Unifying searches for BSM physics

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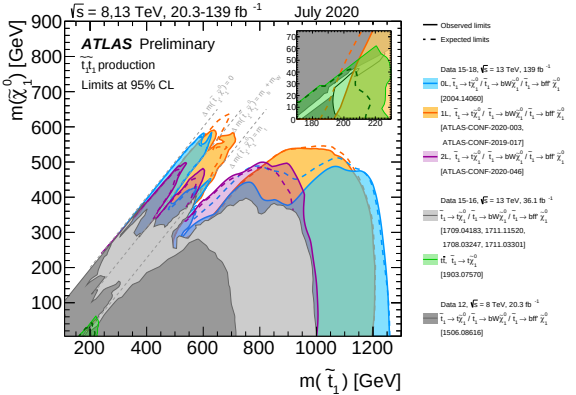
Introduction

- Involved with CoEPP for a number of years
- MSc at Melbourne on dark matter searches with single photons at Belle
- PhD at Adelaide working on ATLAS
- Mostly work on analysis (SUSY, Top), but also active in electron ID and upgrade
- I'll talk about some analysis development work I've been doing recently

Why combine searches?

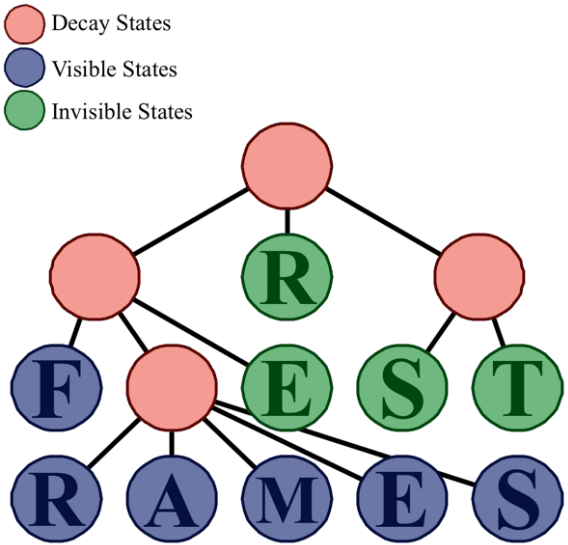
BSM searches are hard!

- Often exploring new kinematic regimes and the tails of distributions
- Largely suffer from lack of statistics
- Combinations form the major method of quantifying and presenting reach
- It's hard to take into account overlaps between analyses
- Increasing interest in doing parameter scans and global fits



To mitigate some of the difficulties it's wise to develop a unified analysis philosophy!

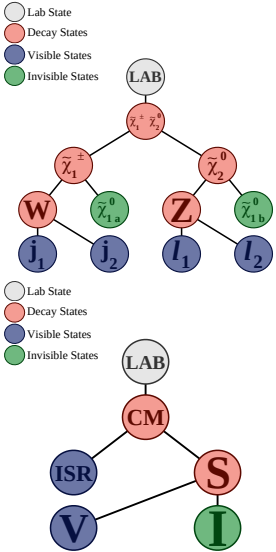
Recursive Jigsaw Reconstruction



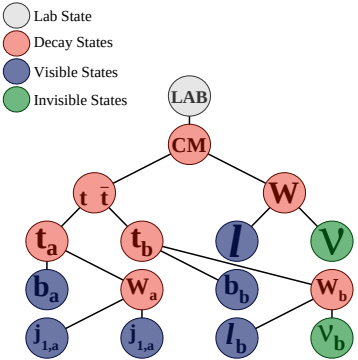
- The aim of the method is to resolve kinematic and combinatoric ambiguities which naturally arise at hadron colliders:
  - not knowing how to group objects together, especially if they are of the same type
  - not knowing how many invisible particles are produced, nor the full missing energy
  - not knowing the true centre-of-mass energy which produced the measured particles
- Use physics driven assumptions to constrain these ambiguities
- Easily implemented using RestFrames package

Developing analyses with RJR

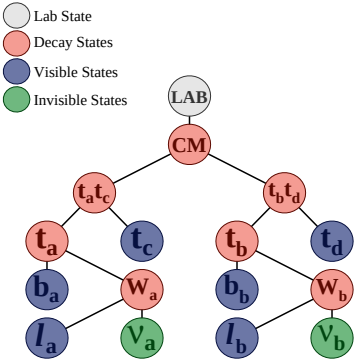
- Build decay tree based on process of interest and define rules
- Design variables to exploit the difference between signal and background
  - Object multiplicity per frame, lepton/jet flavour...
  - Scale variables- masses, vector/scalar sums of momenta...
  - Ratios- partitioning of momentum, transversity, **CM frame reconstruction**...
  - Angles- between objects in a frame, or boosts between frames...
- Analog with ISR boosted systems
  - Object multiplicity per frame, lepton/jet flavour...
  - Scale variables- ISR and invisible momentum, masses of objects...
  - Ratios- R_{ISR}, $\mathbf{R_{CM}}$...
  - Angles- between ISR and (in)visible systems...
- Design regions targetting different kinematic regimes $\rightarrow$ see Jason's talk for an example



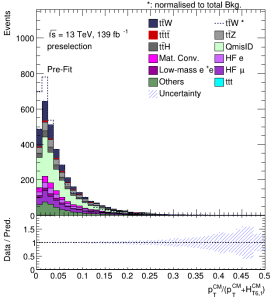
An example: combined-ttX



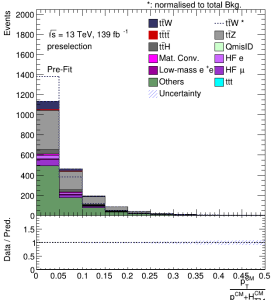
- Reconstruct (same-sign) 2ℓ and 3ℓ final states of $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}h$, $t\bar{t}t\bar{t}$
- All visible objects are assigned using mass minimisation rules
- MET is split using a W mass and width constraint, or mass equalisation
- Use measures of CM frame reconstruction to classify different processes



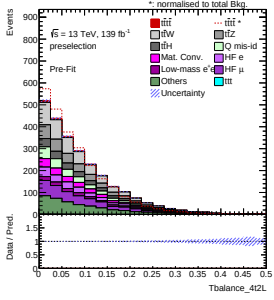
$t\bar{t}W$ and $t\bar{t}t\bar{t}$ reconstruction



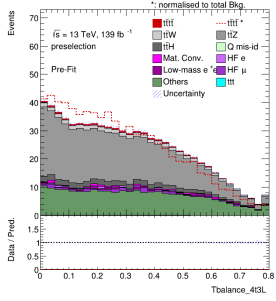
(a) 2ℓ $t\bar{t}W$: CM reconstruction



(b) 3ℓ $t\bar{t}W$: CM reconstruction



(c) 2ℓ $t\bar{t}t\bar{t}$: Momentum balance



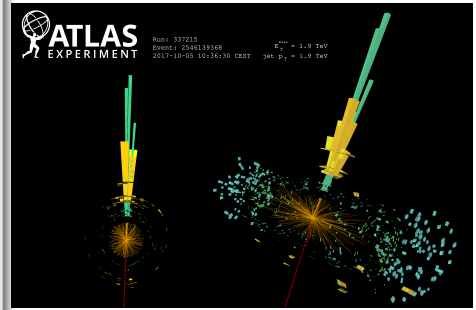
(d) 3ℓ $t\bar{t}t\bar{t}$: Momentum balance

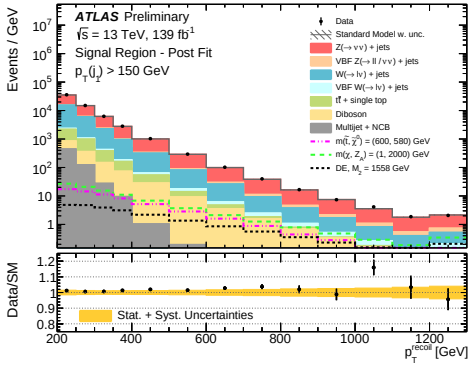
A matter of perspective

- Normally in RJR searches we hypothesise some signal topology (usually SUSY)
- What if we wanted to be more agnostic to the signal?
- Try to reconstruct the SM background processes and look for deviations from that
- Plenty of machine learning implementations, but this is purely kinematic
- This idea has precedent in inclusive squark-gluino searches for QCD reduction

Monojet

- Looking at the archetypal dark matter + other stuff search: the monojet analysis
- Finding bumps in increasing tight regions binned in recoil energy $\rightarrow$ only really useful in the tails *or* for large signals
- What happens when the new physics is diffuse in recoil energy? (more likely than not) $\rightarrow$ can't use bump hunting techniques and lose sensitivity
- Let's try to reduce the pool of background events so any signal is easier to spot!





Method

- Use the same idea as for combined-ttX
- Pass each event through reconstructions corresponding to major background sources:
  - Z+jets → irreducible
  - W+jets → reducible, but tough to differentiate
  - VBF processes → different topology, missing forward jets?
  - Top, VV etc → small enough to not worry
- The new physics *shouldn't* look exactly like the SM backgrounds → will be reconstructed worse
- Use a measure of reconstruction to determine how much worse

Conclusions

- Combining analyses will be increasingly important factor in LHC searches in Run 3 and beyond
- Developing unified analyses will allow for easier interpretation
- Using RJR we can derive variables to compare across processes
- We can also flip the usual methods to look for deviations from backgrounds
- These methods are possible with the current dataset, and any improvements in trigger etc will flow on

Thanks!