Search for new physics in final states with objects originating from a top-quark, a charm-quark and large E_{miss}^{T} in pp collisions at $\sqrt{s}$=13TeV

Tristan Ruggeri, Prof. Paul Jackson, Prof. Martin White
The University of Adelaide

Intro

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  - ATLAS
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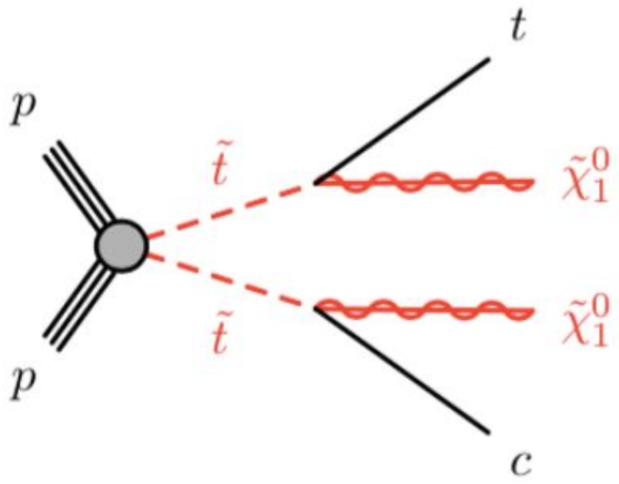
- Charm Tagging
- Background modelling
- Results
- Future Work



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About myself

From City of Manningham, Victoria, Australia

- Suburb is 70% covered in Parklands

Australian with Italian background

- Pretty happy with the continued increase in Cafe culture in the area

SuperSymmetry Overview

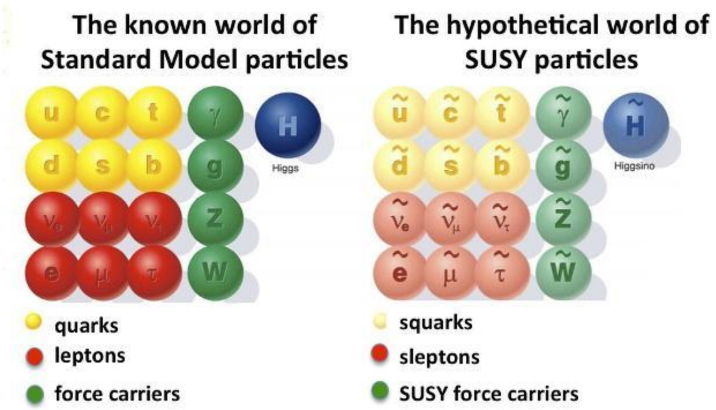
Popular framework for theoretical models of physics beyond the standard model

Has the potential to address unresolved questions in particle physics, such as the hierarchy problem, dark matter candidates and more

Key predicted feature of SUSY:
“Superpartner” particles, counterparts to SM particles with higher mass and the opposite spin properties

Constraining SUSY to contain only minimum number of new particles/interactions results in the Minimal Supersymmetric Standard Model (MSSM)

- Baryon and Lepton numbers no longer conserved, require R-Parity symmetry to suppress couplings between the two



As well as direct superpartners, the Gauginos and Higgsino (superparters of the gauge bosons and Higgs respectively) mix to form mass eigenstates called neutralinos and charginos.

Neutralinos tend to be the lightest supersymmetric particle (LSP) in most models

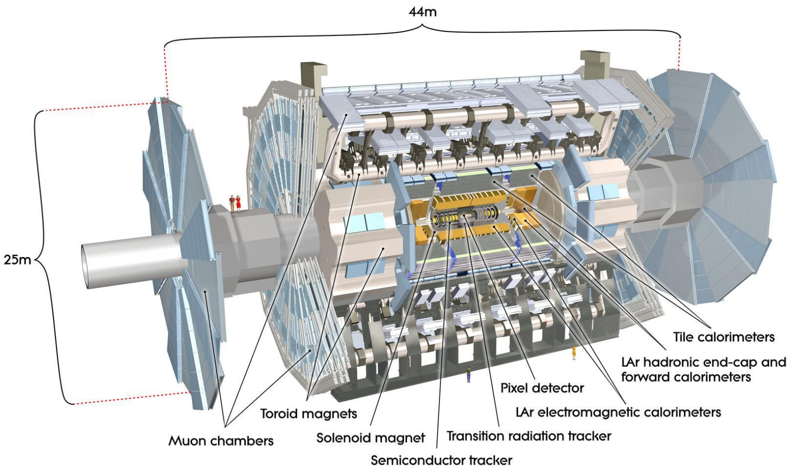
The ATLAS detector

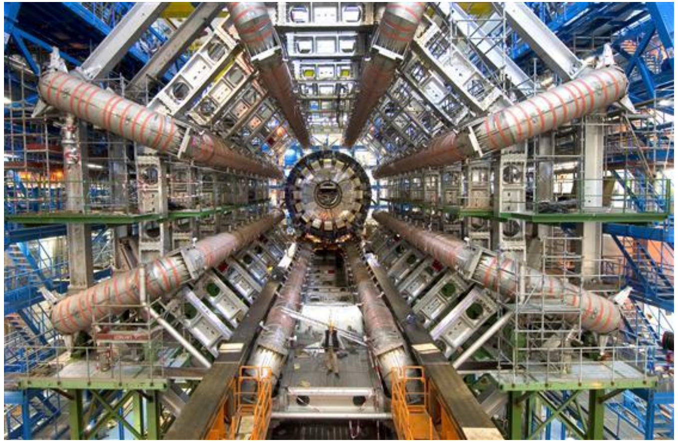
The ATLAS experiment at the Large Hadron Collider is a multi-purpose particle detector functionally comprised of:

- Inner/tracking detectors
- EM and Hadronic calorimeters
- Muon spectrometers

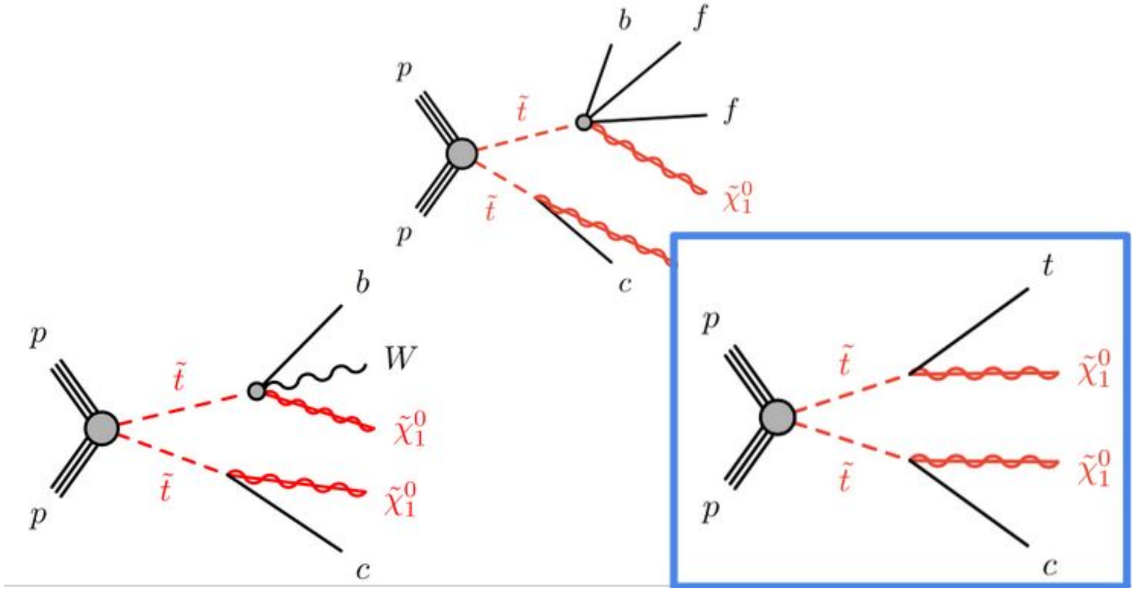
Has been used to take up to 139.1 $fb^{-1}$of event data at a CM energy of 13TeV during Run-II (2015-18)

- Is currently performing Run-III, recording collisions of protons from the LHC at 13.6TeV



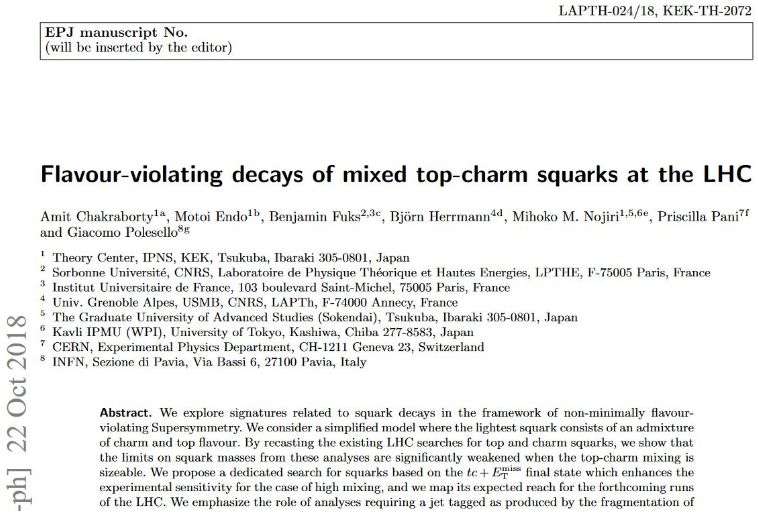


The tc+MET Search



- Signal of interest contains 1 top quark, 1 charm quark, 0 leptons and significant missing transverse energy
- $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \geq m_t$
- Assuming maximal mixing between 2nd & 3rd generation sQuarks/quarks
- Focusing on 2-body decay for this analysis round, produce branching ratio scan
- Using full Run 2 139fb^{-1} collider data

Theoretical Motivations



LAPTH-024/18, KEK-TH-2072

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Flavour-violating decays of mixed top-charm squarks at the LHC

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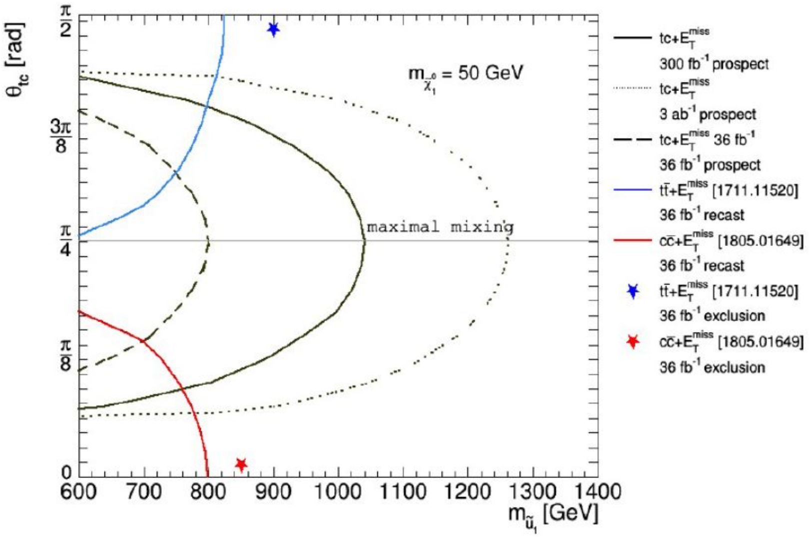
Abstract. We explore signatures related to squark decays in the framework of non-minimally flavour-violating Supersymmetry. We consider a simplified model where the lightest squark consists of an admixture of charm and top flavour. By recasting the existing LHC searches for top and charm squarks, we show that the limits on squark masses from these analyses are significantly weakened when the top-charm mixing is sizeable. We propose a dedicated search for squarks based on the $tc + E_T^{miss}$ final state which enhances the experimental sensitivity for the case of high mixing, and we map its expected reach for the forthcoming runs of the LHC. We emphasize the role of analyses requiring a jet tagged as produced by the fragmentation of

Search motivated by non-Minimally Flavour Violating theory
Arxiv: 1808.07488

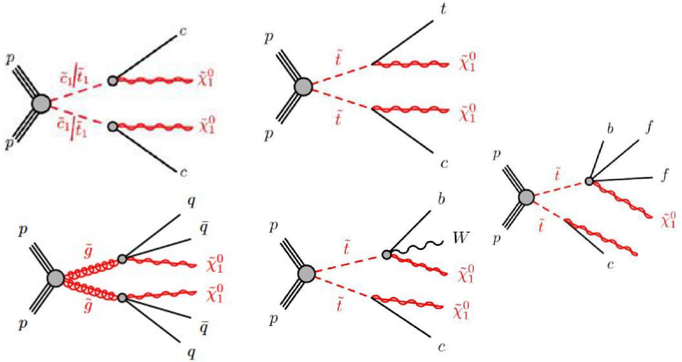


Constraints on mixing of 2nd and 3rd generation weakly constrained by analyses.
Early Run 2 SUSY searches are sensitive to small mixings but insensitive to maximal

Practical/Experimental motivations

Strong Produced SUSY

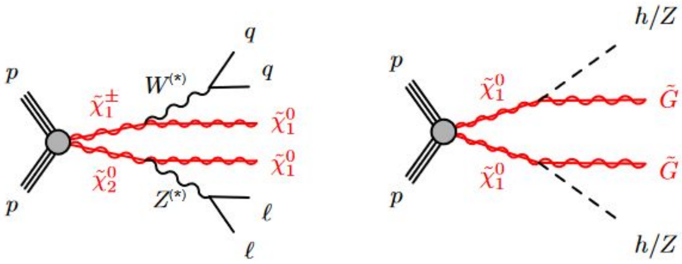
- Produced Squarks/Gluinos decay via strong interactions to LSP
- Higher expected cross-section than Electroweak
- Less clean signals, backgrounds significant
- **Additionally, a useful testbed for novel techniques**



Examples of SUSY signals produced via strong interactions

Electroweak Produced SUSY

- Produced Chargino/Neutralinos decay via electroweak interactions to LSP
- Generally lower expected cross sections than Strong
- Generally cleaner signals



Examples of SUSY signals produced via electroweak interactions

Analysis Strategy

$\Delta m(\tilde{t}_1, \tilde{\chi}^1_0) >> m(t)$: Boosted region (SRA) with highly boosted c-jets, leading b- or c-jet

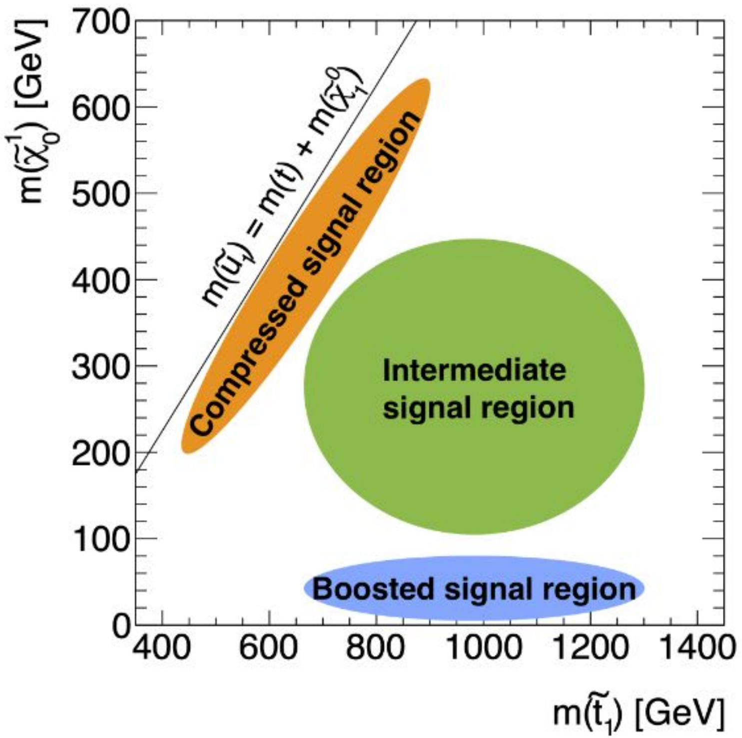
- Main backgrounds: Z+Jets & Single-top

$\Delta m(\tilde{t}_1, \tilde{\chi}^1_0) > m(t)$: Intermediate region (SRB & SRC) with moderate p_T c-jets, leading b- or c-jet

- Main backgrounds: Z+Jets & Single-top

$\Delta m(\tilde{t}_1, \tilde{\chi}^1_0) \sim m(t)$: Compressed region (SRD) with low p_T c-jets, leading Initial State Radiation jet

- Main backgrounds: $t\bar{t}$, Z+jets and W+jets



Signal Discrimination

Boosted and Intermediate

Cut and Count analysis based on:

- E_T^{miss} significance: Parameterizing how important the missing energy is while accounting for detector resolution effects
- m_T - Transverse mass calculated for c-tagged and b-tagged jets and E_T^{miss} vector
  - Useful for rejection of tt backgrounds
- m_{T2} - stransverse mass variable, a generalisation of the transverse mass when two semi-invisibly decaying particles are pair-produced

Compressed

Dedicated Neural Net discriminator scores for signal and background

- Basic preselection based on angular variables and E_T^{miss} significance , mainly reduces multi-jet backgrounds
- Trained on tt, V+Jets and $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$ = 175, 200 GeV events signal events passing preselection
  - pT, η, ΔΦ(j, met) and flavour of leading six jets, leading two b- and c-jets, met and jet multiplicities as input
- Scores produced for signal, tt & V+Jets

Both strategies highly dependant on charm-jet and top tagging
Top tagging based on ATLAS recommended DNN large-R jet tagging

Charm Tagging

ATLAS has established methods of flavour tagging light and b-jets

- Predominantly reliant on scattering angle differences between primary and secondary showers

Currently no established working point recommended for c-jets, difficult to distinguish from light/b-jets

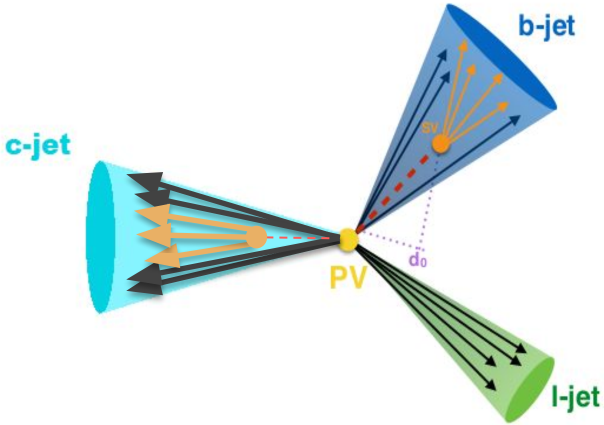
Use Deep Learning tagger probabilities developed for b-jet tagging, reformulated for c-jet scores

Achieve 20-40% efficiency working points with various levels of fakes rejections

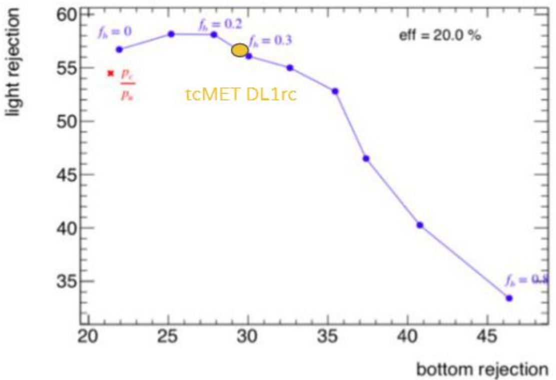
Developed for Strong SUSY analyses:

- tc+MET
- cc+MET

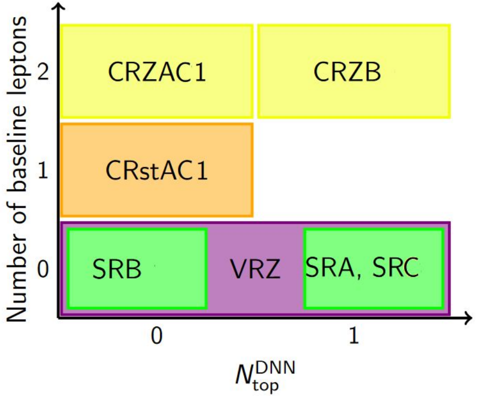
Powerful tool despite statistical limitations



$$\mathtt{DL1r}_c = log\left(\frac{p_c}{f_b * p_b + (1 - f_b) * p_u}\right)$$



Background Modelling



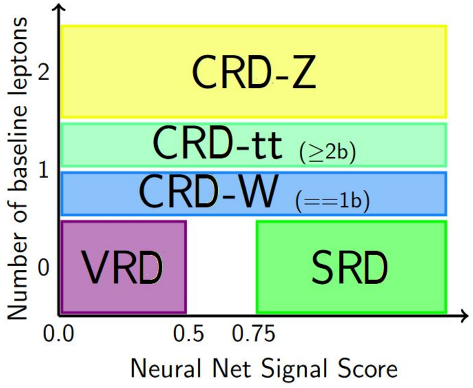
1L (e or μ) preselection to define single-top CRs

- Lepton treated as proxy for tau for both tt or W backgrounds

Boosted/Intermediate VRZ kept orthogonal to SRA/B/C through kinematic selections

2L preselection to define Z+jets CRs, deriving a normalisation factor for each relevant SR

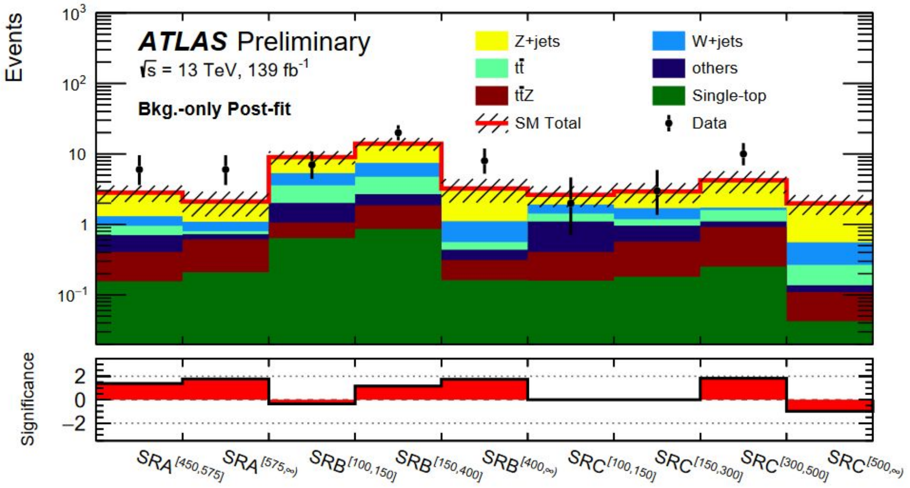
- 2L treated as invisible as proxy for Z->$\nu\nu$ decay background

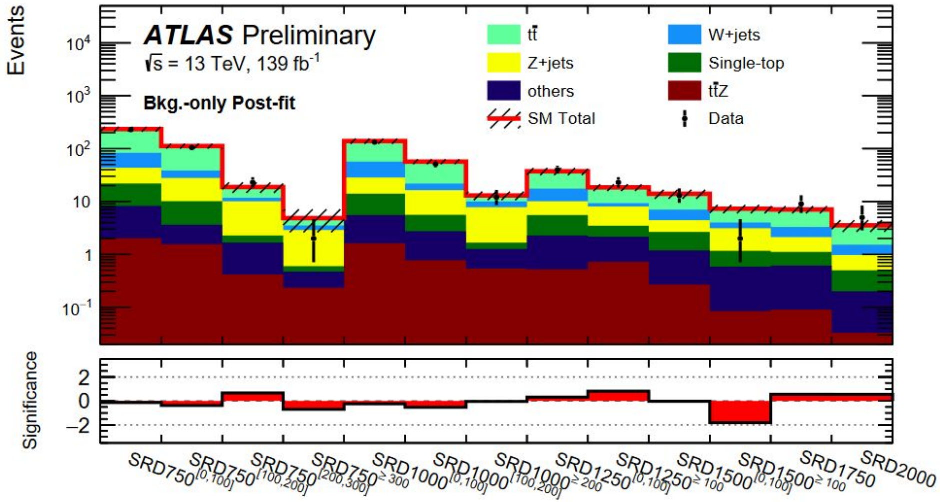


Results - No SUSY discovery

No significant excess seen above SM prediction.

Largest excess seen <2σ





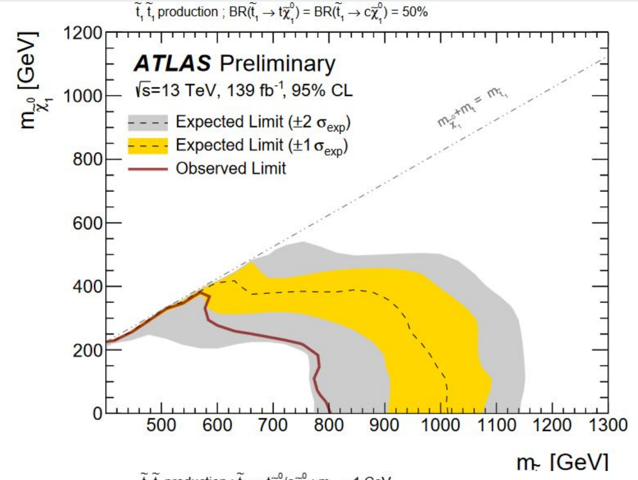
Results

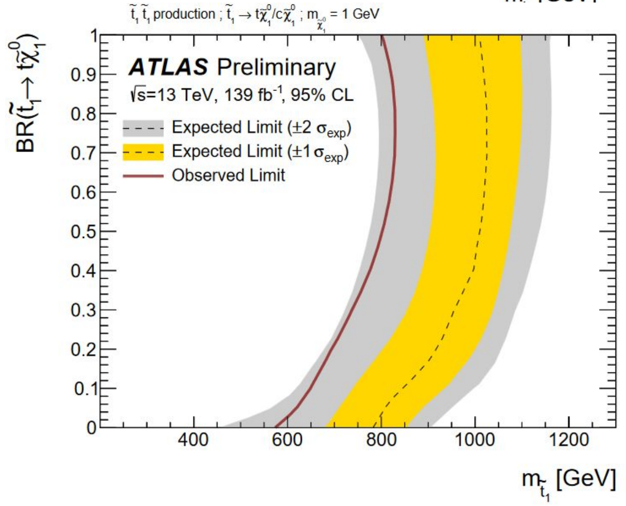
Strong exclusion limits, clear impact of the small excess on the observed limits.

Despite this, an exclusion up to 800 GeV on top-squark masses is observed for a massless neutralino.

In the compressed region,top-squark masses up to 600 GeV are excluded

- Mass plane, stop mass vs χ^0 mass
- BR plane, stop mass vs BR(stop $\rightarrow t\chi^0/c\chi^0$)

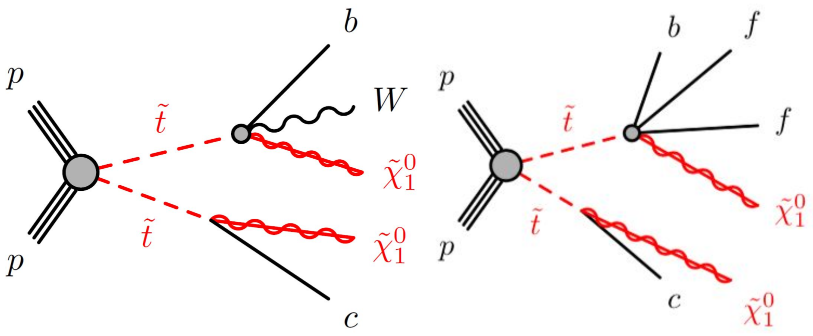




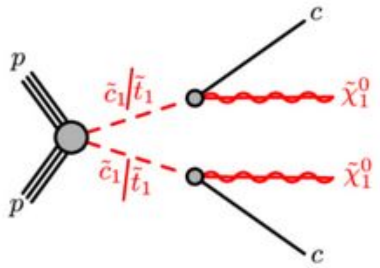
Future Work

- Statistical combination analysis possible with cc+MET analysis in near future
- Run 3 data extension
- 3 & 4 Body decay channels in future round of analysis
    - Most likely in Run 3 extension rather than standalone, since there is a push for analyses to not stay on Run 2
- Analysis made public at Presented at EPS-HEP2023, Hamburg, Germany, De, 20 - 25 Aug 2023
    - Paper coming soon as well!

Looking forward to upcoming analyses in Run 3



3 & 4 body signal final states



cc+MET analysis - Paper coming soon!

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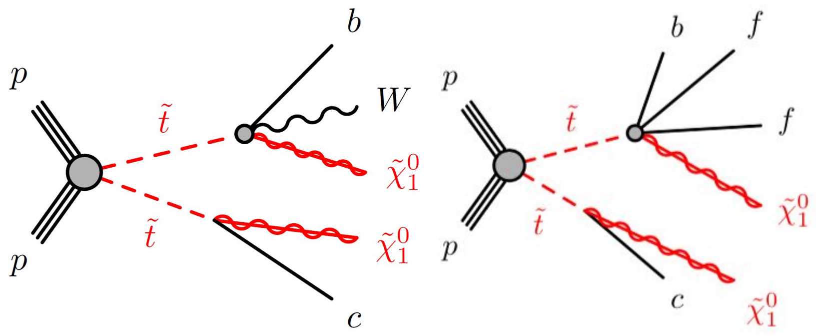

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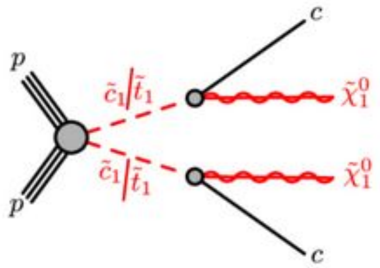


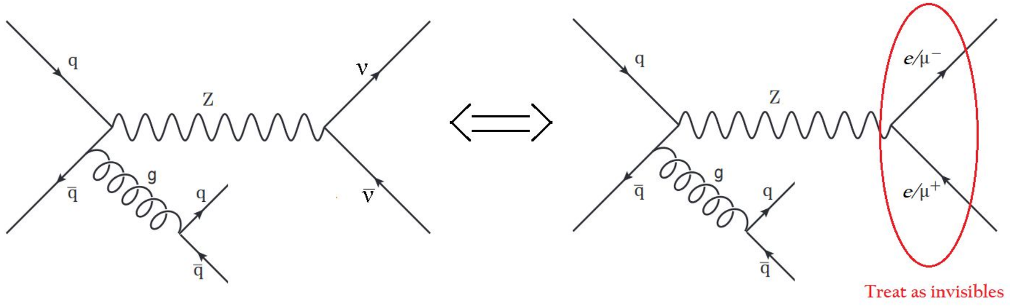
cc+MET analysis - Paper coming soon!

Backup Slides

Example: Z+Jets modelling consideration in 0L signals

One of the largest sources of background in Missing Transverse Energy signals

- Use Control regions enriched in Z+Jets with no/very low signal contamination
- Use 2-lepton regions, orthogonal to 0-lepton SRs
- Treat 2 leptons as invisibles, add to all MET calculations (MET-prime)
- Additional cuts like SR to ensure kinematics are consistent



Types of questions checked

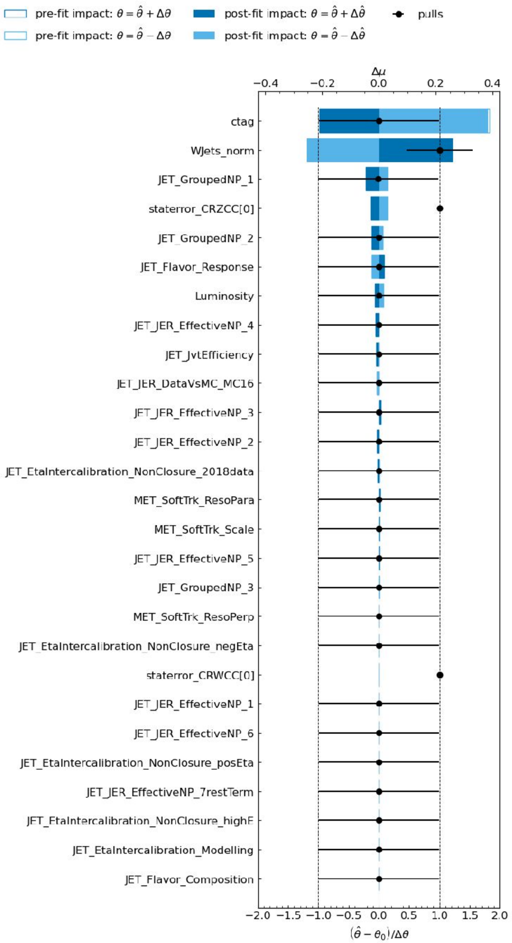
- 2L flavour composition consistent with 0L
- Good modelling in these regions
- Fit to corresponding Validation Region is reasonable

Systematics and extra studies

Using conservative flat uncertainties in analysis development
a
Need full treatment of experimental/detector and theoretical systematics before we can unblind

- Fortunately, ATLAS and SUSY groups have baseline recommendations
- Can obtain full MC with variations of most systematic sources applied, either full events or scale factors

Depending on the more novel strategies used, may need to study and provide extra systematics before unblinding.



Charm Tagging