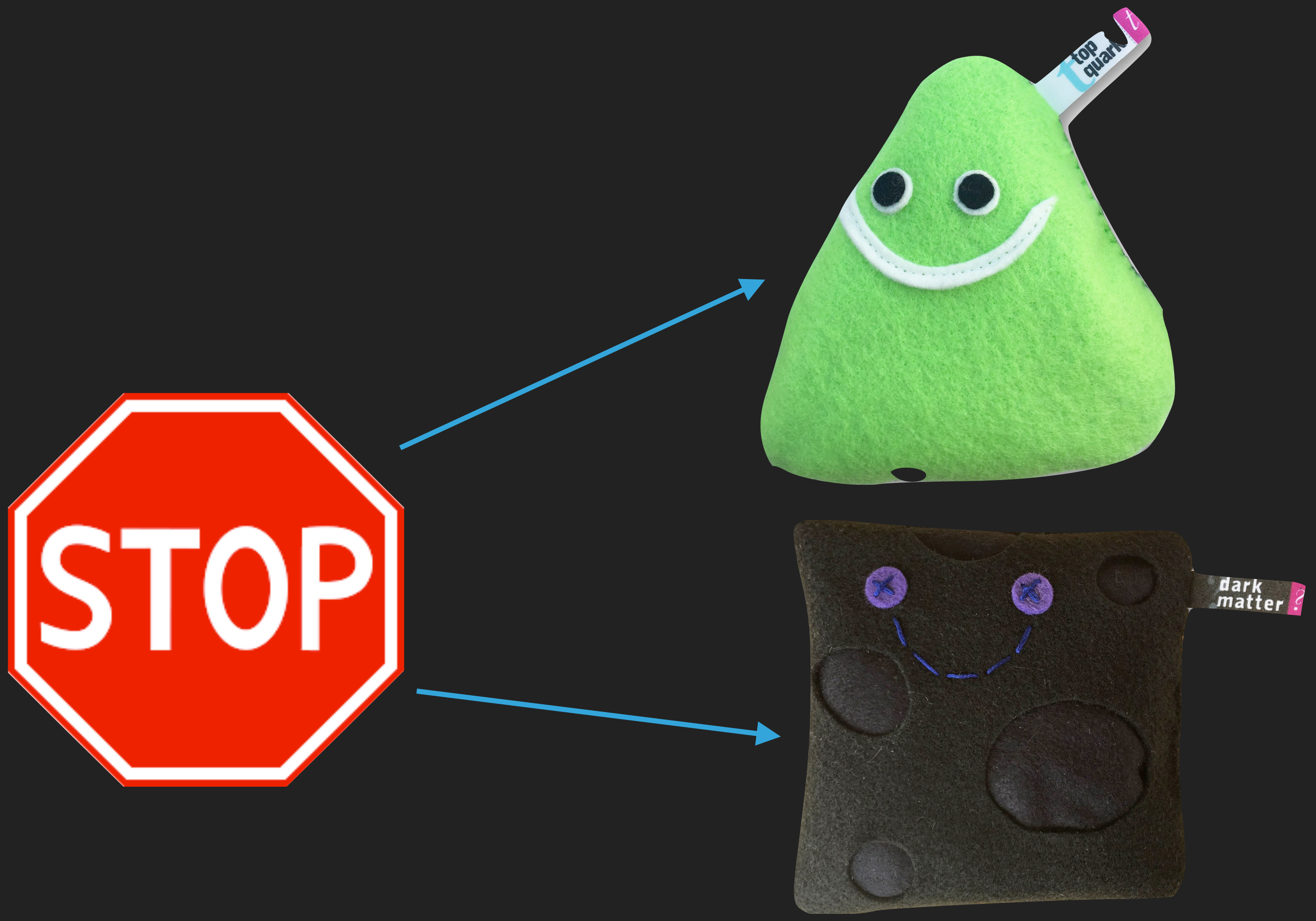


MATTHEW ANTHONY

SEARCH FOR THE SUPERSYMMETRIC PARTNER TO THE TOP QUARK IN THE ALL HADRONIC FINAL STATE WITH THE ATLAS DETECTOR

INTRODUCTION

- In this talk, I will discuss the following:

  A brief motivation for SUSY searches, in particular those for SUSY partners to the third generation quarks.

  ATLAS search strategy for the search for the SUSY partner to the top quark in the 0 lepton final state.

  Improvements in the search strategy:
  Constraining the irreducible tt+Z(->vv) background using tt+Z(->ll).

SUSY OVERVIEW

- Limitation of the Standard Model:
  Higgs mass measurement:

  1) Large divergent corrections arise in the calculation of the corrections to the Higgs mass (O(scale^2)), which would place the Higgs mass in the order of the Planck Scale, rather than the observed value.

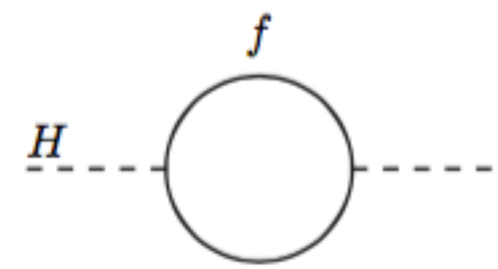
  2) Extensive fine tuning of the relevant terms in the calculation would be required to rectify this issue.
  Naturalness posits that these fine tuning corrections are not physical.

- A rectification exists:
  For each spin state of a fermion, a boson partner (Sfermion e.g. squark) is predicted, and for each boson spin state, a fermion partner is postulated (Bosino, e.g. Wino).
  This can produce the desired cancellation in the Higgs mass corrections.

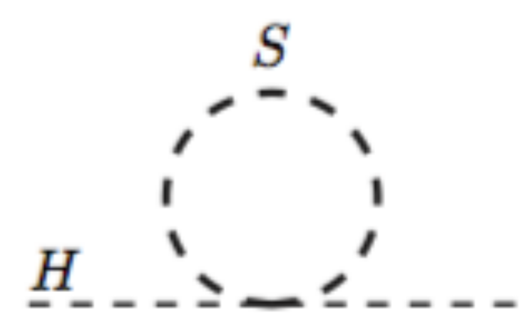
- Soft supersymmetry breaking gives rise to SUSY partners that are distinct in mass from their respective partners.

- Due to the large mass of the top and bottom quark and the mixing of the stop/sbottom, the scalar partners of the 3rd generation quarks are expected to be light.

- The full story is well beyond the scope of this talk, but here is a nice theory primer on SUSY: https://arxiv.org/abs/hep-ph/9709356

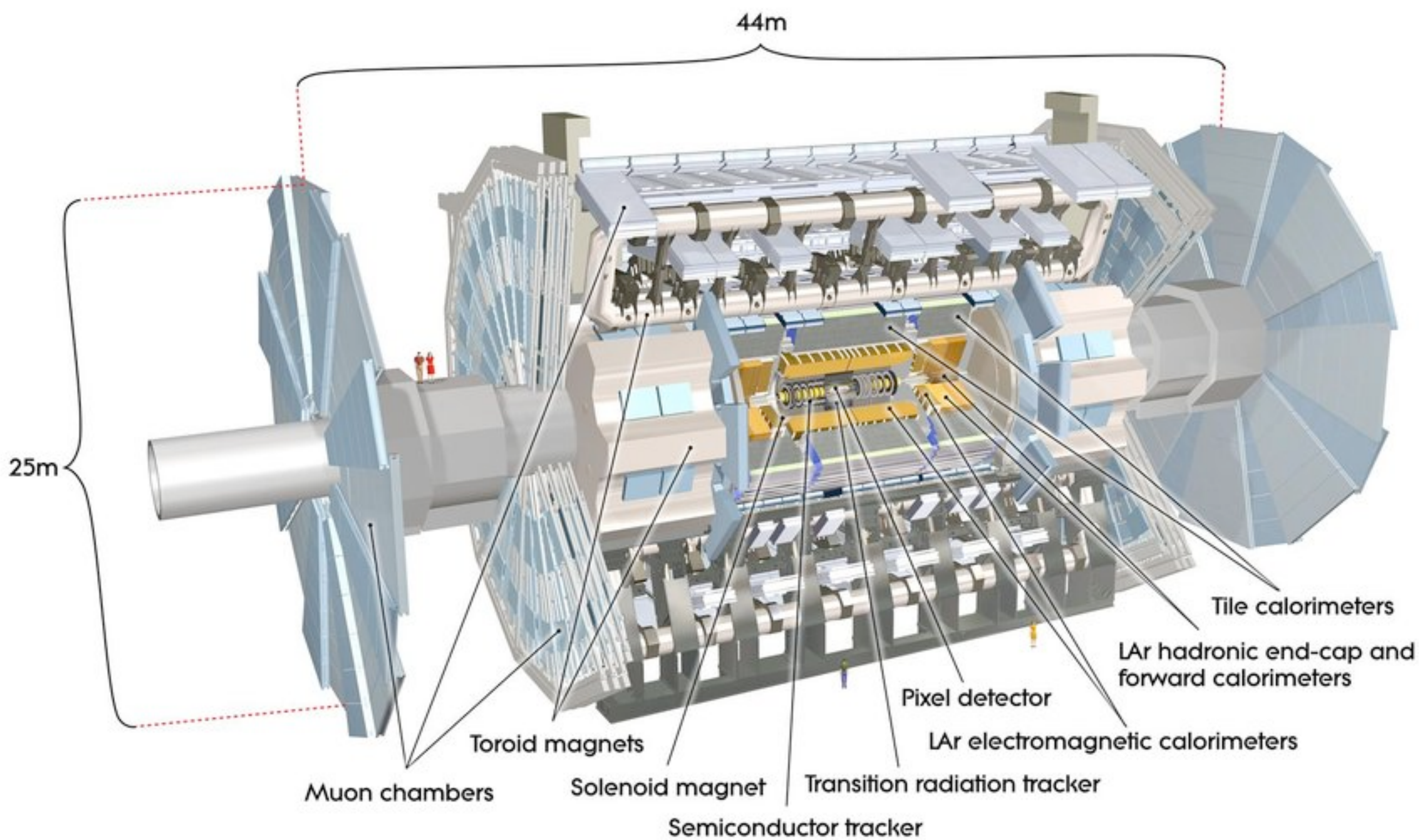


Divergent fermion loop term



Proposed bosonic counter term

ATLAS DETECTOR



Source: https://www.researchgate.net/figure/The-ATLAS-detector-and-subsystems_fig1_226619417 (accessed 11/3/2019)

ATLAS 4 momentum coordinate system: (pt, eta, phi, E) $\eta = -\ln \tan \frac{\theta}{2}$

KEY OBJECTS TO CONSIDER

- Jets: hadronisation of "bare" quarks leads to a formation of a jet.

  ATLAS uses the Anti-KT algorithm to reconstruct such jets from energy deposits (clusters) in the calorimeter, with a radius R (in eta, phi) of 0.4

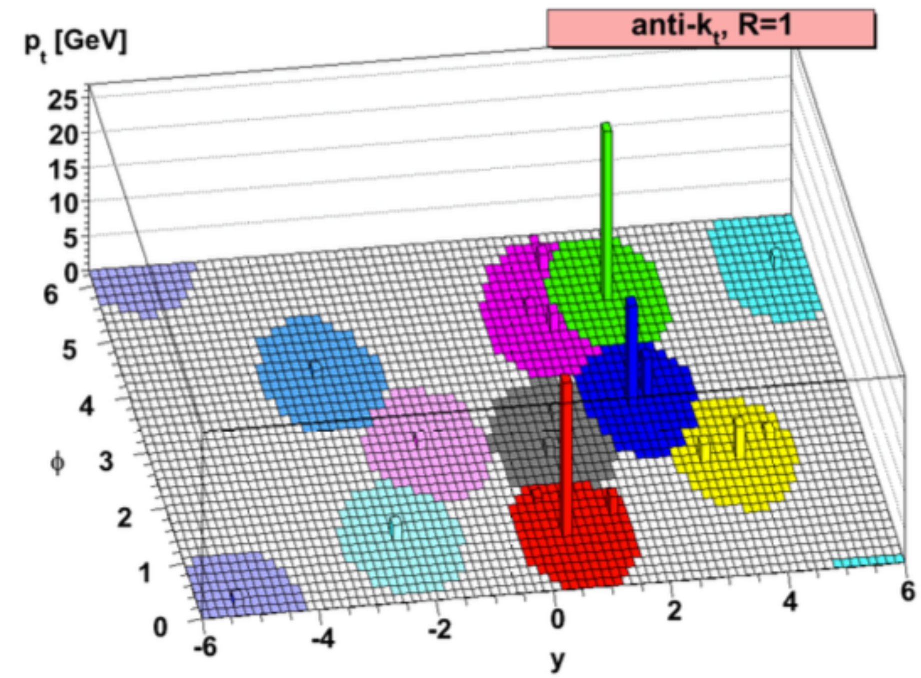
- Large radius re-clustered jets: ATLAS use the KT algorithm to recluster already reconstructed jets into a larger jet object with a radius R (in eta,phi) of 0.8 or 1.2 respectively.

  This is useful in cases for heavy boosted objects (e.g. top), where all (or most of) the decay products are boosted (collinear).

- B-jets:
  Use of high level tagging based on tracking/calorimeter information to identify jets originating from B-hadron decay.

  Makes use of the fact that B-hadrons decay at some observable distance from the impact point with secondary vertex finding algorithms.

- These objects are required to reconstruct the top quark from its decay products



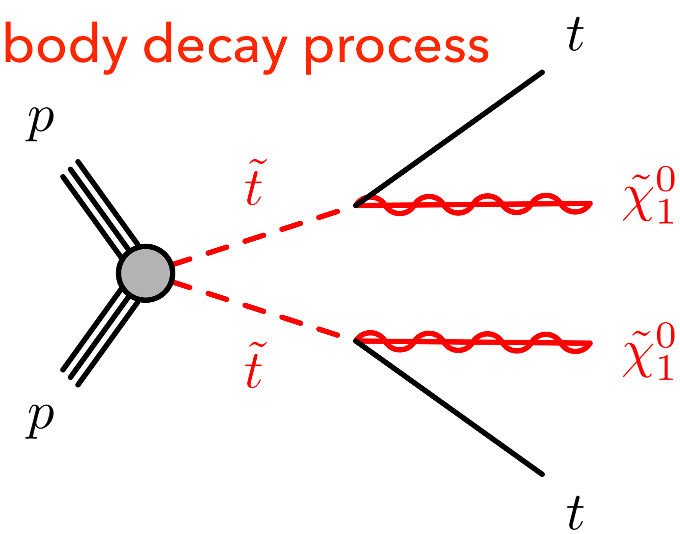
Jet reconstruction from calorimeter deposits

https://arxiv.org/abs/0802.1189 (Fig. 1)

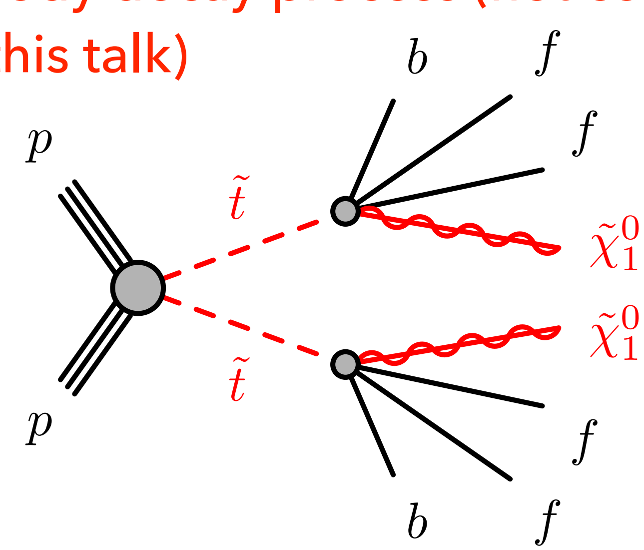
SIGNAL MODELS & PHASE SPACE TARGETED

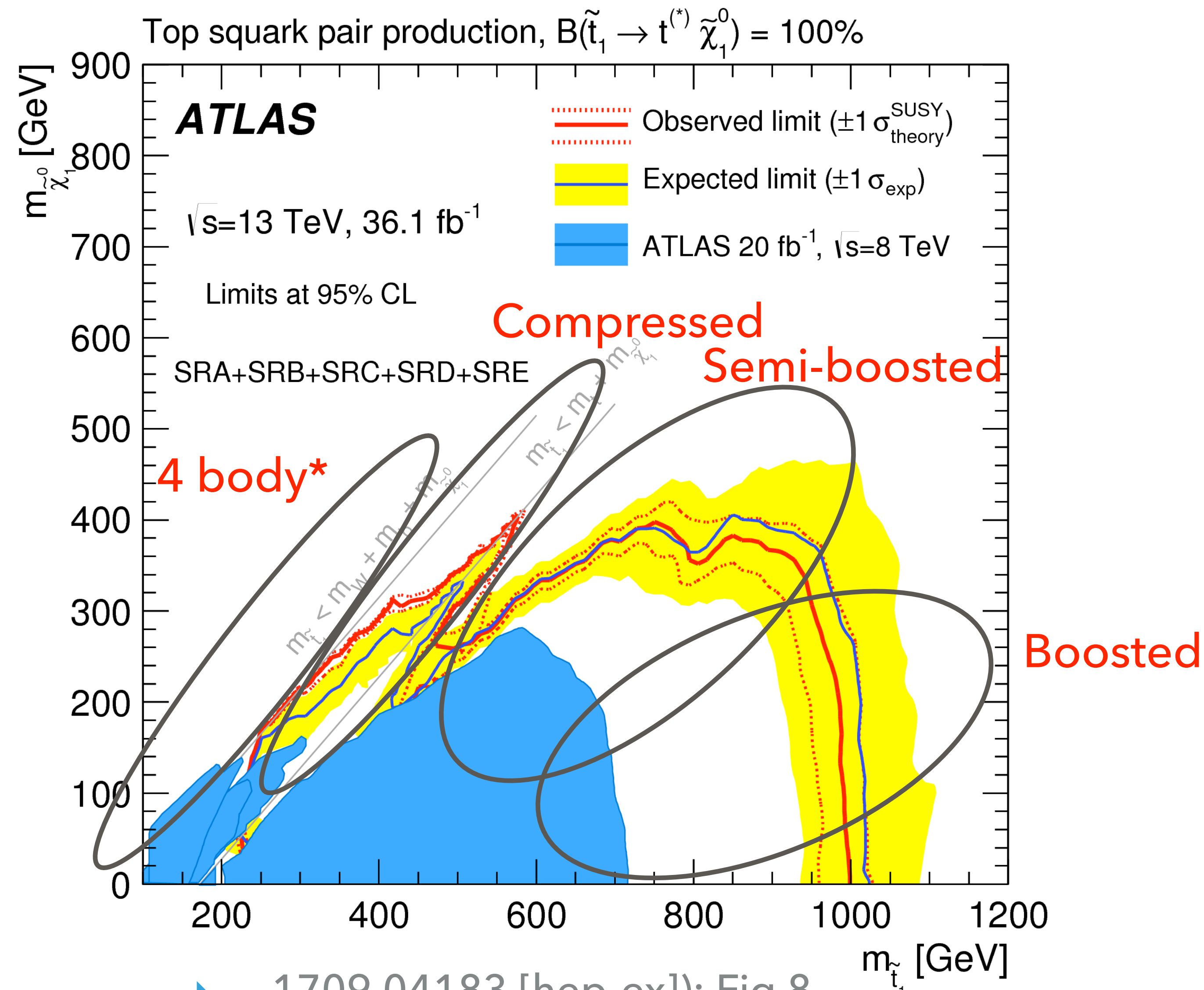
- Simplified models assuming a single SUSY decay process with a 100% branching ratio.
  Considering only R-parity conserving decays.
  R-parity: (-1)^(3B+L+2s), where L, B and s are the lepton, baryon and spin quantum numbers.
- Assume that the stop decays with 100% branching ratio to the Neutralino (Lowest mass mixed state of the Wino, Bino and Higgsino), the lightest supersymmetric partner (LSP).
- R-parity conservation means that the neutralino cannot decay into a lighter standard model particle, thus it is stable.

2 body decay process



4 body decay process (not covered in this talk)

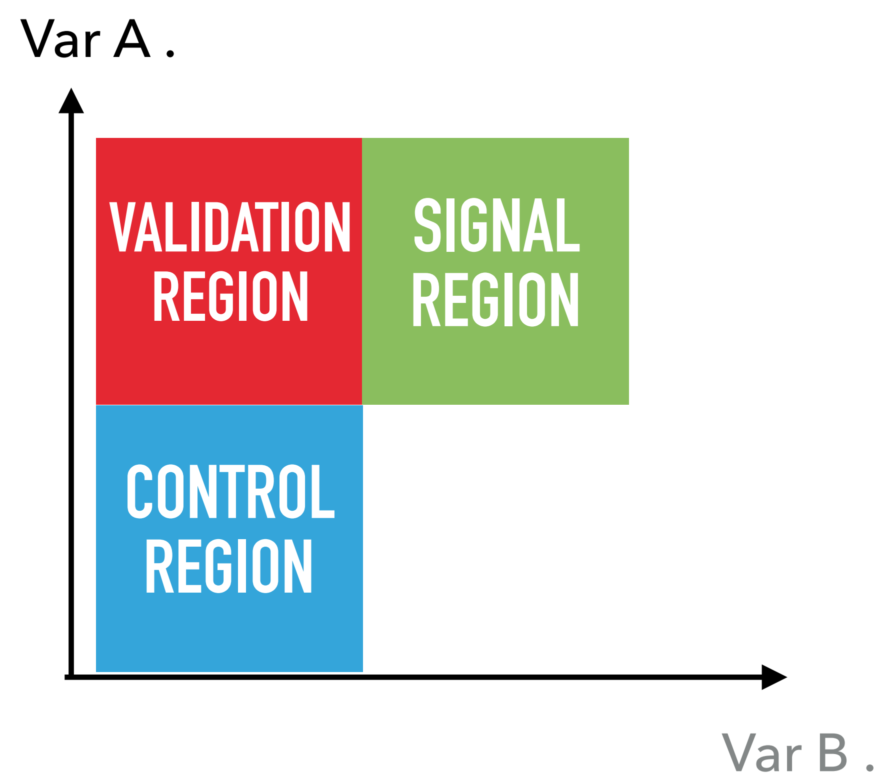




- 1709.04183 [hep-ex]): Fig 8

ATLAS SEARCH STRATEGY

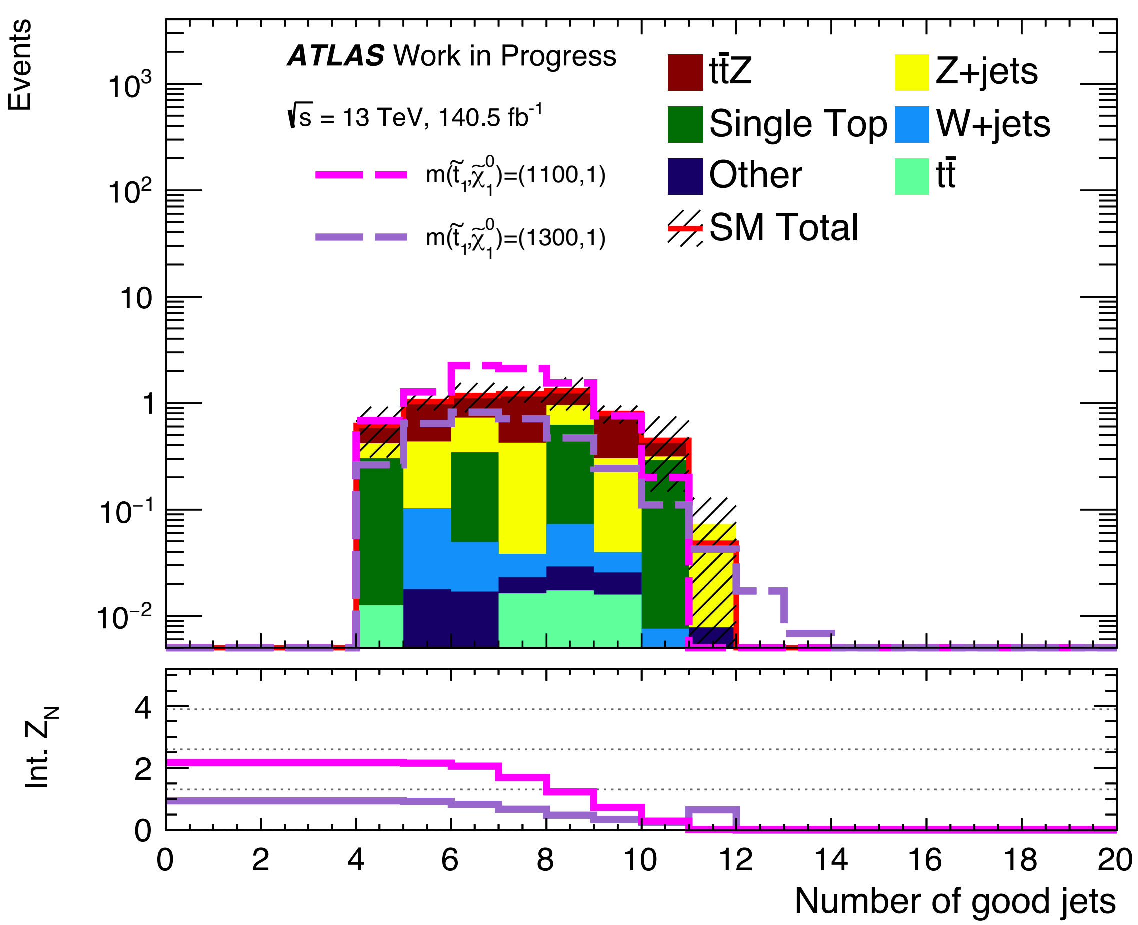
- Target phase space for 2 body decay processes:
  >=2 b-tagged jets, >=4 jets, large missing energy in the transverse plane (MET)
- Subdivided phase space into 3 distinct components:
  Control region (CR): No SUSY process expected, used to constrain SM backgrounds
  Signal region (SR): SUSY search region, already normalised backgrounds are applied here.
  Validation regions (VR) : Region used to check modelling of backgrounds. No SUSY expected here.
  Where possible, these regions are meant to be as kinematically similar as possible.
- Leading backgrounds:
  tt+Z (->vv) (Irreducible: Standard Model process indistinguishable from signal process)
  ttbar
  Single top:
  Z+ Heavy Flavour jets
  W+Heavy Flavour jets
  Multijet "QCD" background.
- Four signal regions:
  SRA: Boosted stop decays
  SRB: Semi-boosted stop decays
  SRC: Compressed stop decays
  SRD: 4 body decays

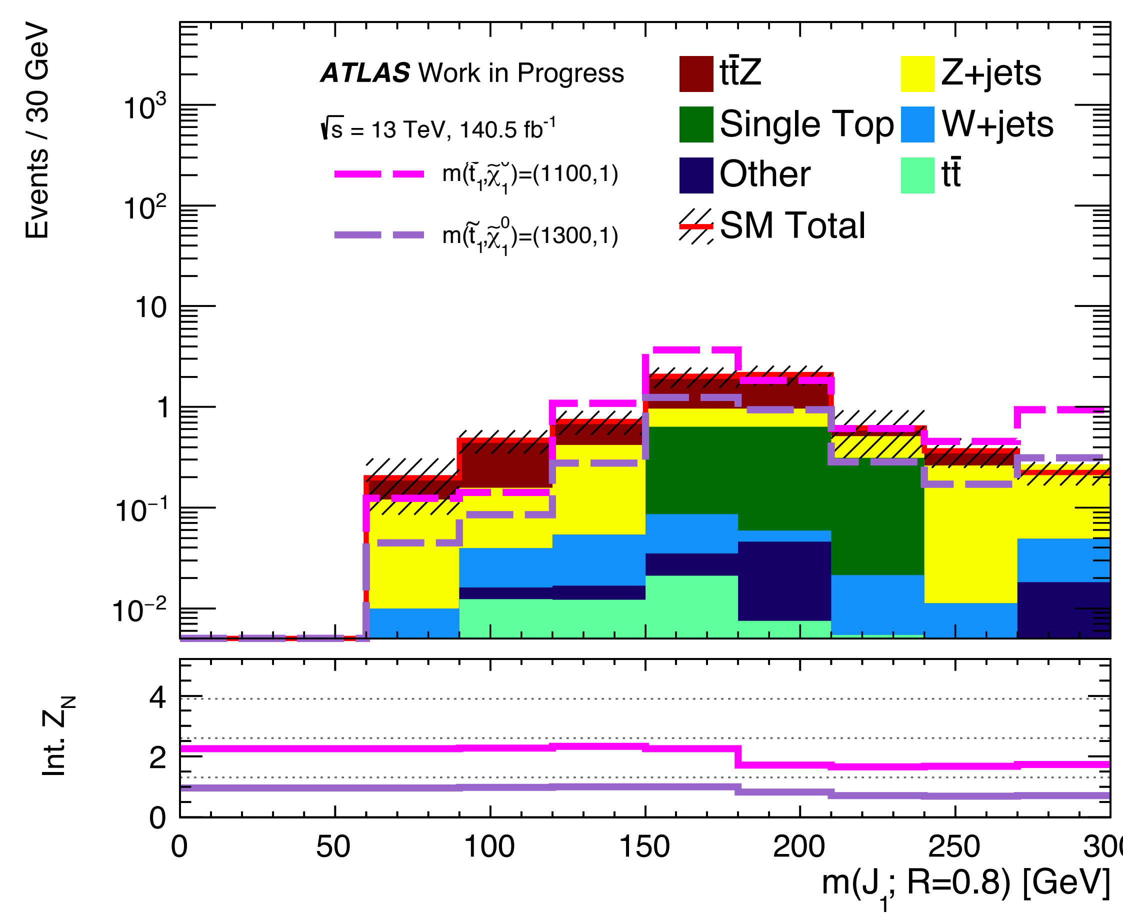


Optimal setup for a signal/control/validation region. Each of these regions is kinematically orthogonal (statistically independent).

BOOSTED REGION (SRA)

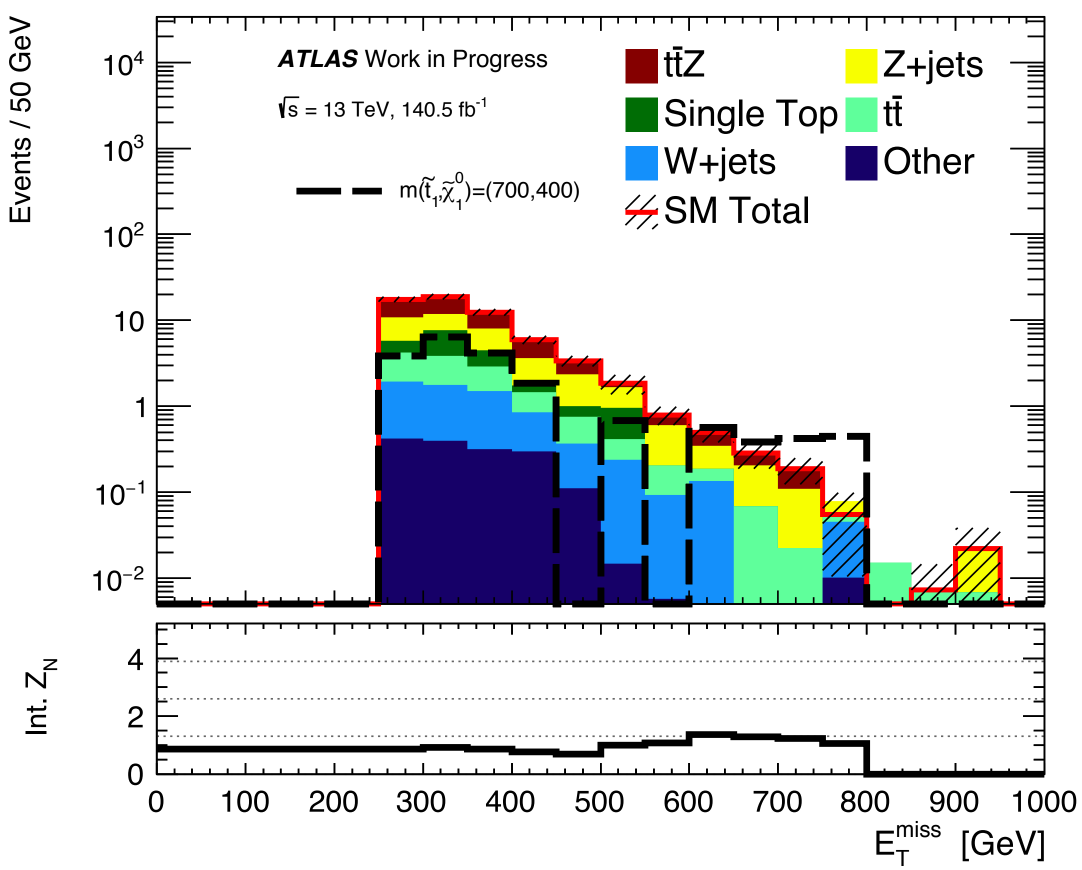
- Boosted region. Require N jets>=4, N b-tagged-jets>=2, MET >250 GeV.
- Targeting large delta M(Stop, Neutralino), where the top is expected to be boosted and the top decay products are expected to be observed close together.
- Use large-R reclustered jet observables to reconstruct the top from its boosted decay products. (e.g. mass of the highest-pT reclustered jet with radius of R=0.8)

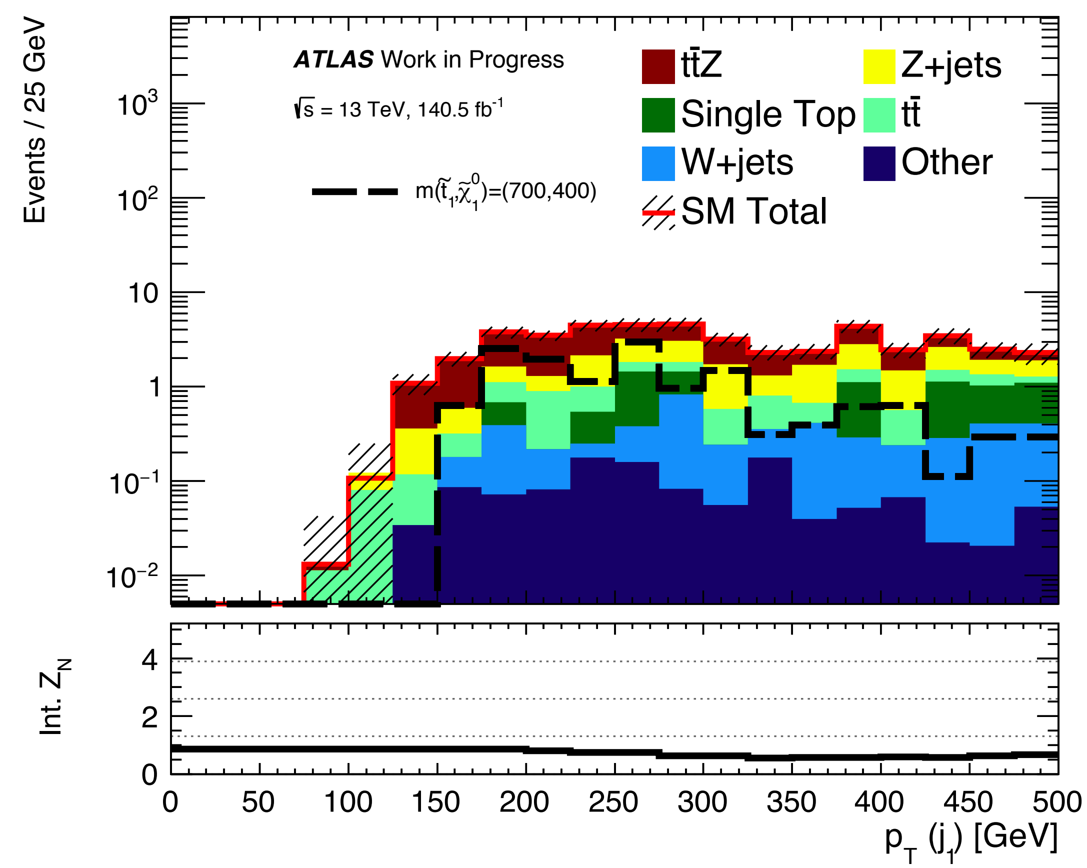




SEMI-BOOSTED REGION (SRB)

- Require NJets>=4, NbJets>=2, MET >250 as minimum selection
- Optimised to target signal models where dM(Stop, neutralino) > m(top).
- These regions will be subdivided based on the mass of the leading and sub-leading (in pT) R=1.2 reclustered jet, namely:
  Two top / TT category (Both masses > 120 GeV) ,
  TW category (leading mass >120 GeV, sub-leading mass in [60,120] GeV),
  single top (T0) (leading mass >120 GeV, sub-leading mass < 60 GeV.



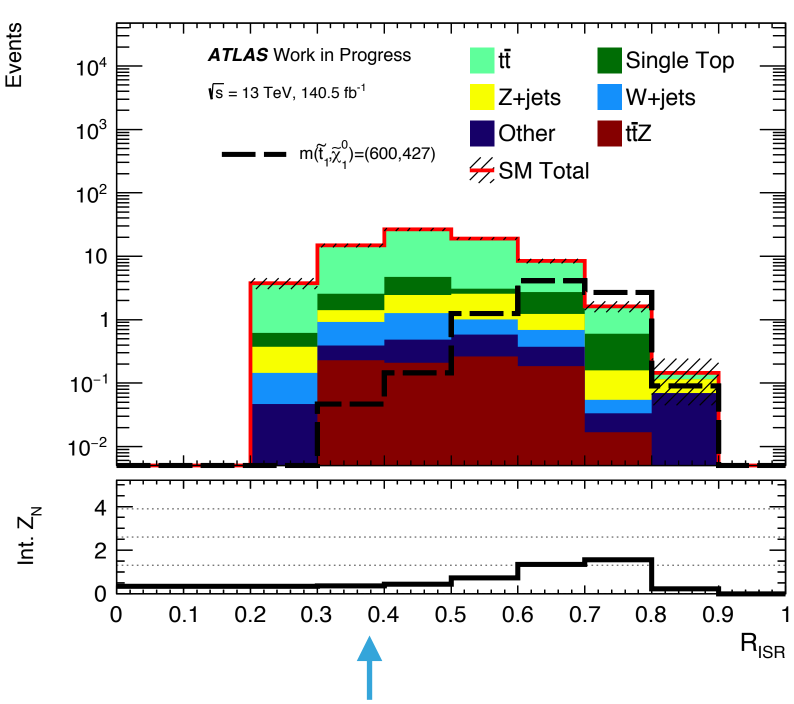


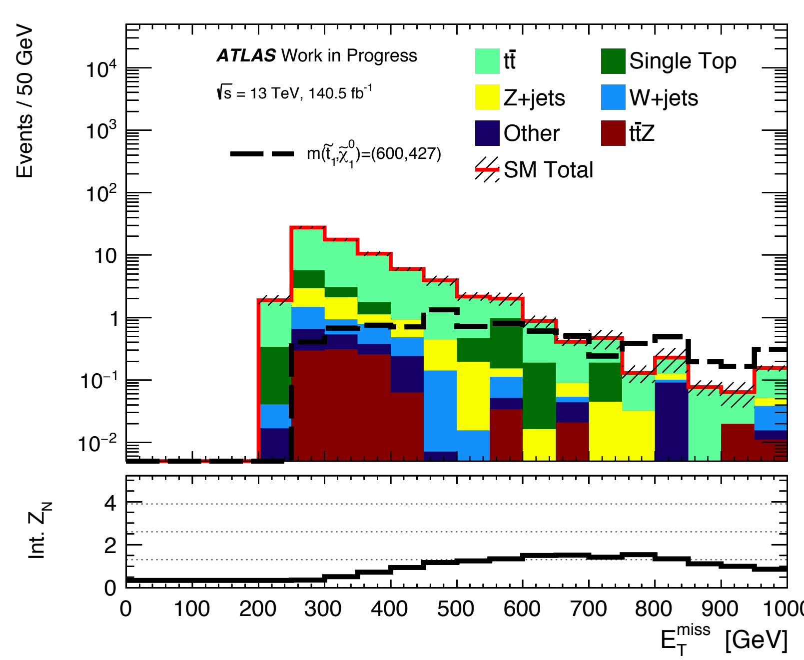
COMPRESSED REGION (SRC)

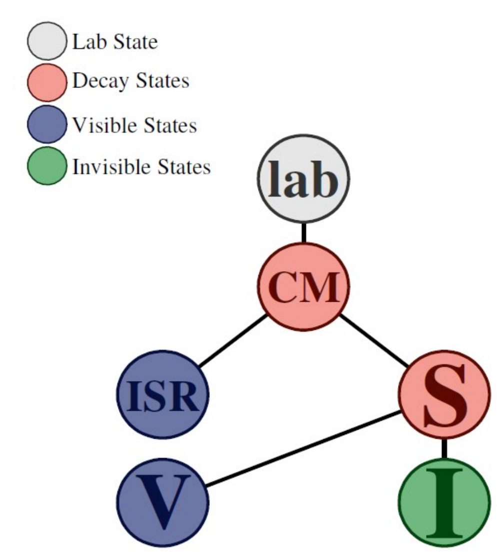
- Compressed region targets dM(stop, neutralino) ~ top, whereby the top is expected to be relatively soft.
- Compressed region would initially produce a low MET final state and soft top decays: indistinguishable from ttbar events. Require that the compressed system recoils from a large initial state radiation (ISR) jet.
- Since some parts of the decay chain are invisible, some reconstruction information is lost in combinatoric/angular ambiguities. Recursive Jigsaw reconstruction uses a series of "Jigsaw rules" to estimate the invisible decay component (and hence the parent particle) in terms of observable quantities in different frames of reference. The key components of this are outlined in the diagram below.

  The finer details of this reconstruction algorithm are beyond the scope of this talk, a nice paper on it can be found here: https://arxiv.org/abs/1705.10733

- RISR = MET/ pT(ISR jets) ~ M(Neutralino) / M (Stop). (See: arxiv:1709.04183 [hep-ex]).







- 1709.04183 [hep-ex]).

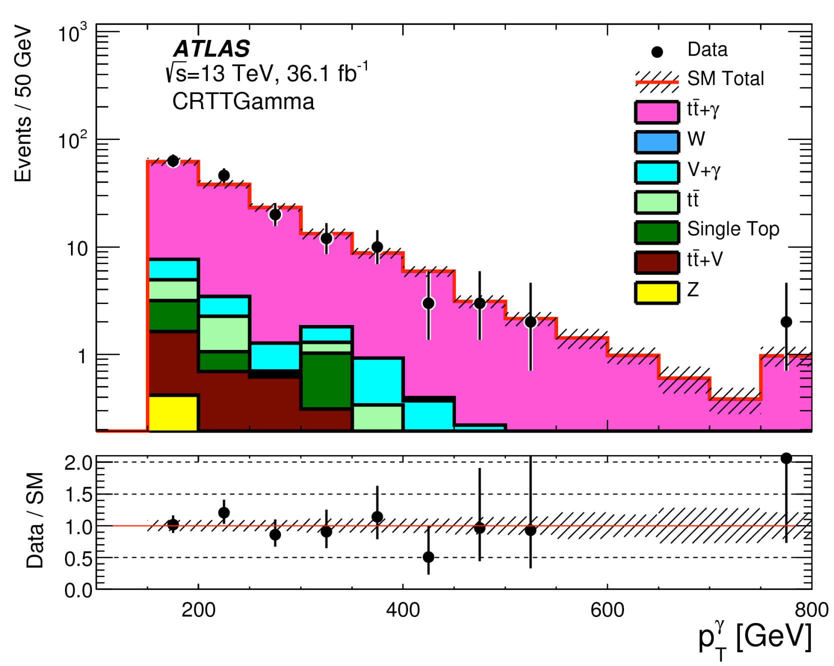
SRC is binned in this variable to improve significance.

Decay diagram considering all of the component parts of the recursive jigsaw reconstruction in SRC.

NEW IMPROVEMENTS FOR END OF RUN 2: CONSTRAINING THE TTZ BACKGROUND

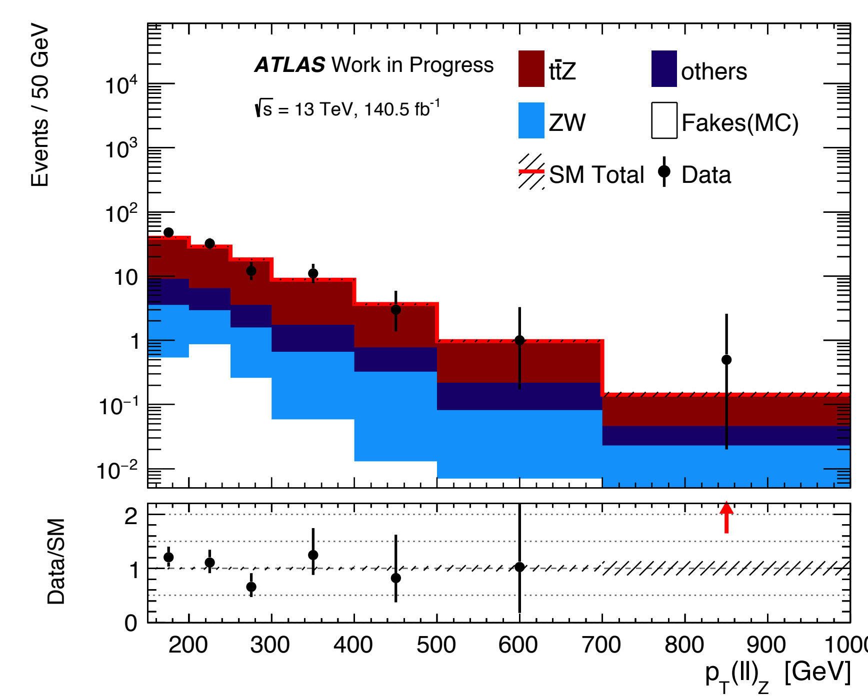
- Previous analysis used a semi-leptonic tt+photon process to model the all-hadronic tt+Z(->vv) process due to low statistics.
- Thanks to sufficient statistics at high pT(Z), can use the tt+Z(->ll) process to model the tt+Z(->vv) process. This is possible due to the increased luminosity from the entirety of LHC Run 2.
- Considered two possibilities, following on from the tt+V ATLAS analysis (1901.03584 [hep=ex]):
  2 OSSF leptons + jets,
  3 Leptons.
- Key variable of interest: pT(Z), also denoted as pT(ll).
- As shown in some of the previous slides, this improvement benefits the new boosted and semi-boosted signal regions in particular.

2015/16 control region for tt+Photon



- 1709.04183 [hep-ex]). : Figure 4(f).

End of run 2 Trilepton preselection for tt+Z(ll)

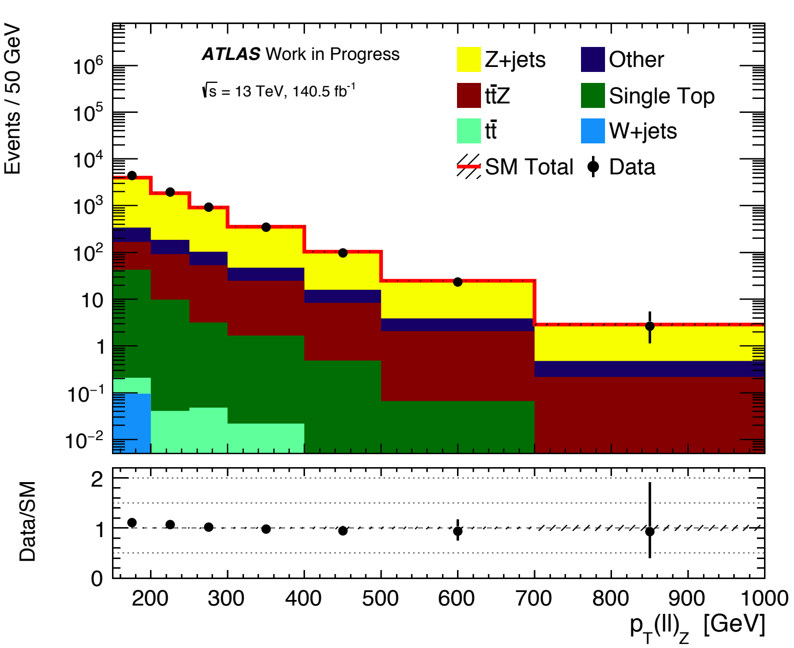


The University Of Sheffield.

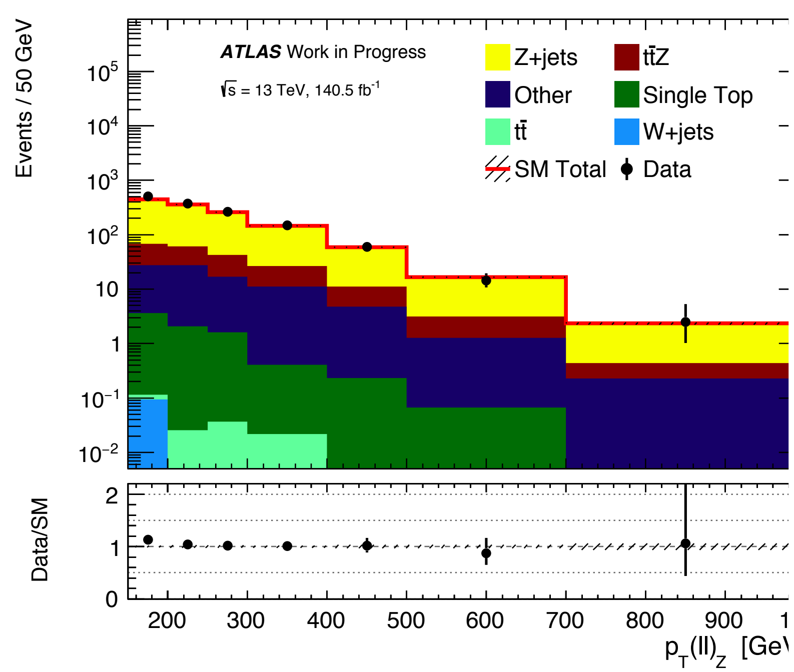
TTZ CANDIDATE CONTROL REGIONS

	2L OSSF (Opposite sign Same Flavour) (Hadronic tt+Z)	Trilepton (Semi-leptonic tt +Z)
Advantages	Direct model of hadronic tt+Z(->vv) Good statistics for ttZ(->ll)	Good purity of tt+Z(ll) “out of the box” Sufficient statistics in pT(ll) tail to match signal region MET requirements for ttZ(vv)
Disadvantages	Large Z+jets contamination. tt+Z->(ll) is not the dominant background in this region: Low purity. Significant difficulty removing other backgrounds (e.g. Z+jets) while keeping sufficient statistics for the control region	Uses a semi-leptonic ttbar component to model the all-hadronic ttbar component Low statistics in control region kinematically similar to signal region. Differing background composition to signal region.

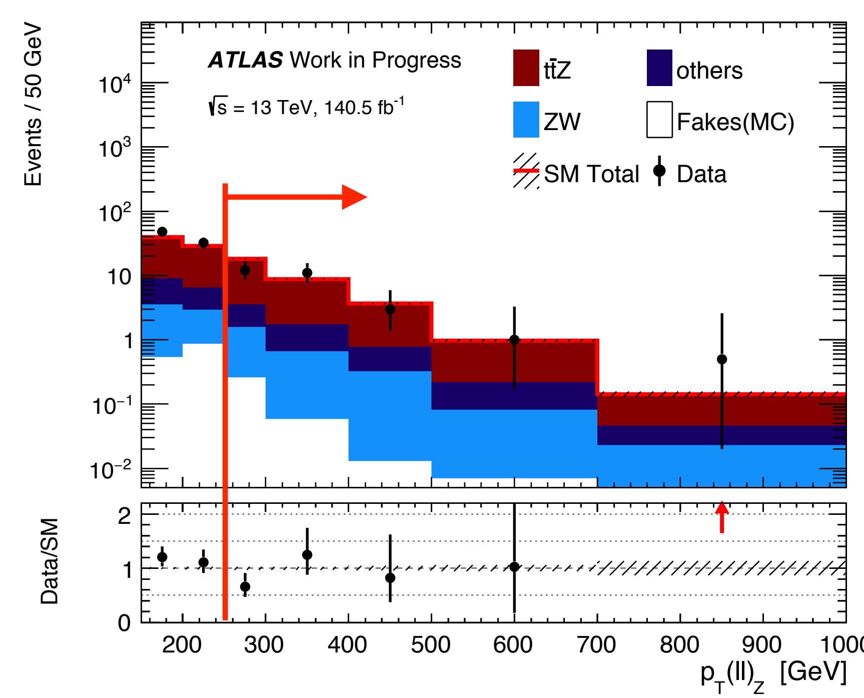
2 opposite sign same flavour leptons, >+4jets, >=2b-jets



2L region including Top tagging: leading Pt large R reclustered jet has mass >120 GeV



Trilepton control region:
nJets>=4, n B-tagged-jets>=2,
3 leptons (of which 2 are OSSF and consistent with Z mass)



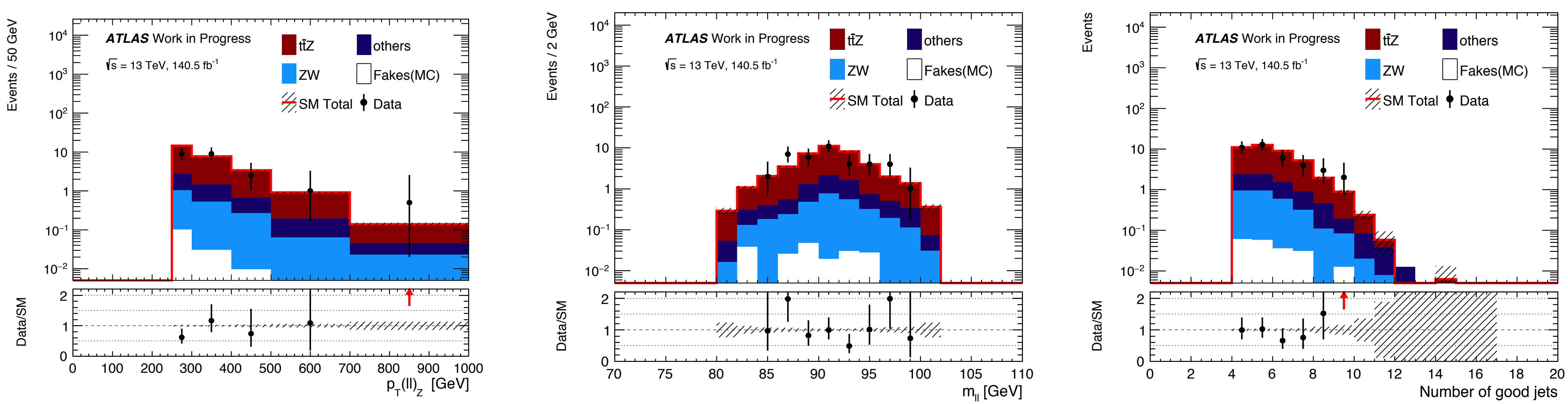
European Research Council

EXTENSION: USING SEMILEPTONIC TT +Z TO MODEL ALL HADRONIC TT + Z

- Limitation of trilepton CR: Direct application of both selections on jet pT and the pT(ll) results in a control region with very low statistics.
- Propose the following prescription, which is used to model the hadronic branch of tt+Z(->vv) using a semi-leptonic tt+Z(->ll) process use the following algorithm:

  1) Identify the Z as a pair of opposite sign, same flavour leptons
  2) Choose the pair with mass most consistent with Z mass.
  3) Treat the lepton not associated to the lepton and the MET as a jet.
  4) Apply Jet pT selections to the jets (incl. the MET, non-Z lepton) of (>80,80,40,40) GeV: This matches the selection on the jet pTs in the signal region.

- Require in addition a cut on pT(Z) > 250 GeV to match signal region MET cut.
- Normalisation uncertainties due to fakes background / WZ being estimated using Monte Carlo only have been determined to be negligible compared to statistical uncertainty in data, thus no additional control regions are required.



CONCLUSION

- The ATLAS search for the supersymmetric partner to the top quark has been outlined.
- Proposed a new constraining control region for the tt+Z background, to replace the tt+Photon control region previously defined.
- Thanks for listening.

credit: https://looneytunes.fandom.com/wiki/That%27s_all_Folks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BIBLIOGRAPHY

- Slide 2: S.P. Martin “A Supersymmetry Primer” https://arxiv.org/abs/hep-ph/9709356
- Slide 3: Source: https://www.researchgate.net/figure/The-ATLAS-detector-and-subsystems_fig1_226619417 (accessed 11/3/2019)
- Slide 6. : Search for a scalar partner of the top quark in the jets plus missing transverse momentum final state at $\sqrt{s}$=13 TeV with the ATLAS detector (arXiv:1709.04183 [hep-ex]): Figure 8.
- Slide 11: Search for a scalar partner of the top quark in the jets plus missing transverse momentum final state at $\sqrt{s}$=13 TeV with the ATLAS detector (arXiv:1709.04183 [hep-ex]). : Figure 4(f).
- Slide 15: https://looneytunes.fandom.com/wiki/That%27s_all_Folks (accessed 07/04/2019)