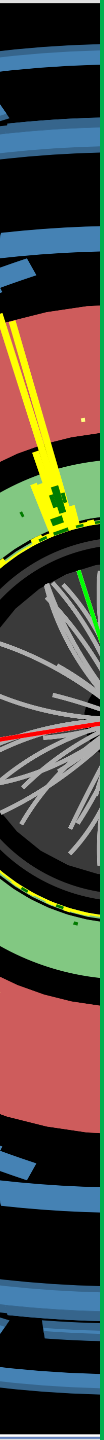
SEARCHES FOR STRONG PRODUCTION OF SUPERSYMMETRIC PARTICLES

Marco Rimoldi (CERN)
on behalf of the **ATLAS Collaboration**

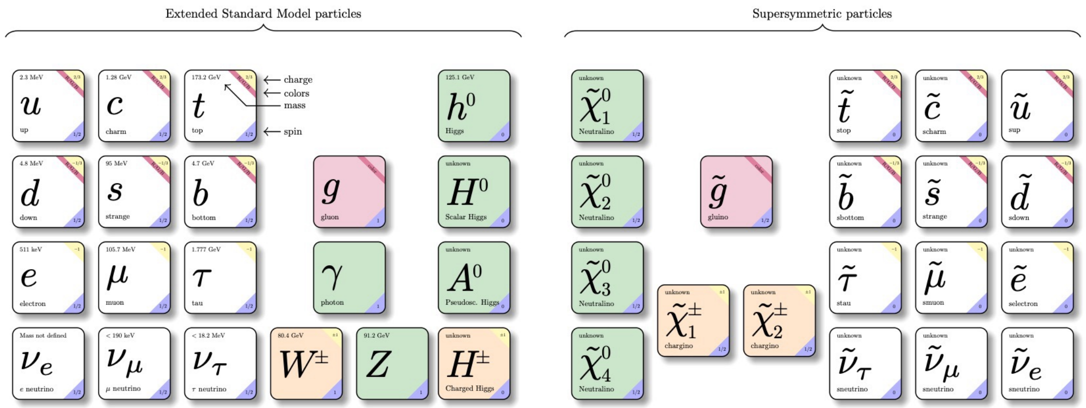
ICHEP 2024 - Prague

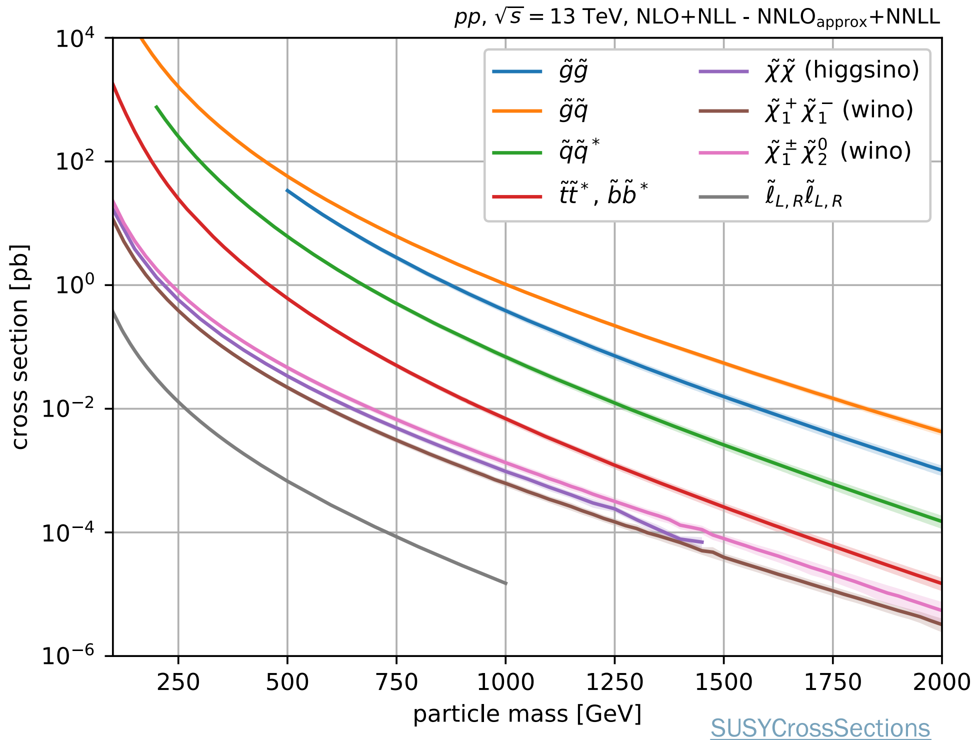


Searches for strong production of supersymmetric particles

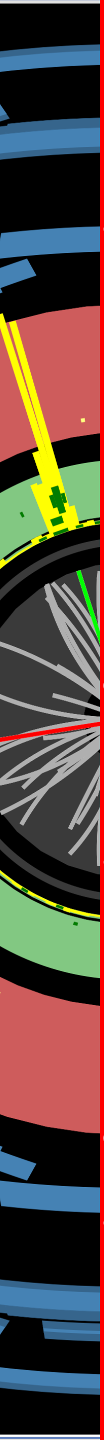
SUSY search program at the LHC

- Supersymmetry (SUSY) has the potential to
  - Provide a dark matter candidate;
  - Unify the forces at high energy;
  - Solve the fine-tuning problem of the Higgs mass.
- Broad search program to ensure that we get the most out of the LHC data.
- **Presents results for strong production in R-Parity Conserved scenario**
- **Electroweak production** was covered in Antonia's talk (LINK).
- Lauren's talk covered **R-Parity Violated** scenario (LINK) and Andrew's will conver **Long Lived Particle** scenario (LINK)
- Simplified models used for optimization and model-dependent exclusion limits.
  - Masses of non-relevant SUSY particles put very high.
  - 100% BR to specific final state.
- Check coverage in large pMSSM scans.
- Model-independent upper limits, HEP data, ..
- All results presented today with the 139/140 fb^{-1} dataset





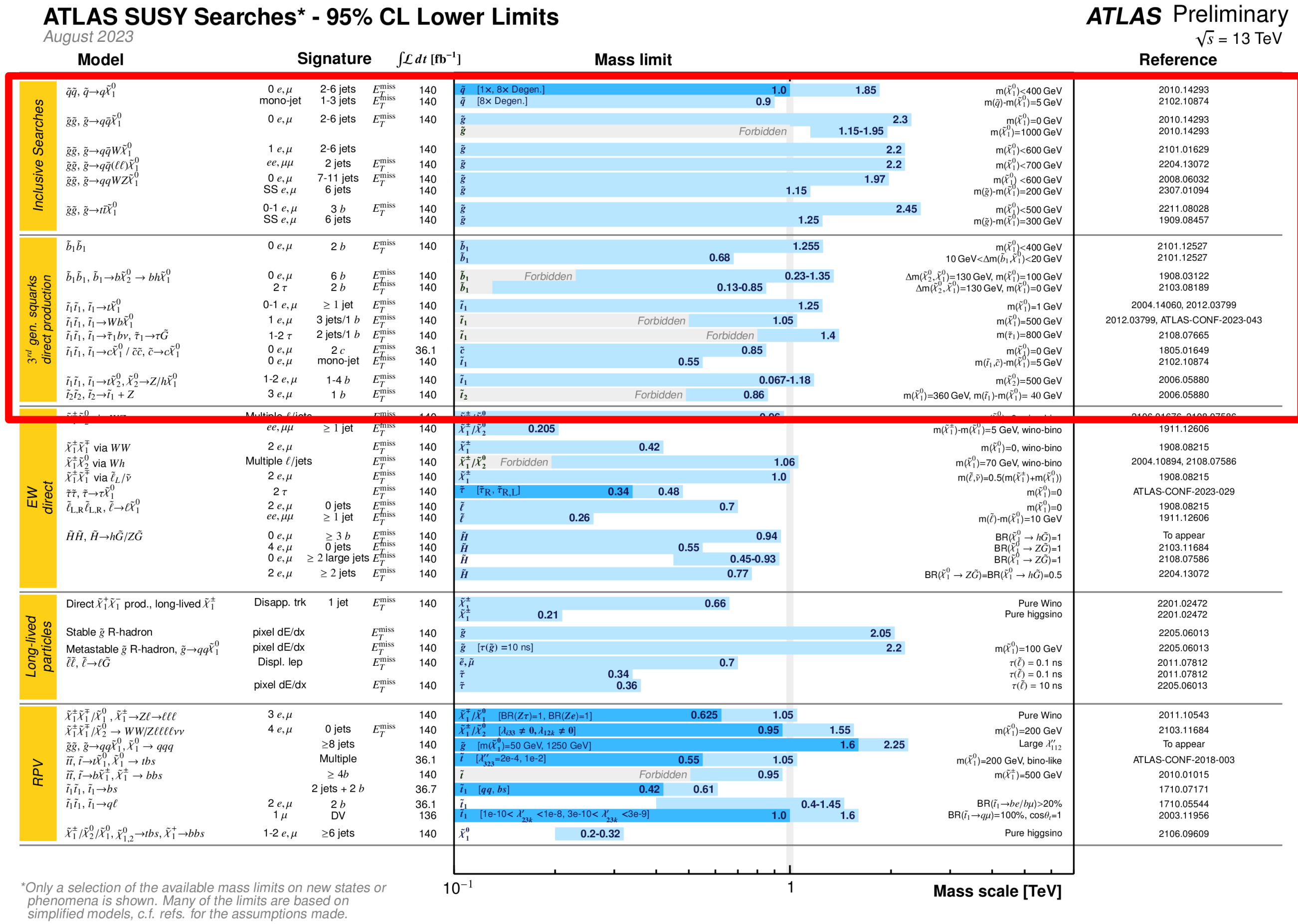
SUSYCrossSections

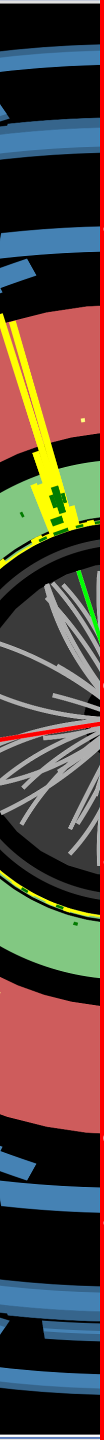


Searches for strong production of supersymmetric particles

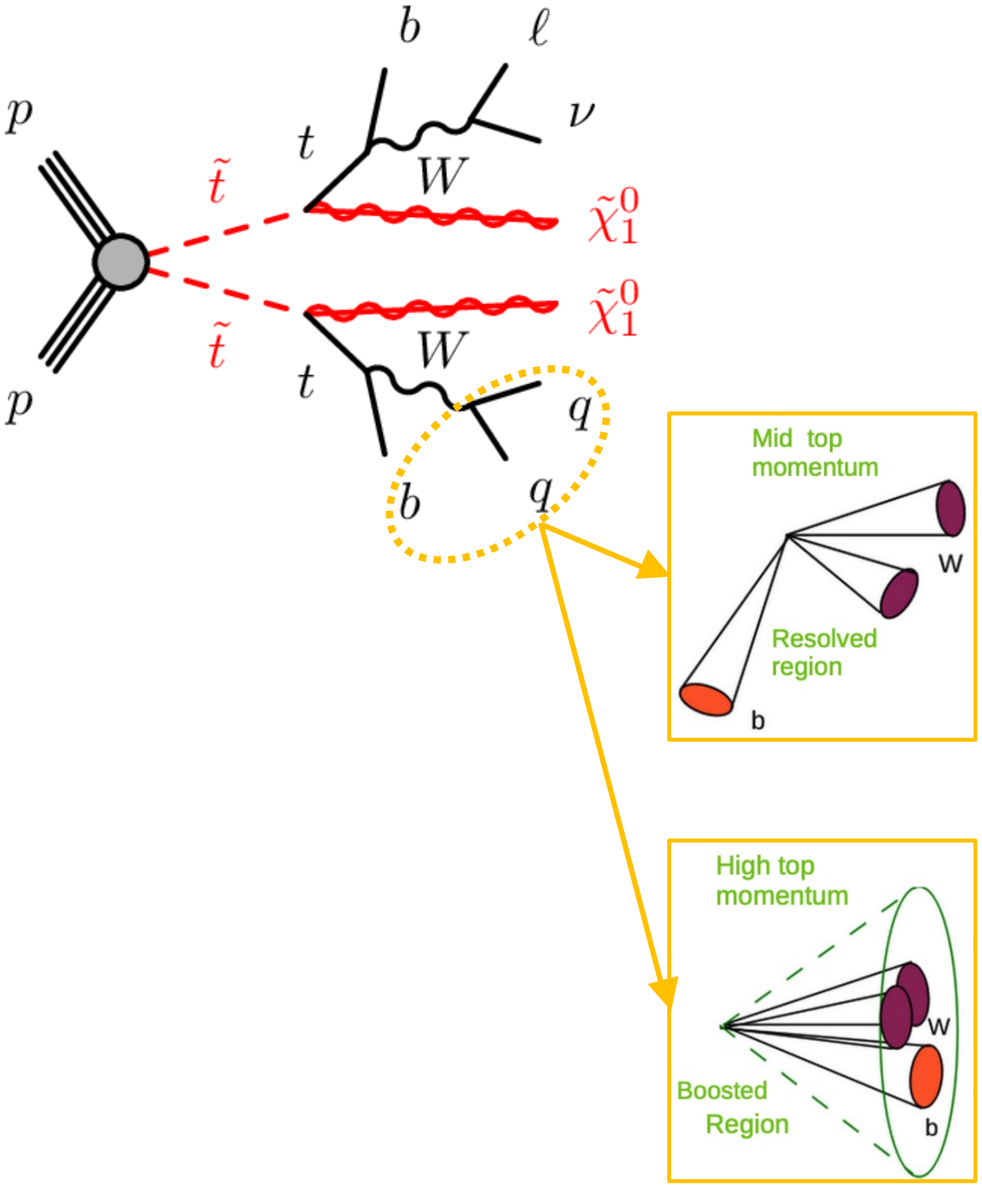
Latest results from ATLAS in strong SUSY production

- SUSY-2023-22
  - Search for new phenomena with top-quark pairs and large missing transverse momentum
- SUSY-2019-23
  - Search for top-squark pair production in final states containing a top quark, a charm quark and missing transverse momentum





Stop to top-N1 analysis 1L



- **Signature-based search strategy**:
  Events selection based on object multiplicities.

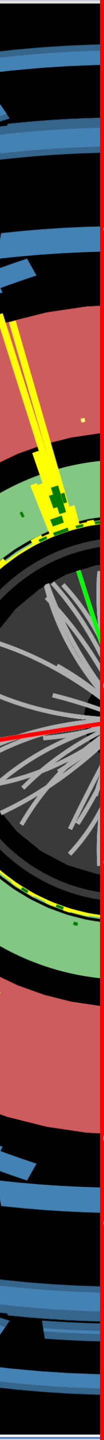
- Novel approach that provides sensitivity to a **wide range of parameter space**.

Resolved «High-MET», (p_T < 600 GeV): "top-NN"

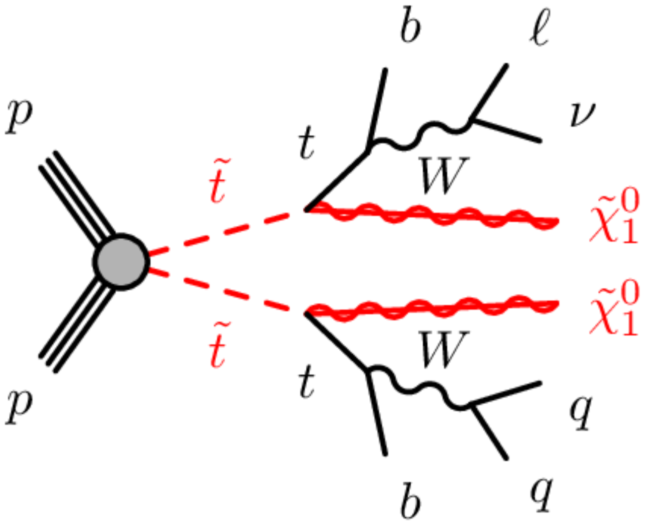
- Assigns score to all two and three (small-R) jet combinations (with exactly 1 b-jet) in event
- Combination with highest NN output value in each event is chosen as the top candidate
- 70% selection efficiency for top quarks with 200 GeV < p_T < 600 GeV

Boosted (p_T > 600 GeV):

- Reconstructed as large-R jet.
- Multivariate classifier uses substructure to tag top jets with 80% efficiency.



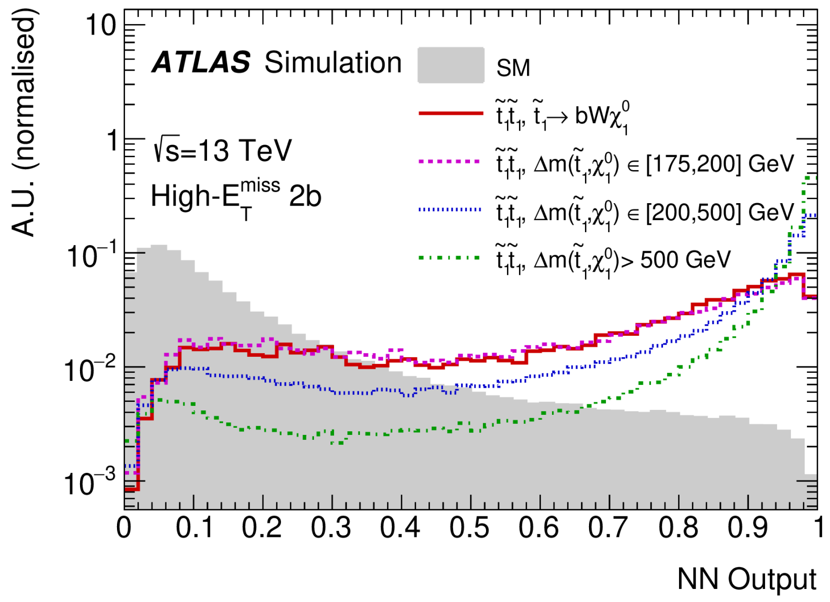
Stop to top-N1 analysis 1L



Resolved «High-MET»

$N_{\text{LargeR-jet}} = 0$

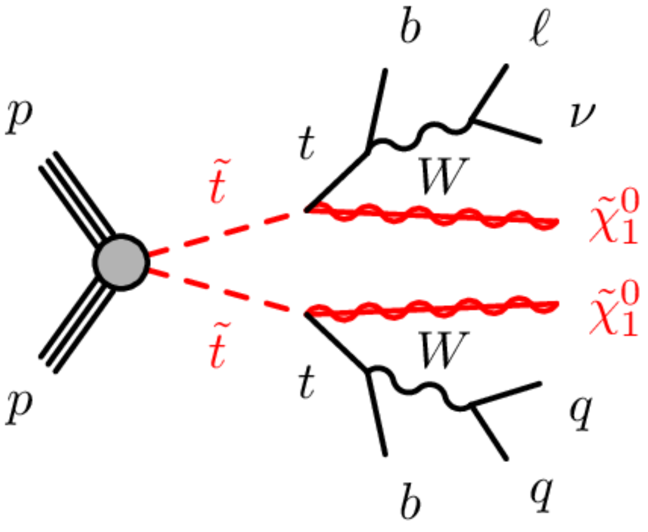
Further split into '1b' and '2b' for events containing exactly one, or two or more, b-tagged jets



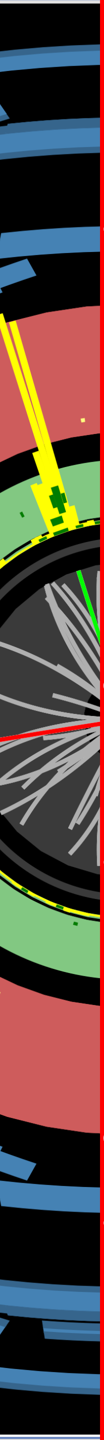
"Boosted»

$N_{\text{LargeR-jet}} \geq 1$

Six orthogonal regions depending on whether large-R jet is top-tagged, and the number of b-tagged jets (1 or 2+) and whether they lie inside or outside the large-R jet

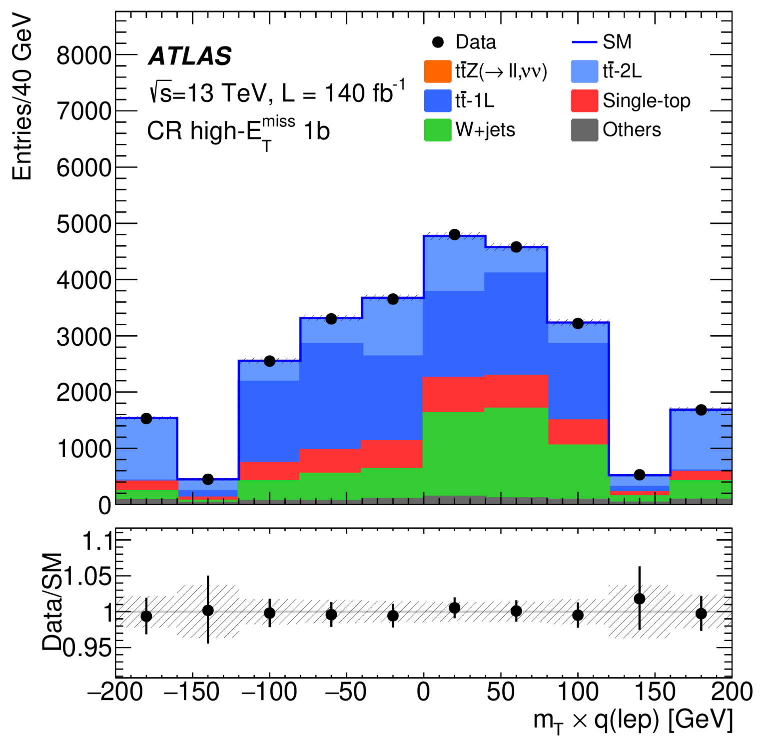


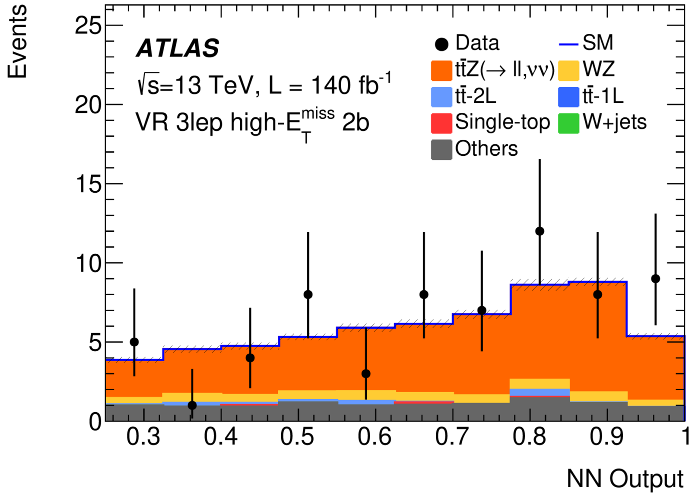
- For each region defined, a NN classifier is trained, using SUSY signal events from **across parameter space**.
- In high-MET regions, a second NN is also trained with *tt*+DM events as the signal



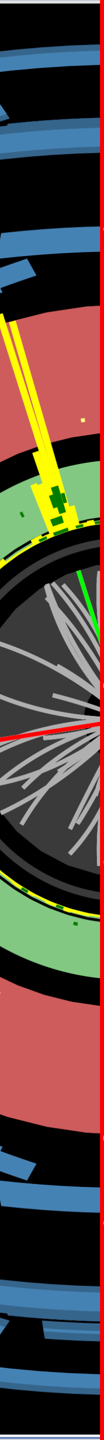
Stop to top-N1 analysis 1L - Backgrounds Estimations

- Main backgrounds:
  - **ttZ, tt1L, tt2L, W and single-top**
- CRs binned in **mT * q(l).**
  Backgrounds with 1 leptonically-decaying W have endpoint at m_W (i.e. all but tt_{2L}).
- Lepton charge discriminates between W+jets and tt_{1L} (different cross-section for W^+ and W^-).
- Normalisation factors derived for tt1L, tt2L, W and single-top backgrounds.





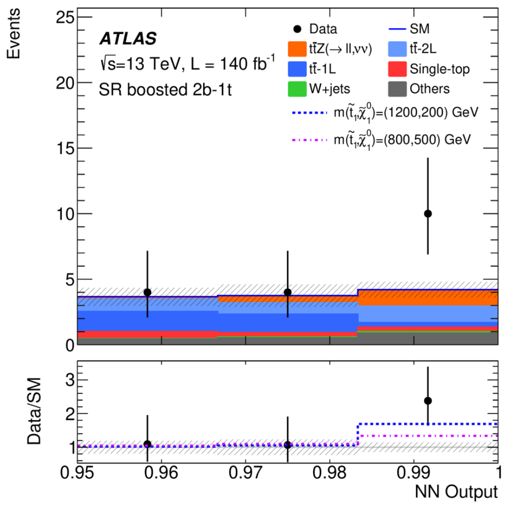
ttZ(⟶vv) has low cross section but identical signature as signal. Not fitted; Validated in 3 lepton VRs with two SFOS leptons compatible with Z (mimic v in SRs by vectorially adding to MET)

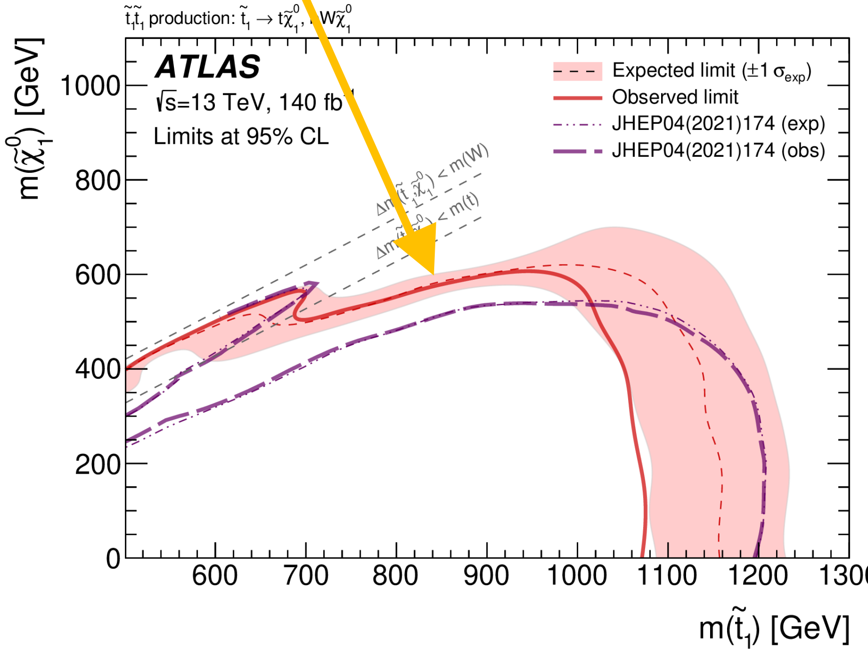


Stop to top-N1 analysis 1L - Results

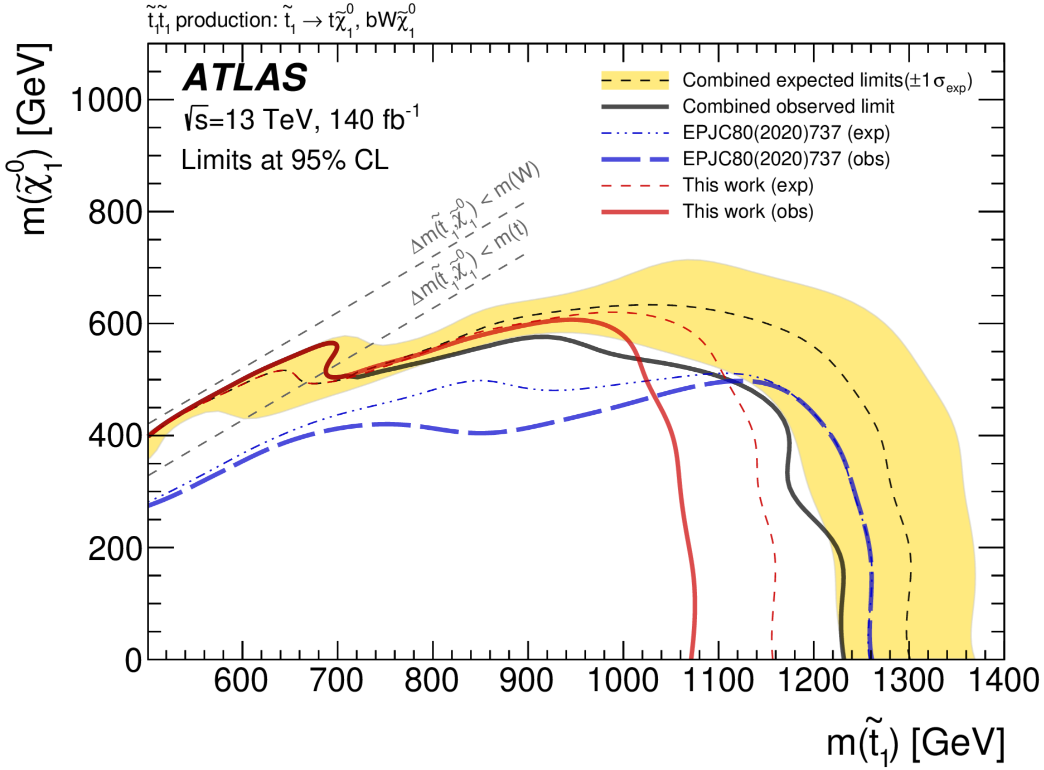
- Good agreement between data and MC in all CRs, VRs and SRs
- Largest uncertainties for single top, related to tW diagram removal.

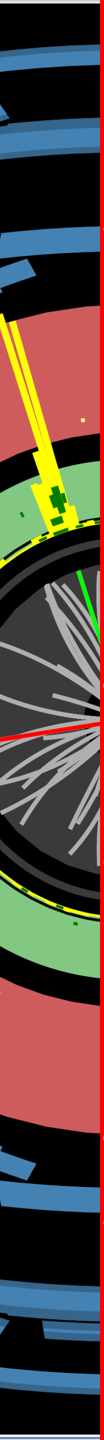
- In SRs, largest deviations (~2σ) seen in regions with 2 b-tagged jets
- Improvements in analysis strategy help probe the **compressed region**. Using the same dataset





- No significant excess: Set limits
  - Statistical combination with stop-0L analysis (EPJC80 (2020) 737)
  - Exclusion limits using 95% CL
  - For low Neutralino mass → Exclusion up to 1.25 TeV

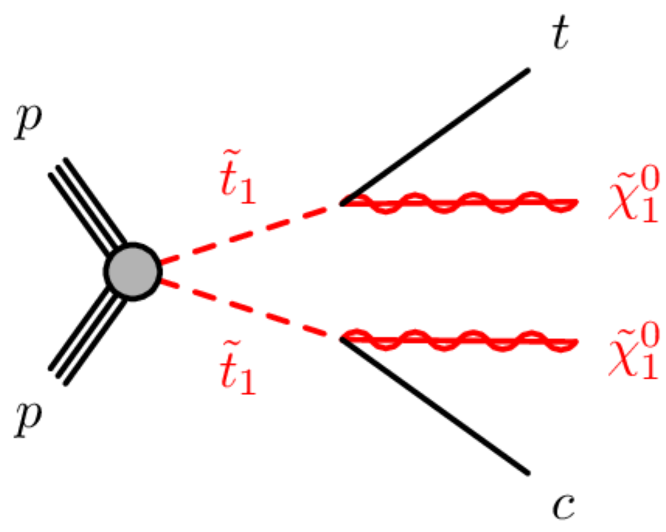




Stop to top-charm analysis

First LHC result in this final state!

- Stop pair production with decay to neutralino and SM top or charm
- Motivated by non-minimal flavour violating extensions of MSSM
- Only consider scenarios where top can be produced on-shell (2-body decay): $\Delta(\tilde{t}_1, \tilde{\chi}_1) > 175$ GeV
- Final state: **Hadronically-decaying top, Charm quark, and Large Missing Transverse Momentum**



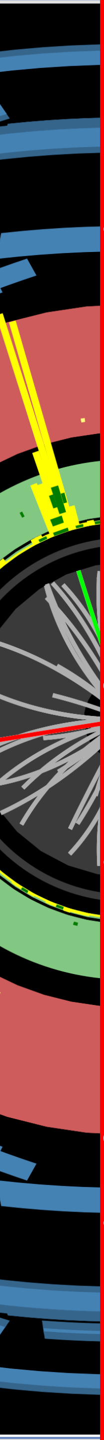
b-tagging jets is well-established…

c-tagging jet not so much!

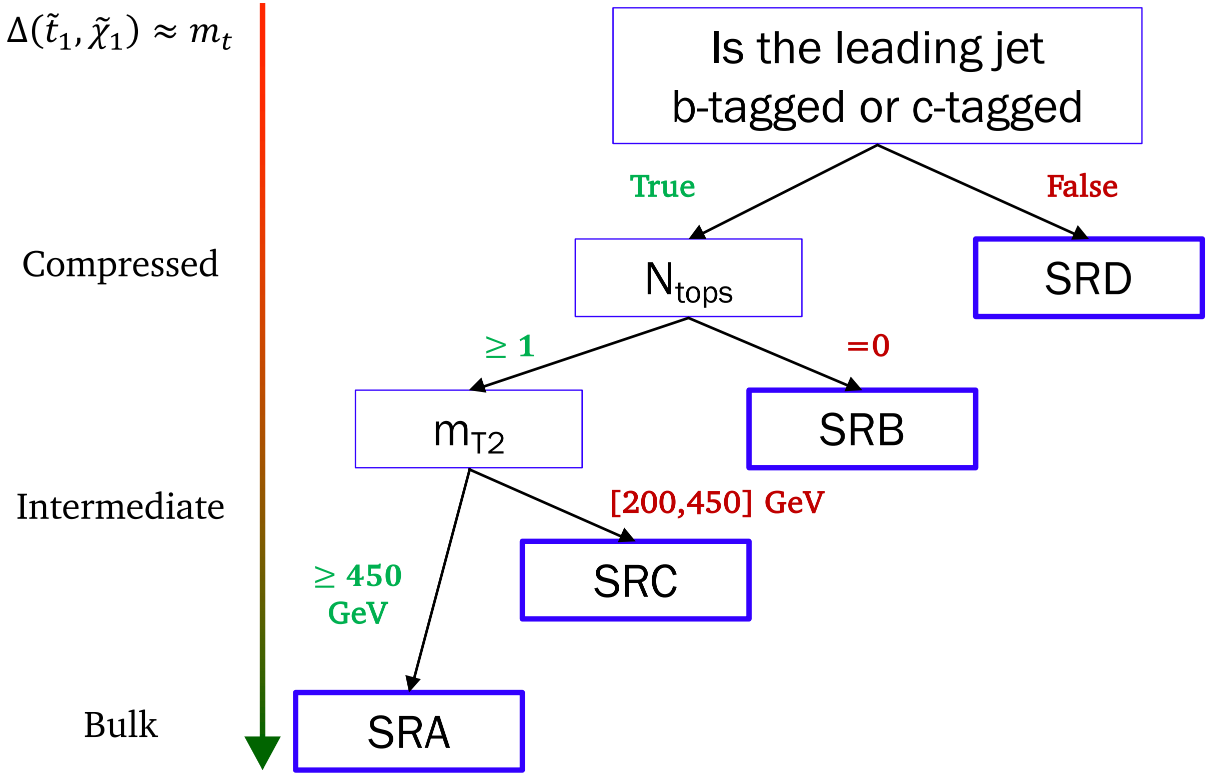
- High-level DNN tagger (DL1r) leverages jet topology, impact parameter taggers, and secondary vertex finding algorithms
- Multidimensional output (p_b, p_c , p_{light}) combined for c-tagging
- b-tag takes precedence: avoids high b-mistag rates

$$DL1_r = \log\left(\frac{p_c}{f_b p_b + (1 - f_b) p_u}\right)$$

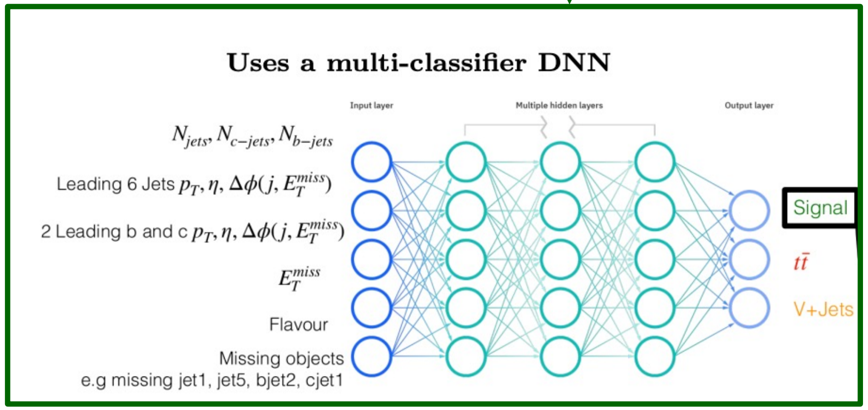
ε_c	b-rej.	light rej.
20%	29	57



Stop to top-charm analysis - Analysis strategy



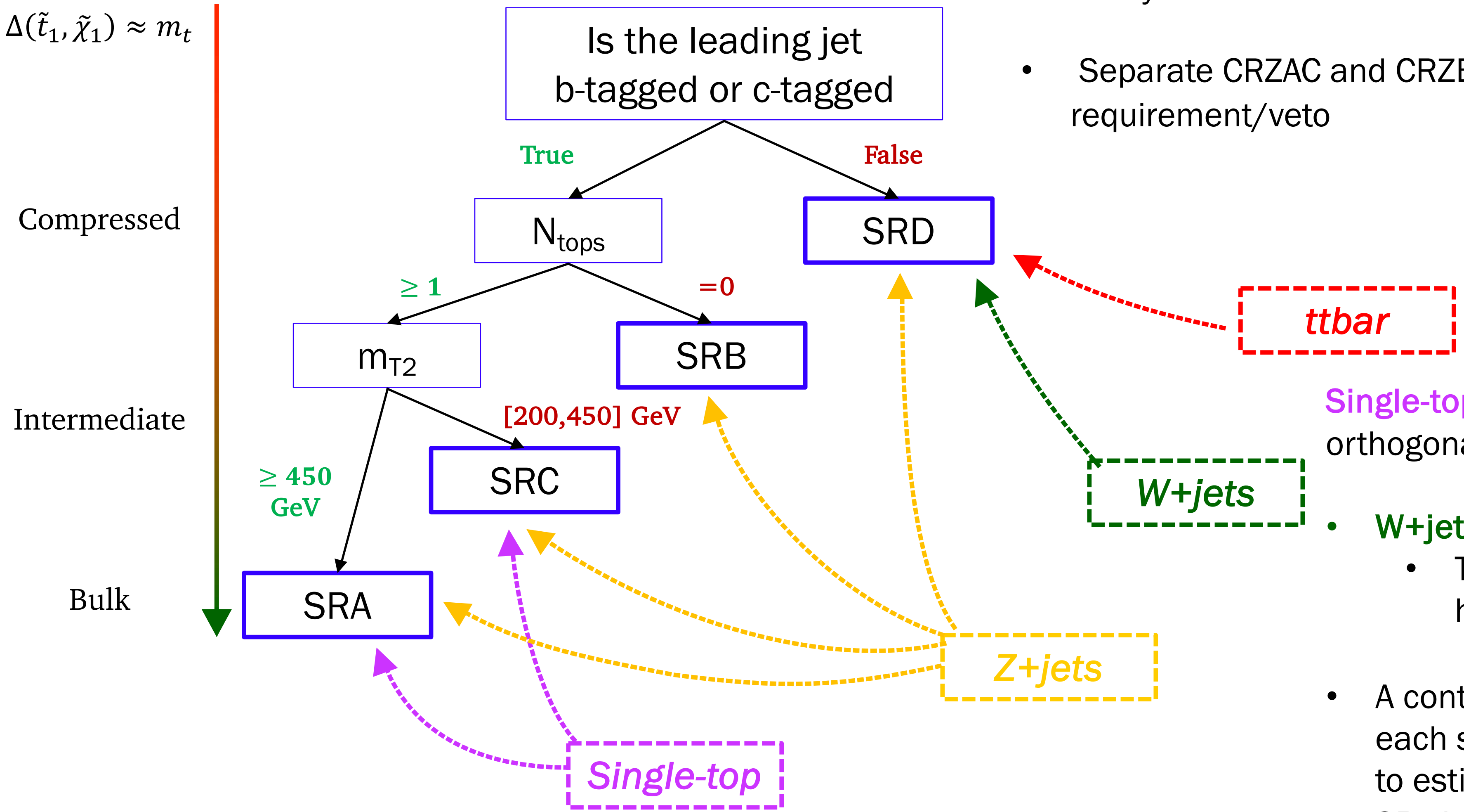
- Four signal regions targeting different regions of parameter space.
- Trigger on Missing Transverse Energy (MET),0 Leptons (μ/e), ≥1 b-tagged and ≥1 c-tagged.
- **SRD** (Compressed region)
  - **Required ISR JET**
  - Binned in m_{eff} and $m_T(j,MET)_{close}$
  - **Multi class NN to separate signal and tt-like and V-jets-like events.**
- **SRB,SRC** (Intermediate selection)
  - Binned $m_T(j,MET)_{close}$
- **SRA** (bulk selection)
  - High m_{T2} (top and c-tagged jet)



Stop to top-charm analysis – Backgrounds Estimation

- Z(→νν)+jets CRs defined with 2 (SFOS) leptons required. Added to MET ("lepton-corrected MET") to mimic invisible Z-decay in SR

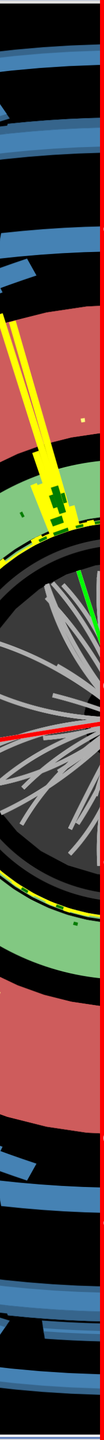
- Separate CRZAC and CRZB with top-tagged jet requirement/veto



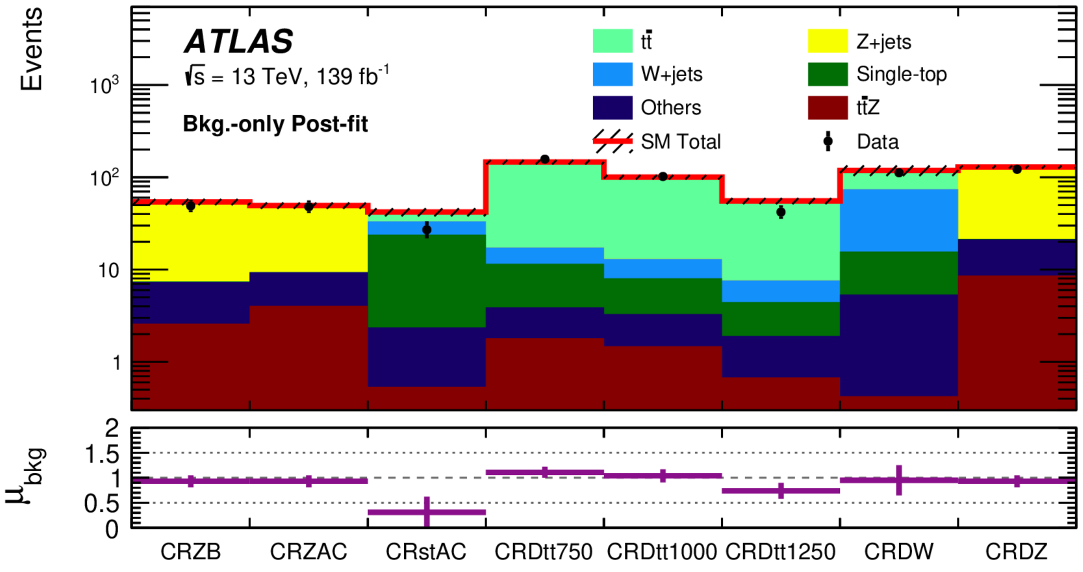
Single-top, W+jets and ttbar CRs are orthogonal to SRs via 1L selection:

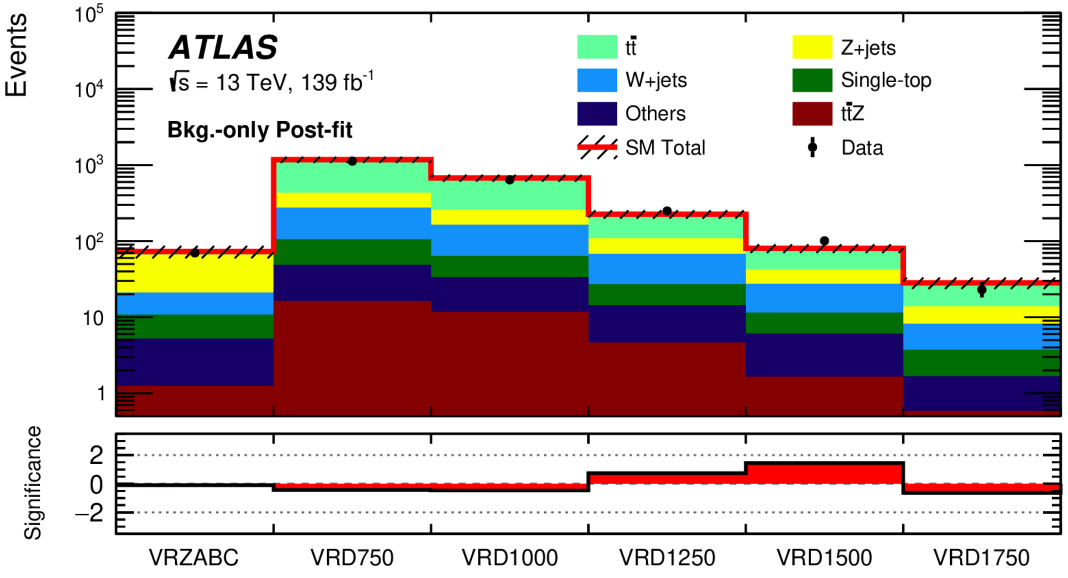
- W+jets and ttbar:
  - Treat lepton as jet to mimic hadronically-decaying τ in SR

- A control region (CR) is defined for each set of different-coloured arrows to estimate that background in the SRs indicated



Stop to top-charm analysis – Backgrounds Estimation



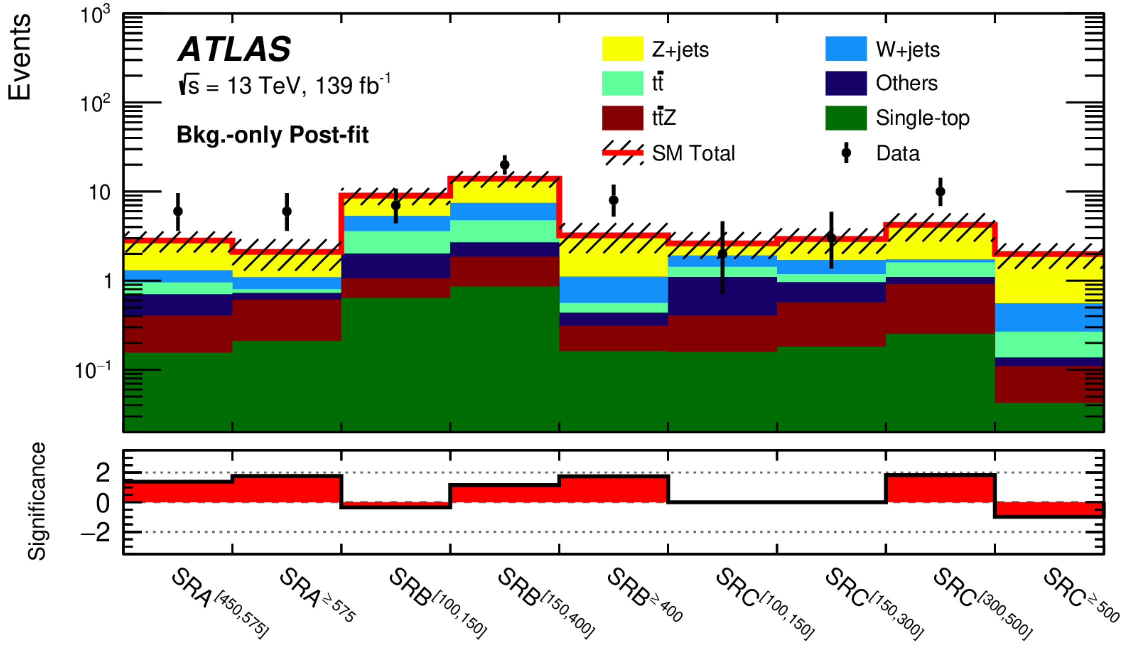


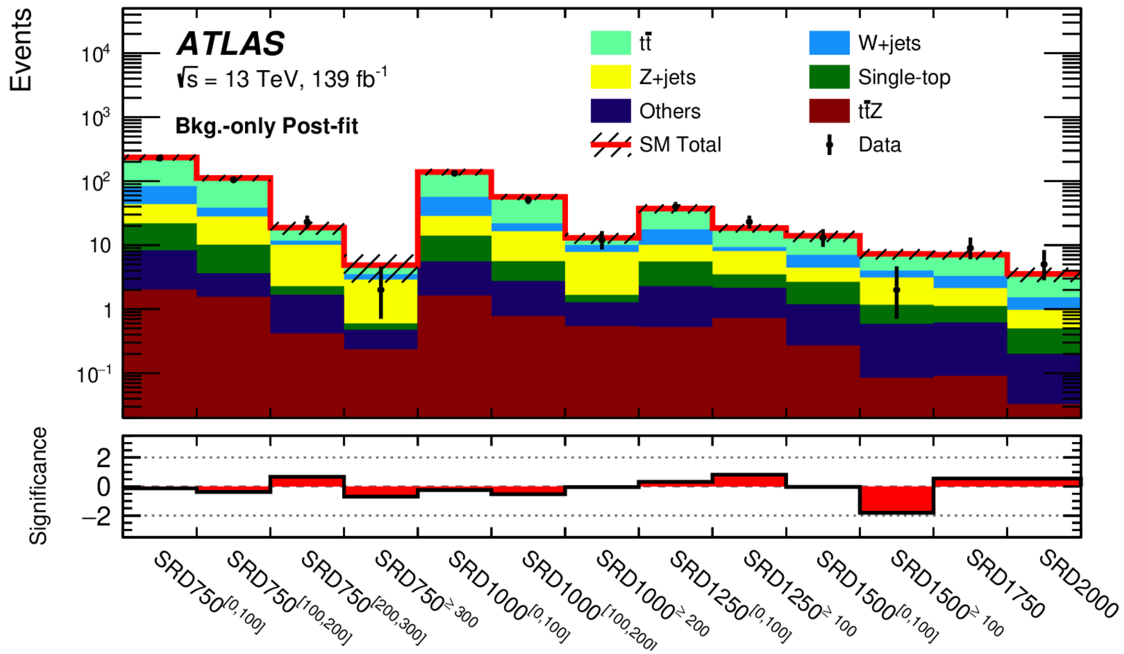
- A profile-likelihood fit is done yielding almost all normalization factors consistent with 1
- Most discrepancy for single-top SF.
  This is quite common in the extreme phase spaces in SUSY
- Three different ttbar normalization factors are considered
  - CRD $tt_{750} \rightarrow tt_{1000} \rightarrow tt_{1250}$ binned in HT
  - Highly correlated with increasing pT ttbar events → need increasing correction

NFs extracted from Control Regions applied to corresponding Validation Regions:

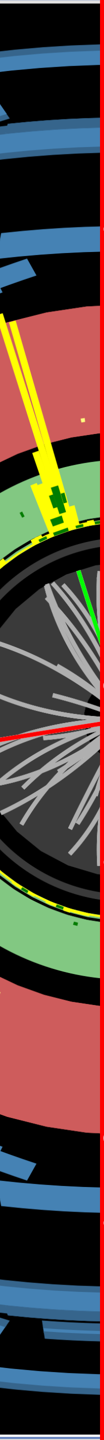
- Post-fit excesses in VRs < 2 sigma
- These are not used in the fit, they are used to validate the profile-likelihood fit in Control Regions

Stop to top-charm analysis - results





- Each signal region is binned to increase sensitivity
- SRA, SRB and SRCs have excesses but within 2 sigma.
- Data agrees well with SM prediction. Largest deficit in $SRD1500_{[\geq 100]} \sim 1.8$ sigma

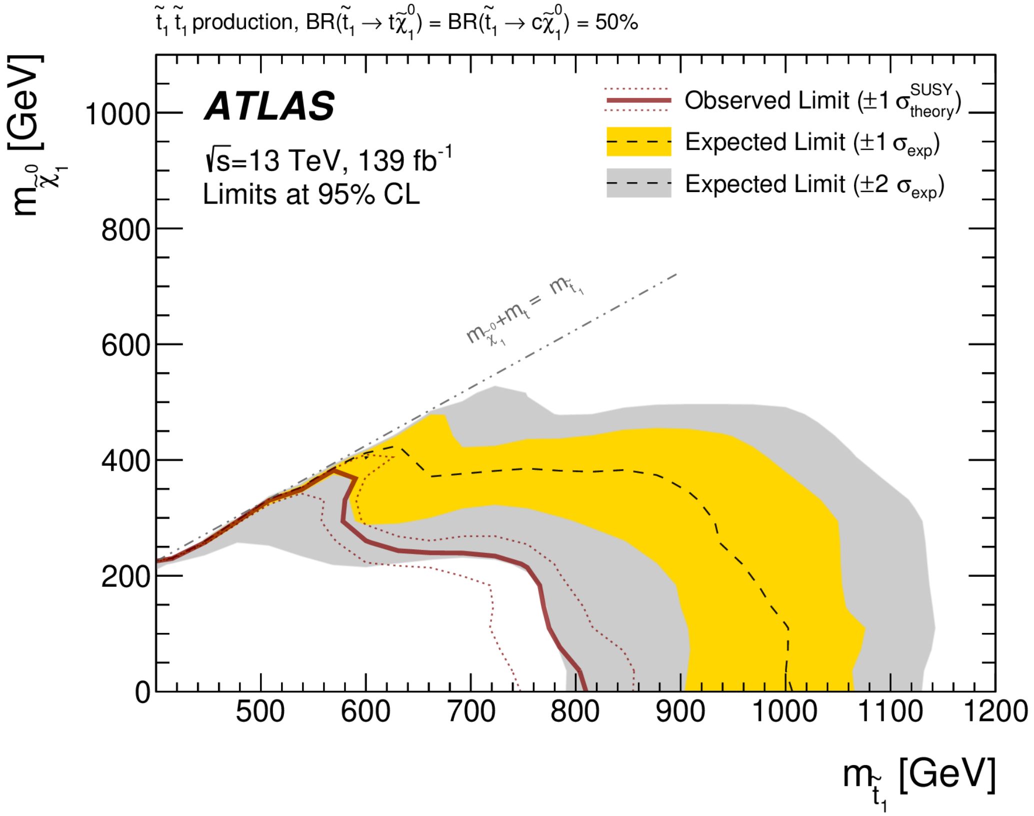


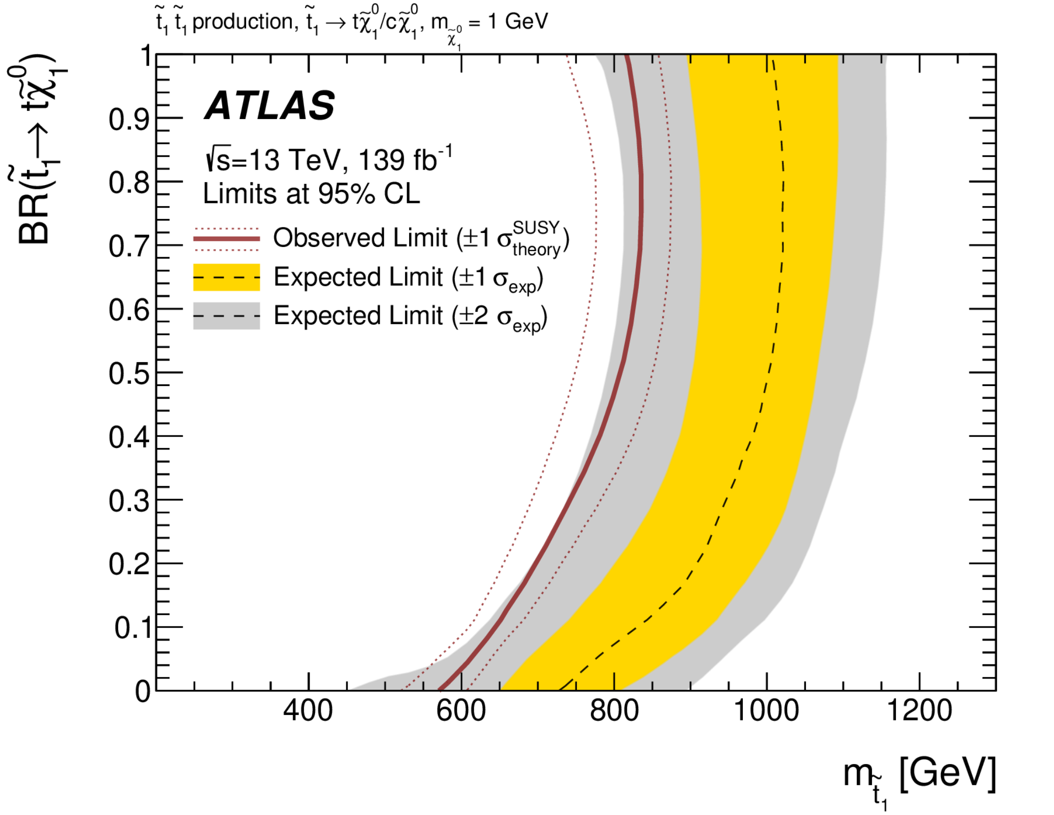
Searches for strong production of supersymmetric particles

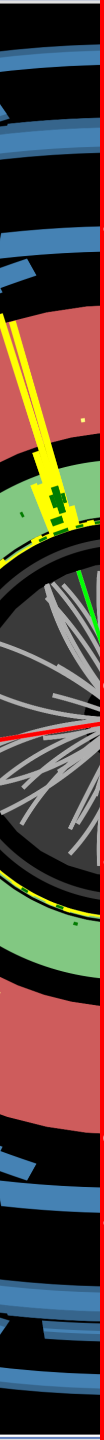
Stop to top-charm analysis - results

- First LHC result in this final state!
- $m(\tilde{t}_1) \lesssim 800$ GeV excluded for high mass,
- $m(\tilde{t}_1) \lesssim 600$ GeV for compressed
- Results for $BR(\tilde{t}_1 \rightarrow t\,\tilde{\chi}_1) = 50\%$

- Scan in $BR(\tilde{t}_1 \rightarrow t\,\tilde{\chi}_1)$ at fixed N1 mass = 1 GeV



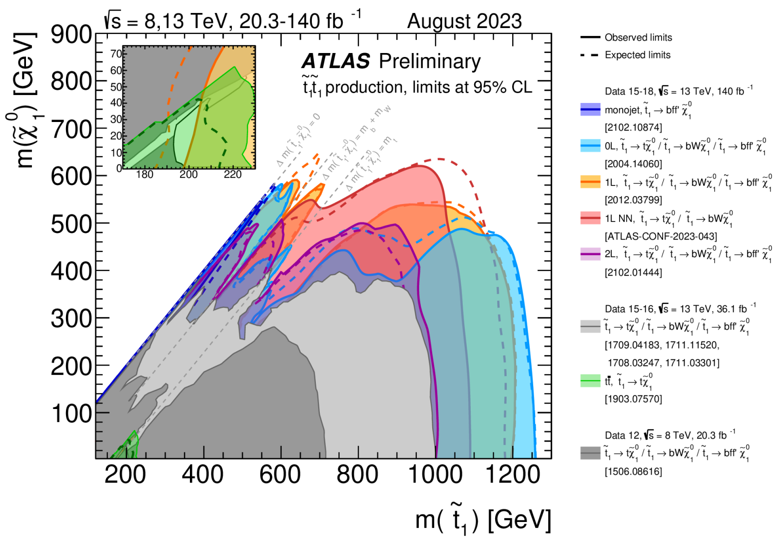


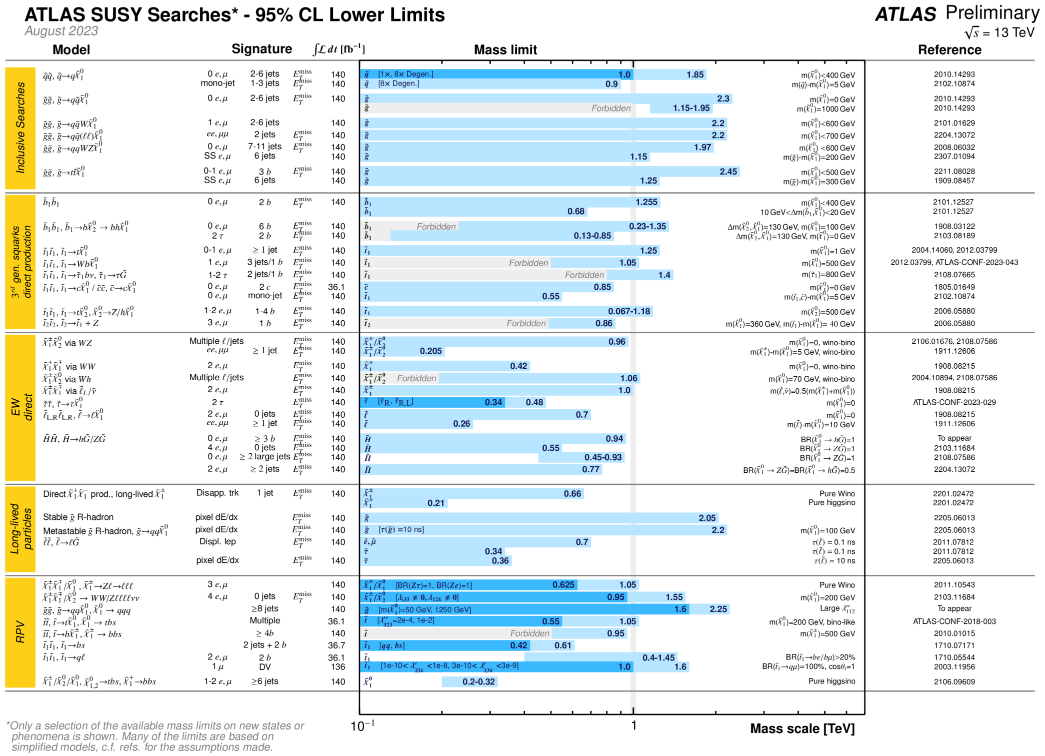


Searches for strong production of supersymmetric particles

Summary and Outlook

- Two recent results using Run 2 data presented in this talk.
  - Strong production of stops motivated by RPC SUSY
  - Novel ML-based analysis strategies featuring improved background modelling, object reconstruction, …
- No significant excesses seen over SM backgrounds
  - Limits set on stop pair production cross-section
  - Including interpretations in DM models
- Many Run 2 results already public from ATLAS Collaboration!
- Run 3 ongoing: many new analyses in the works!

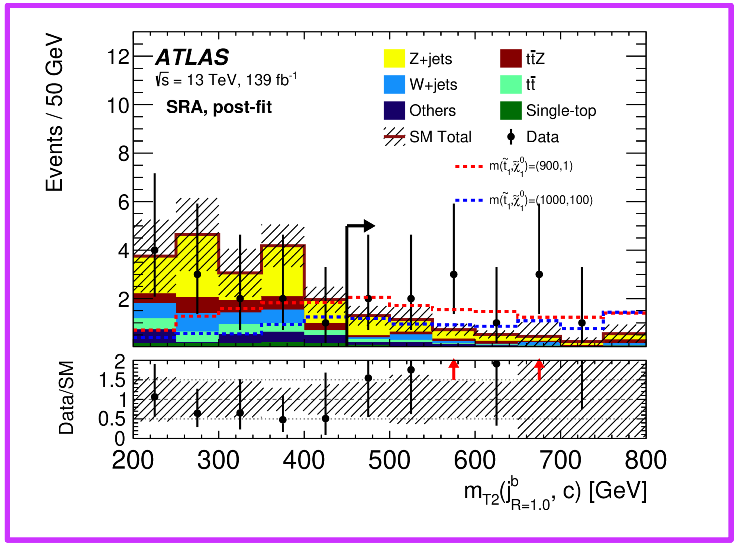




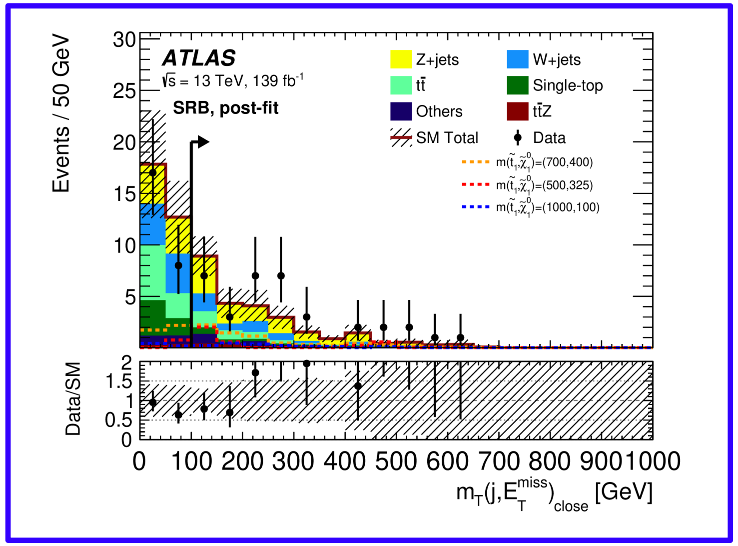
Backup

Stop to top-charm analysis - results

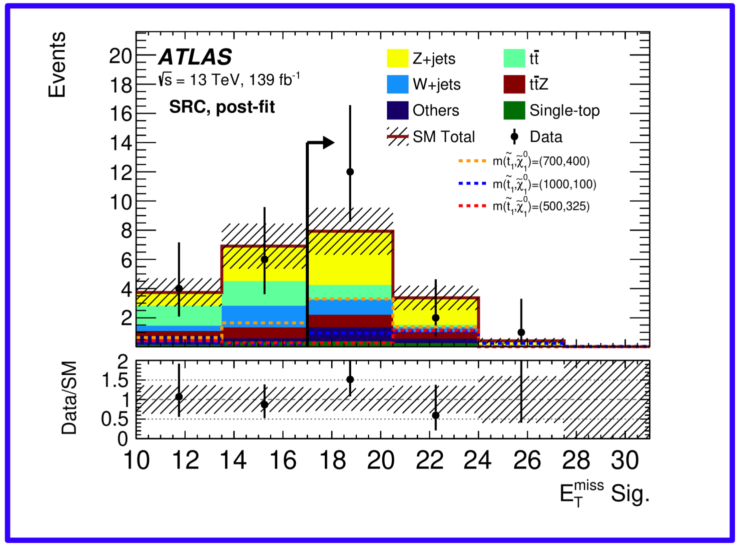
SRA



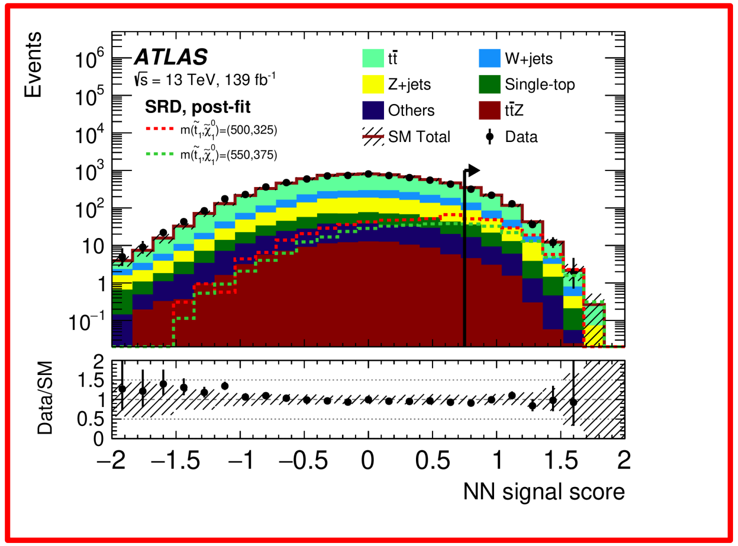
SRB



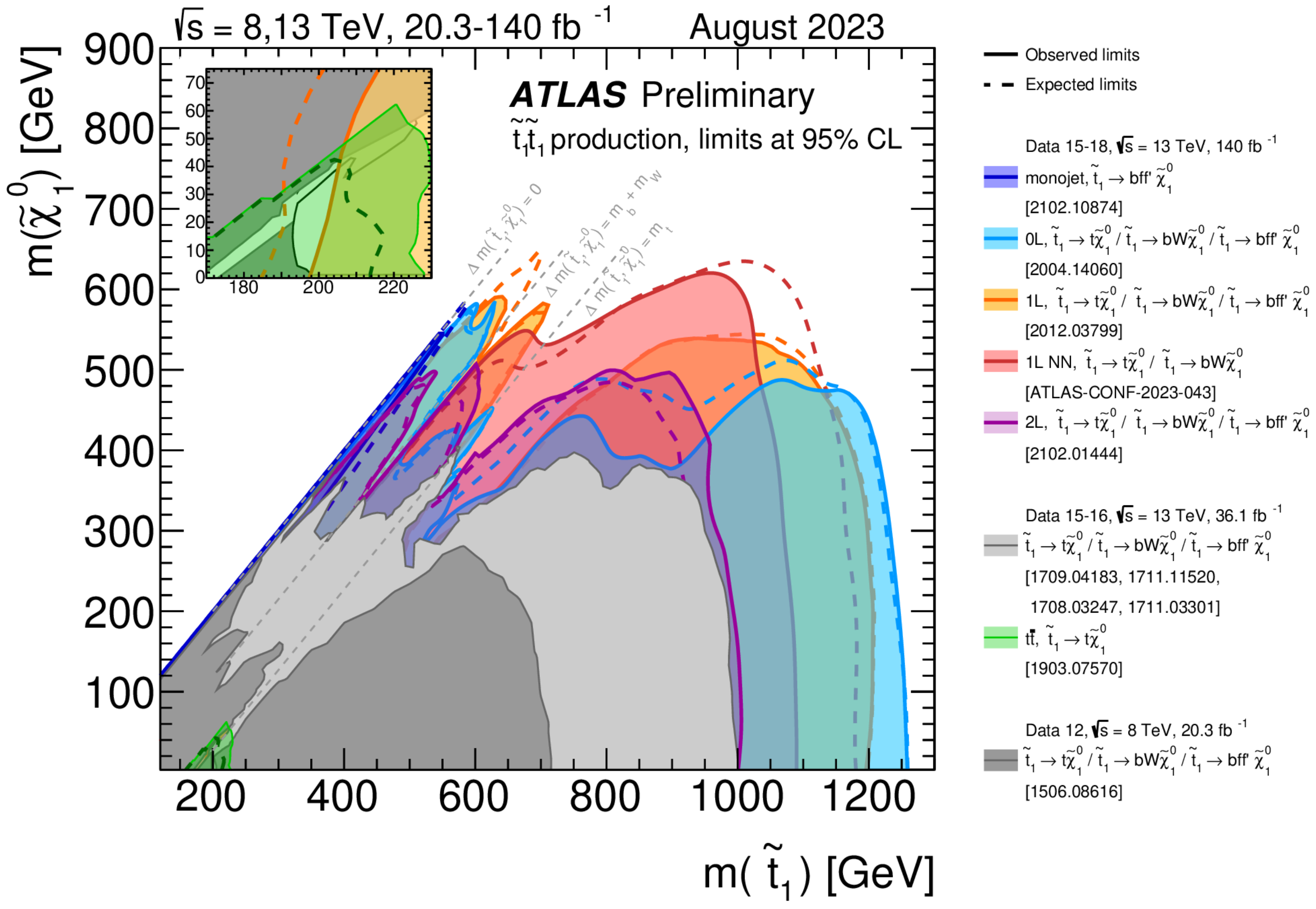
SRC



SRD



Other results for Stop-N1



Stop-NN and DM-NN

Table 3: Summary of the selections on the stop-NN and DM-NN output values that define CRs, VRs and SRs. Signal efficiencies, computed as the fraction of signal events in a given category with a NN output value in the range accepted in the SR, are also reported. The quoted range encompasses efficiencies estimated for all signals across the simulated parameter space. In boosted categories, only efficiencies for $\tilde{t}_1\tilde{t}_1$ signals with $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) > 500$ GeV are quoted.

	stop-NN				DM-NN			
Category	CR Range	VR Range	SR Range	Eff.	CR Range	VR Range	SR Range	Eff.
High-$E_{\mathrm{T}}^{\mathrm{miss}}$ 1b	[0.2, 0.64)	[0.64, 0.79)	[0.79, 1.0]	0.4-0.9	[0.3, 0.69)	[0.69, 0.87)	[0.87, 1.0]	0.3-0.4
High-$E_{\mathrm{T}}^{\mathrm{miss}}$ 2b	[0.1, 0.56)	[0.56, 0.70)	[0.70, 1.0]	0.5-0.9	[0.3, 0.60)	[0.60, 0.76)	[0.76, 1.0]	0.6-0.8
Boosted 1b-lep-1t	[0.0, 0.65)	[0.65, 0.80)	[0.80, 1.0]	0.5-0.9				
Boosted 1b-had-1t	[0.0, 0.65)	[0.65, 0.85)	[0.85, 1.0]	0.6-0.9				
Boosted 2b-1t	[0.0, 0.75)	[0.75, 0.95)	[0.95, 1.0]	0.6-0.8				
Boosted 1b-lep-0t	[0.0, 0.70)	[0.70, 0.85)	[0.85, 1.0]	0.6-0.8				
Boosted 1b-had-0t	[0.0, 0.75)	[0.75, 0.95)	[0.95, 1.0]	0.4-0.8				
Boosted 2b-0t	[0.0, 0.65)	[0.65, 0.80)	[0.80, 1.0]	0.6-0.9				