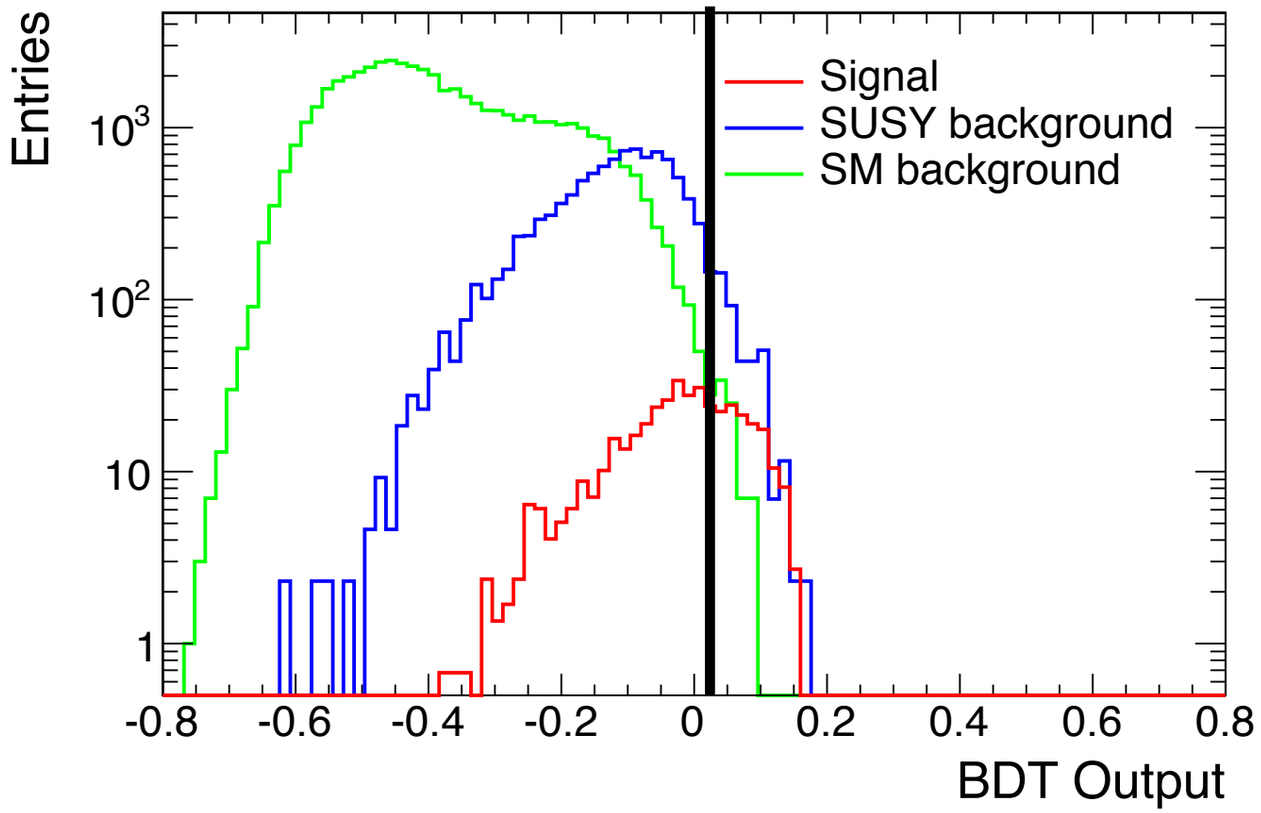


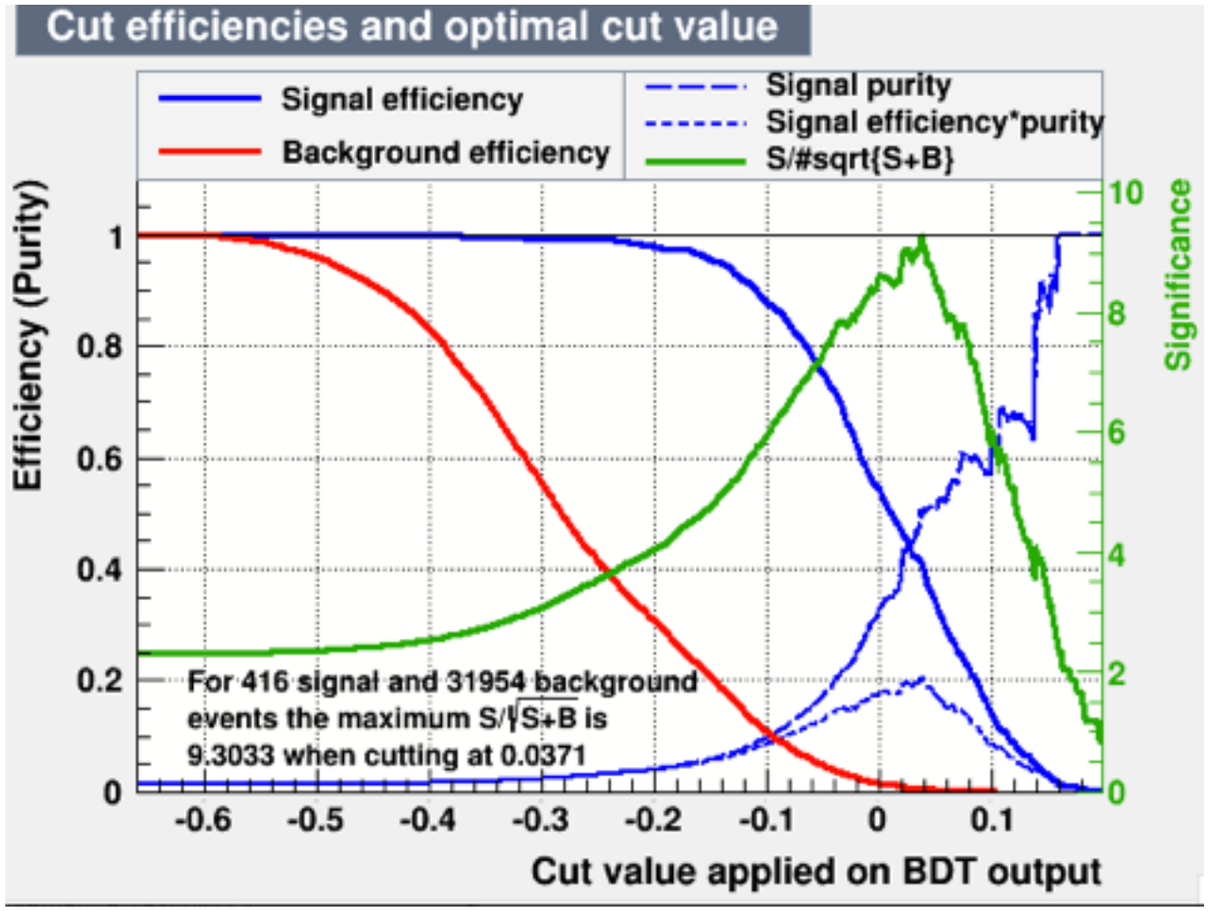
- Red = signal. Black = $e^+e^- \to t\bar{t}$ (Hadronically). Other colours = SUSY Channels (Hadronically)

BDT Performance

NEW

- Boosted Decision Tree used in adaptive boost mode.
- BDT cut selected to optimise the significance. Significance achieved was 9.3.
- 32% of signal events survive BDT cut. 2% other top squark events pass and 0.05% of SM background.



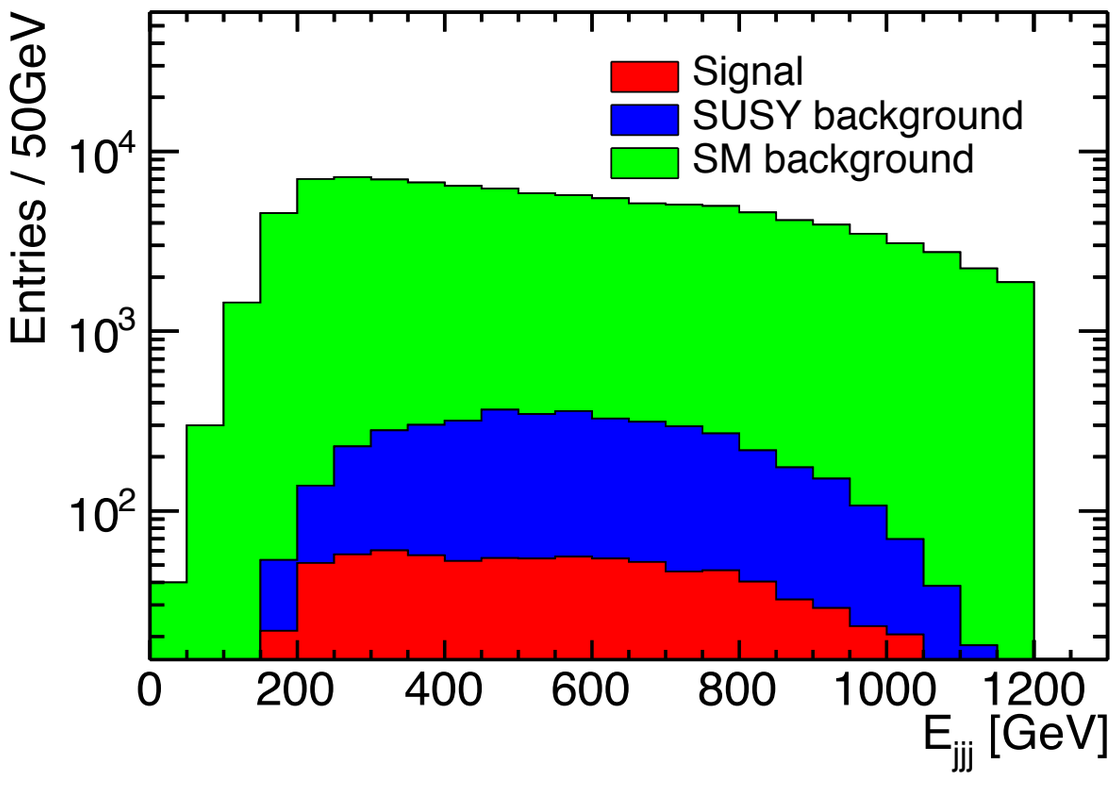


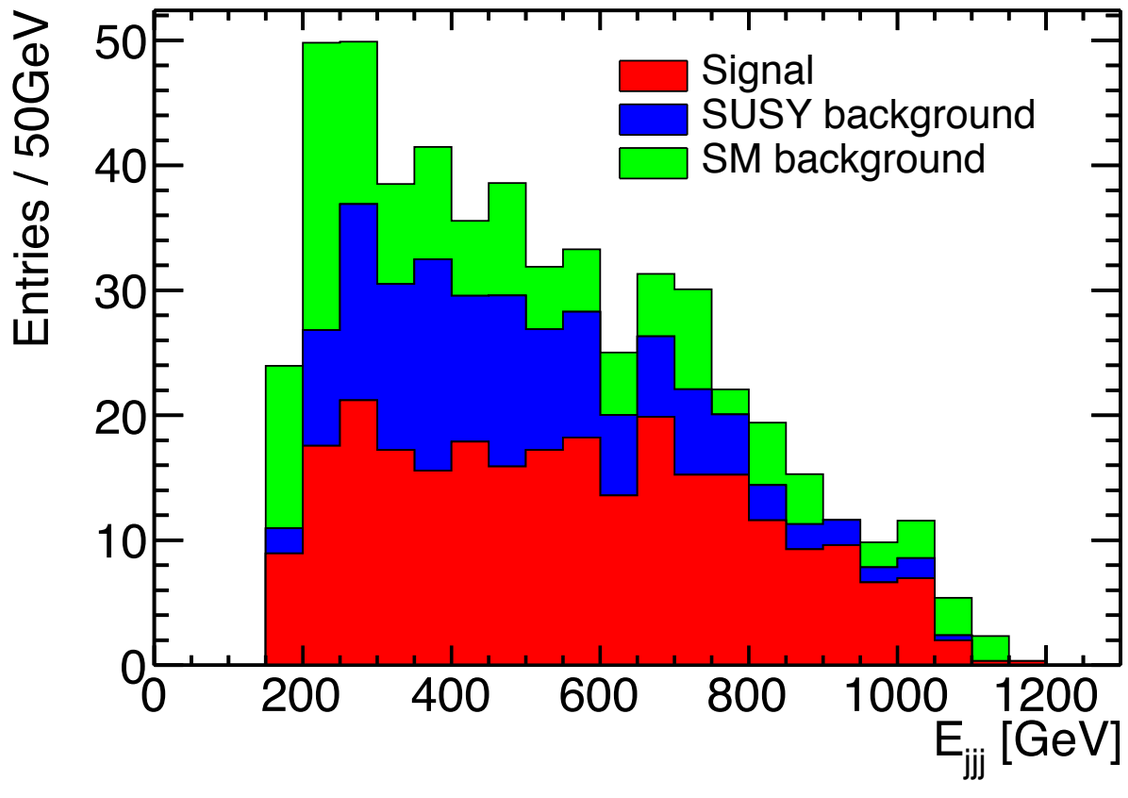
Top quark energy spectrum

NEW

- Weights from BDT applied to data samples not used to train the BDT. Large SM background sample available so no scaling required.

- Top quark energy spectrum after preselection and after BDT cut is shown below. Significant improvement in the signal to background ratio.





Template Fit

NEW

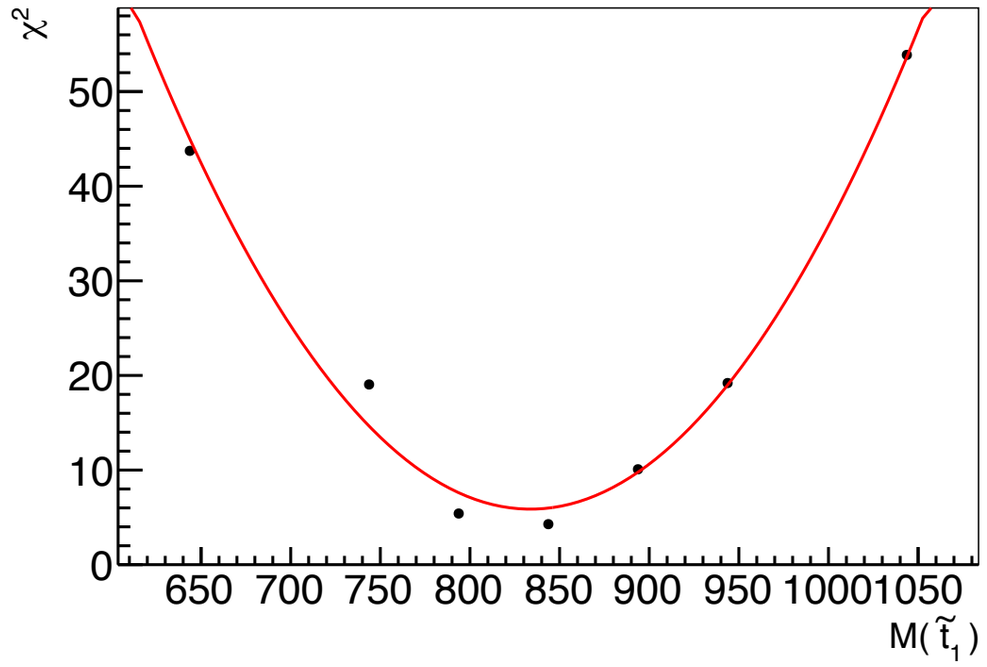
- Mass of stop1 =844GeV. cross section = 1.65fb.
- Templates currently available →

$M_{template}$	σ (fb)	ProdID
$M(\tilde{t}_1)$ - 200GeV	2.8	4368
$M(\tilde{t}_1)$ - 100GeV	2.2	4321
$M(\tilde{t}_1)$ - 50GeV	1.9	4370
$M(\tilde{t}_1)$	1.65	4195
$M(\tilde{t}_1)$ +50GeV	1.4	4319
$M(\tilde{t}_1)$ +100GeV	1.2	4335
$M(\tilde{t}_1)$ +200GeV	0.8	4333

- χ^2 used in template fit:

$$\chi^2 = \sum_i \frac{(n_{data_i} - n_{template_i})^2}{\sigma^2_{data_i} + \sigma^2_{template_i}}$$

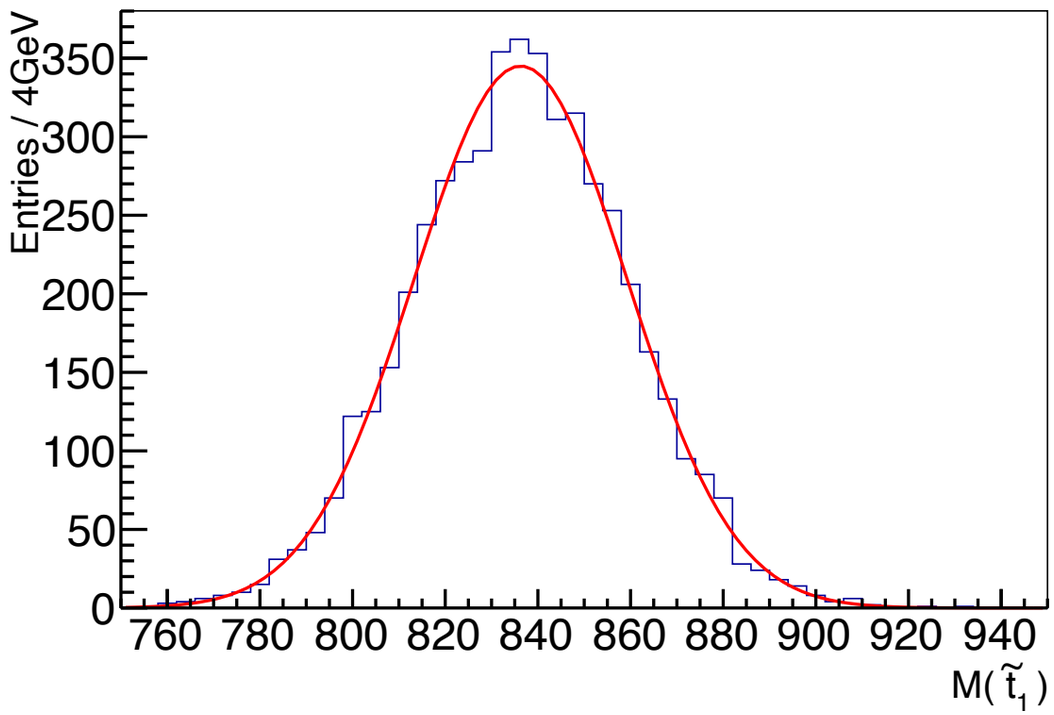
- Both the signal and SUSY background events are used from each top squark mass to create the templates.
- 2nd order polynomial fitted to χ^2 vs mass plot. Minimum of polynomial gives 834GeV. Toy MC used to find error on next slide.



Toy MC

NEW

- Toy MC method is used for statistical uncertainty. For the data histogram, no. of entries in each bin smeared with a gaussian of width $\sqrt{n_{data_i}}$.
- Mass measurement is repeated 5000 times. Gaussian fitted to mass distribution. Width of fitted gaussian is 23GeV.
- Mass of top squark measured as 834(23)GeV, agrees with the generator value of 844GeV.



Further Work

NEW

- Current template fit assumes knowledge of cross section and

$$BR(\tilde{t}_1 \to t\tilde{\chi}_1^0) = 52.4\%$$

- Can implement template fit with the cross section as free parameter but not sure about $BR(\tilde{t}_1 \to t\chi_1^0)$. Should it also be left as a free parameter?

- Systematic Uncertainties. Intention is to consider systematic uncertainty due to event selection by using the templates to train the BDT.