A search for B-L R-parity-violating scalar tops in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS experiment

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https://cds.cern.ch/record/2265808

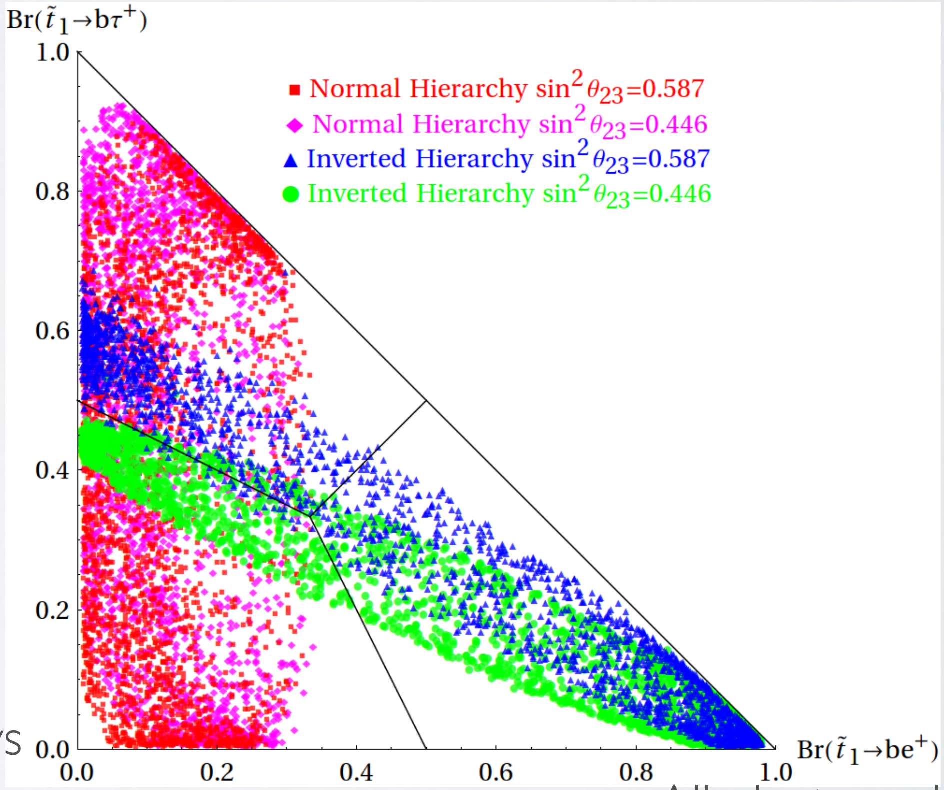
B-L STOP: MOTIVATION

- The B-L model is a $U(1)_{B-L}$ gauged **extension to the MSSM.**
  - Additional particle content: right-handed neutrinos
- **R-parity is not conserved** in this model so the "collider" LSP can carry color and electric charge.

$$R = (-1)^{3(B-L)+2s}$$

  - Gravitino LSP provides a dark matter candidate
  - No missing energy
  - Only lepton number is violated
    → proton is stable
- Observables in this model are related to the neutrino hierarchy.
  - RPV couplings are small since related to neutrino mass

All tau decays
bτbτ



All muon decays
bμbμ

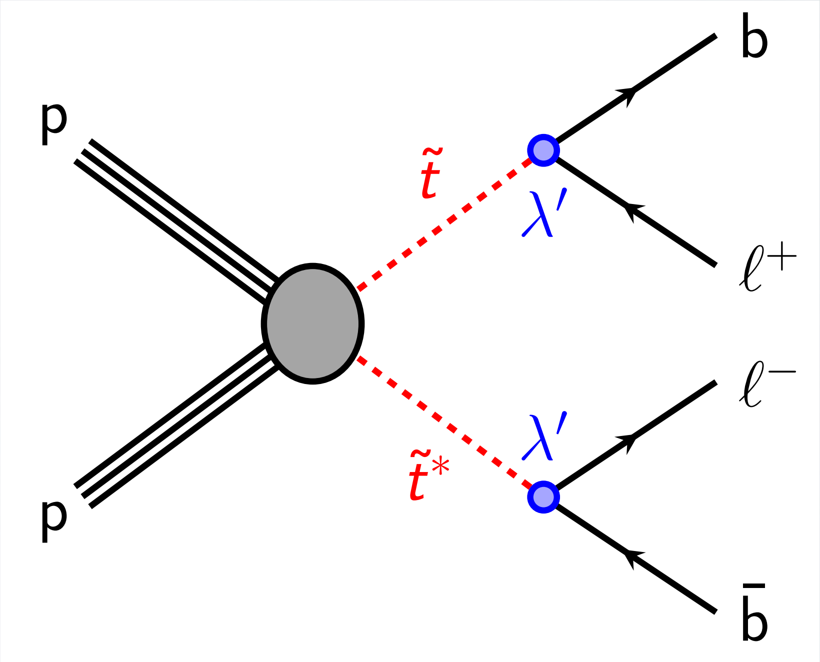
All electron decays
bebe

Stop LSP decay:
1401.7989
1402.5434

Minimal SUSY B-L:
1412.6103
1503.01473

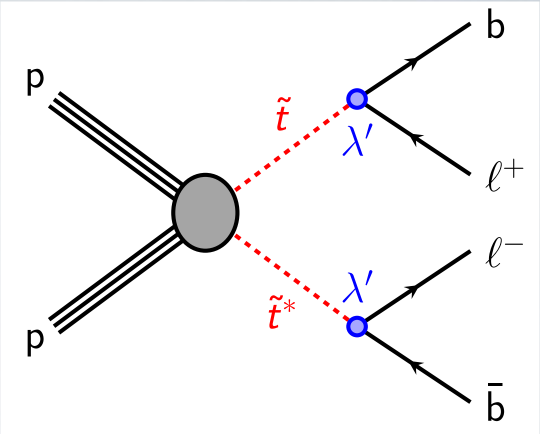
INTRODUCTION

- We are interested in the **pair production of top squarks** which then decay via the B-L R-parity violating (RPV) coupling
- If the stop is the (n)LSP, it preferentially decays to a lepton (ℓ) and a *b*-quark (*b*).



- We search for final states with *eebb*, μμ*bb*, eμ*bb*, with a **resonance in the invariant mass $m_{b\ell}$.**
- Results are reinterpreted with BR($\tilde{t} \rightarrow b\tau$)≠0 for leptonically decaying taus.
- Run1 search excludes masses from 500 to1000 GeV for branching ratios of at least 20% to *b*e or *b*μ

SIGNAL MODEL



- Assume standard $\tilde{t}$ pair production then decay with RPV coupling
- Signal points are generated with **$m_{\tilde{t}}$ ranging from 600 GeV to 1.6 TeV** and with equal BR to *be*, *b*μ, *b*τ
  - Signal model does not necessarily have equal BR to each lepton flavor
  - We apply truth reweighting to probe any BR
- Signal Regions are optimized assuming **BR($\tilde{t}$→*be*)=BR($\tilde{t}$→*b*μ)=50%**
  - Most tables and figures presented here assume these BRs

Stop mass [GeV]	Pair production cross section [fb] (NLO+NLL Tool)	
	√s=8 TeV	√s=13 TeV
600	25±4.1	175±23
800	2.9±0.6	28±4.0
1200	(7.6±2.8)×10^{-2}	1.6±0.3
1500	(6.6±3.4)×10^{-3}	0.26±0.06

BL PAIRING

- Select from the event: 2 highest p_T leptons ($p_T > 40$ GeV) and 2 highest p_T jets ($p_T > 60$ GeV), at least one of which must be *b*-tagged (overall 77% efficient as measured with ttbar)

- To identify the jet and lepton from the same stop decay leg, select the 2 pairs which minimize **$m_{b\ell}$ asymmetry**

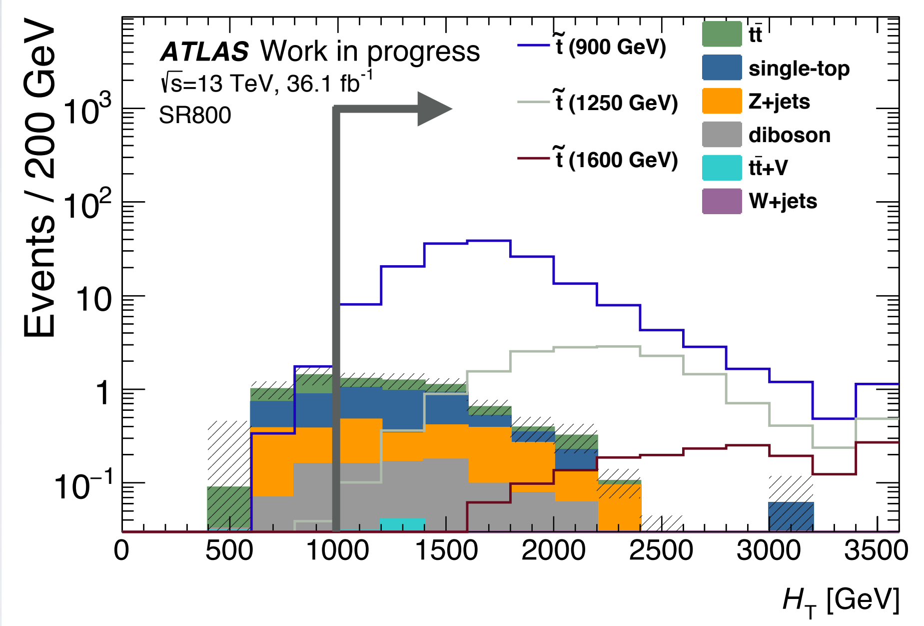
$$m_{b\ell}^{\text{asym}} = \frac{m_{b\ell}^0 - m_{b\ell}^1}{m_{b\ell}^0 + m_{b\ell}^1}$$

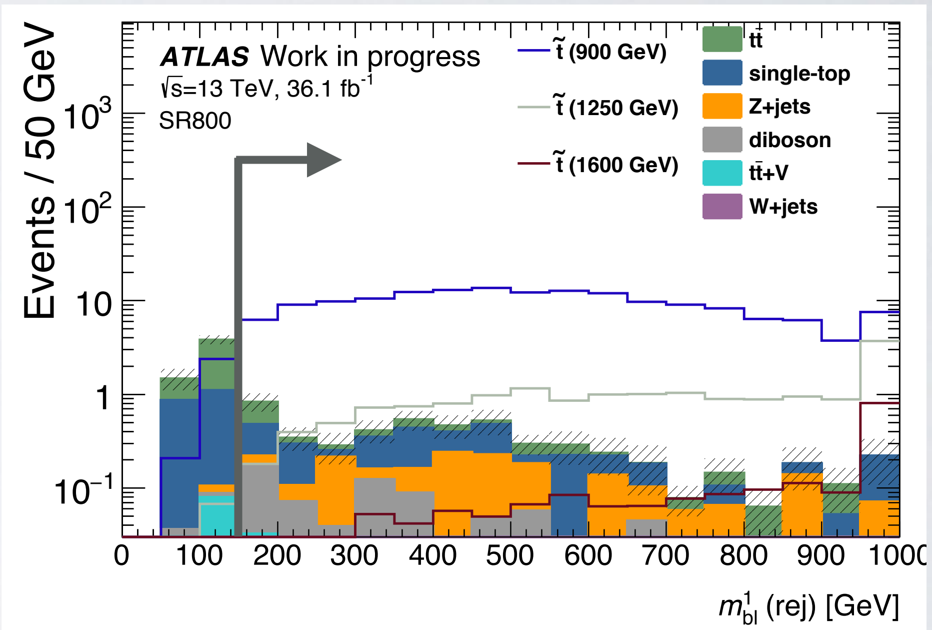
- We now have two selected ($m_{b\ell}^{\text{acc0}} > m_{b\ell}^{\text{acc1}}$) and two rejected ($m_{b\ell}^{\text{rej0}} > m_{b\ell}^{\text{rej1}}$) $b\ell$ pairs

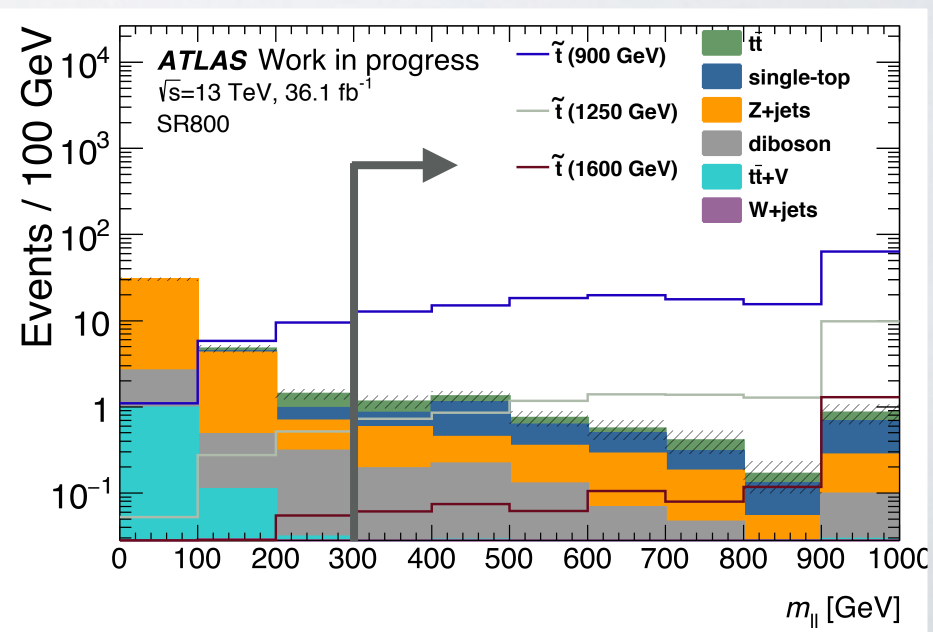
- We search for a **resonance in $m_{b\ell}^{\text{acc}}$**

MAJOR BACKGROUNDS

- Drell-Yan, ttbar, and single top
  - Reduce all backgrounds using a cut on H_T = scalar sum of p_T of 2 signal leptons and 2 signal jets
  - Reduce ttbar and single top using a cut when the rejected $b\ell$ pairing reconstructs the top decay
  - Reject Drell-Yan using a cut on $m_{\ell\ell}$







SELECTION

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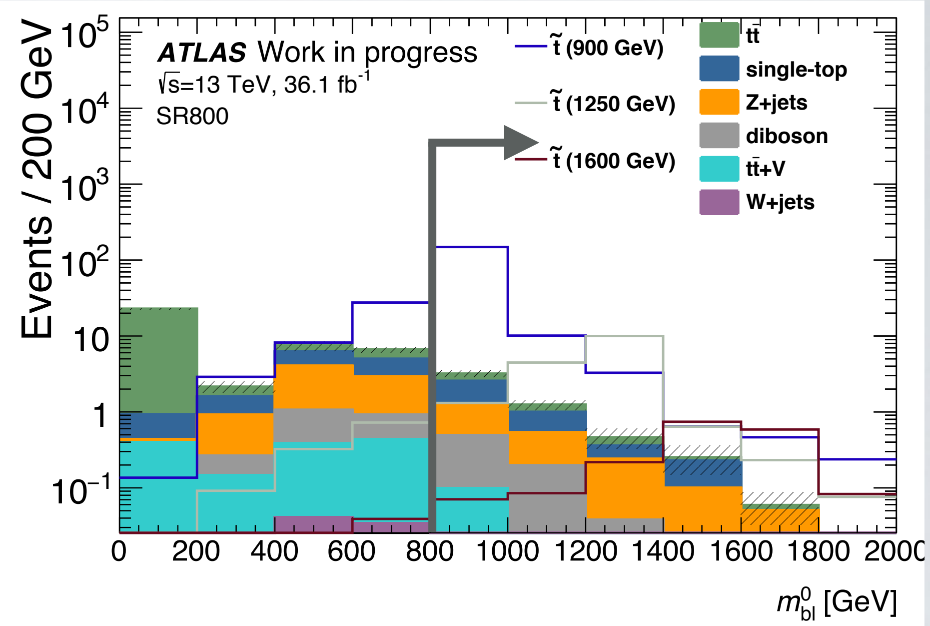
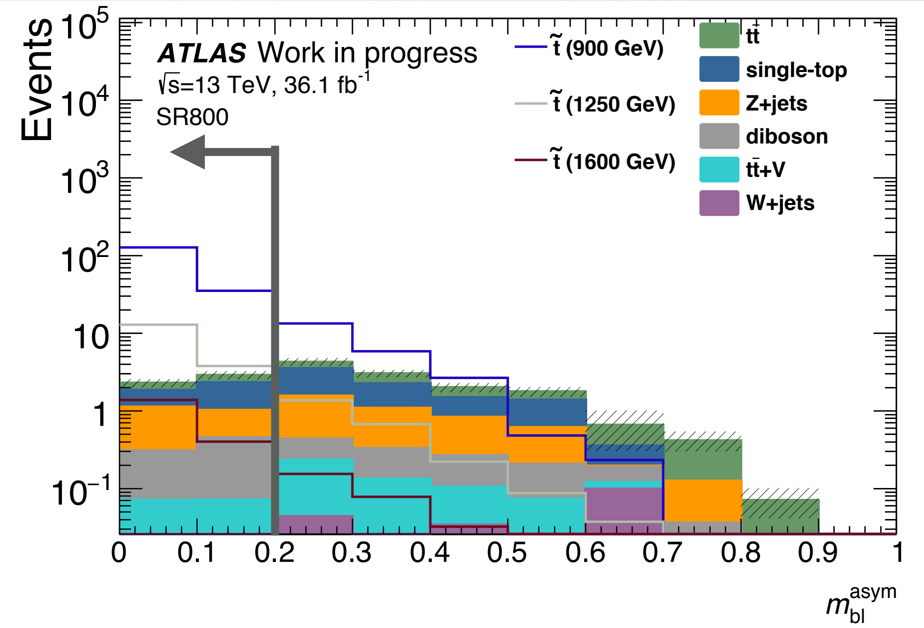
- Signal is expected to have:
  - $m_{b\ell}^{acc}$ resonance, reconstructing stop mass
  - small $m_{b\ell}^{asym}$
- In contrast, backgrounds are expected:
  - to fall off with $m_{b\ell}^{acc}$
  - to be relatively flat with $m_{b\ell}^{asym}$
- Define two nested signal regions (SRs) for low- and high- mass signals:

→ **Require $m_{b\ell}^{acc}$ > 800 or 1100 GeV**

→ **Require $m_{b\ell}^{asym}$ < 0.2 for all regions**



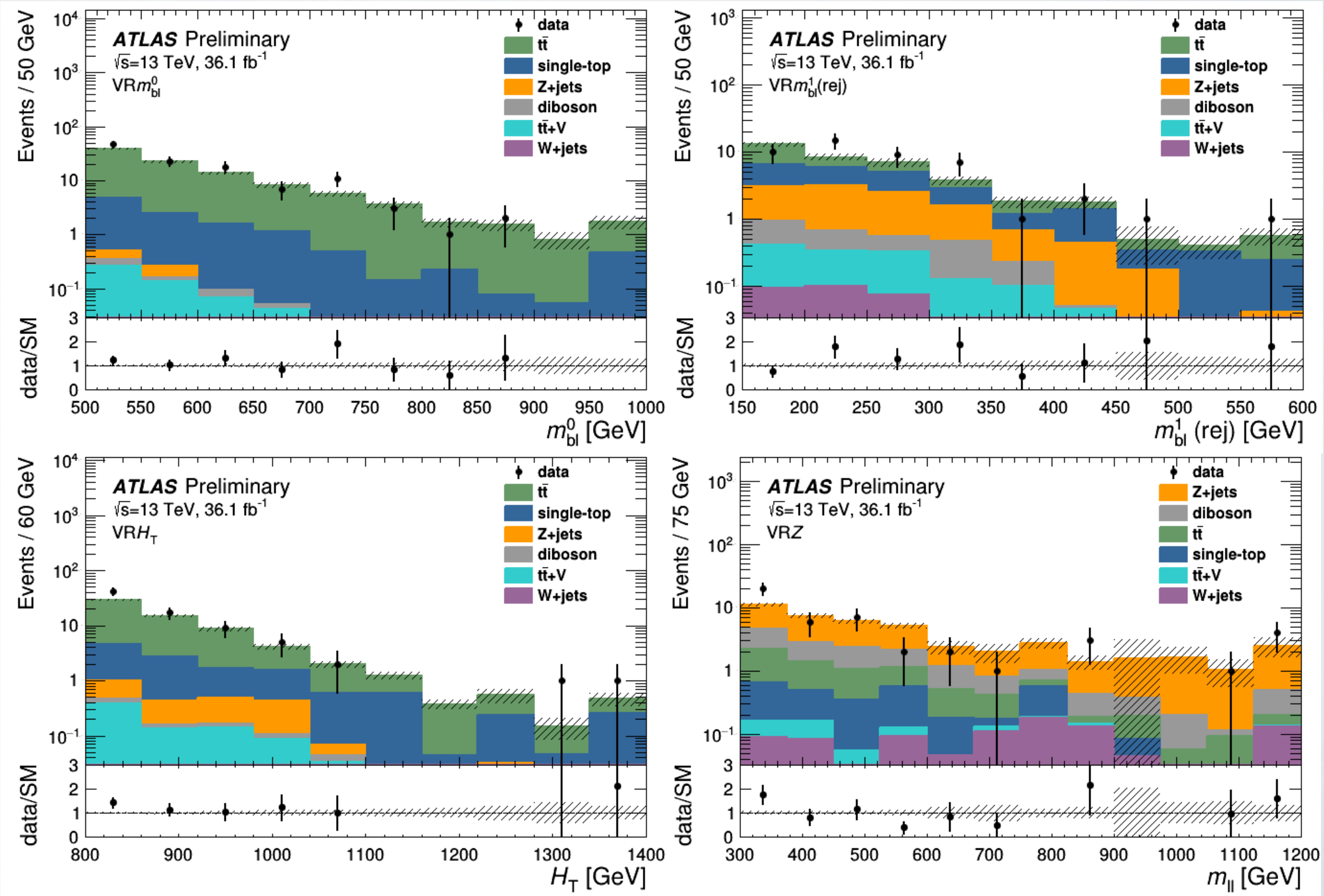


Region	N_b	$m^0_{b\ell}$ [GeV]	$m^1_{b\ell}$(rej)[GeV]	H_T [GeV]	$m_{\ell\ell}$ [GeV]	m_{CT} [GeV]
SR800	≥ 1	> 800	> 150	> 1000	> 300	–
SR1100	≥ 1	> 1100	> 150	> 1000	> 300	–

+ $m_{b\ell}^{asym} \leq 0.2$ for all regions

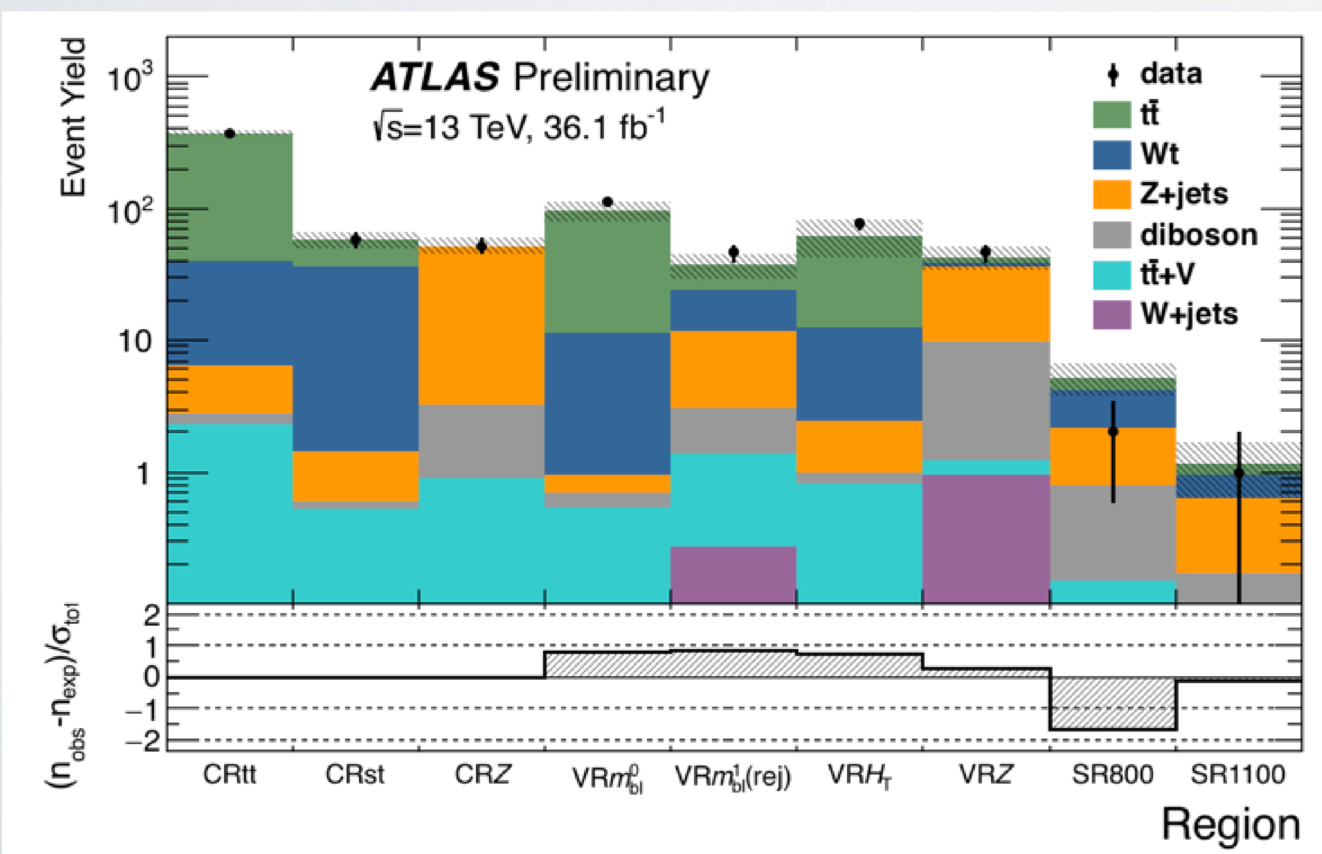
BACKGROUND ESTIMATION

- Dedicated control regions (CRs) are defined to set background rates for ttbar, single top, and Drell-Yan, then applied to validation regions (VRs) and SRs
- Four VRs extrapolate one variable each between CRs and SRs



RESULTS

- Two events in SR800 (slight deficit)
  - One of these events also passed SR1100 (no deficit)
- Both events are **μμ**



	SR800 inclusive	SR1100 inclusive
Observed yield	2	1
Total post-fit bkg yield	5.2 ± 1.4	$1.2^{+0.6}_{-0.5}$
Post-fit single-top yield	2.0 ± 1.3	0.32 ± 0.29
Post-fit Z+jets yield	1.40 ± 0.33	0.47 ± 0.15
Post-fit $t\bar{t}$ yield	1.0 ± 0.5	$0.21^{+0.55}_{-0.21}$
Post-fit diboson yield	0.64 ± 0.23	0.13 ± 0.05
Post-fit $t\bar{t}+V$ yield	0.12 ± 0.03	0.03 ± 0.01
Post-fit W+jets yield	0.03 ± 0.03	$0.01^{+0.02}_{-0.01}$
Total MC bkg yield	4.9 ± 1.2	$1.1^{+0.6}_{-0.5}$
MC single-top yield	1.9 ± 1.0	0.29 ± 0.25
MC Z+jets yield	1.15 ± 0.21	0.38 ± 0.10
MC $t\bar{t}$ yield	1.1 ± 0.5	$0.22^{+0.57}_{-0.22}$
MC diboson yield	0.64 ± 0.23	0.13 ± 0.05
MC $t\bar{t}+V$ yield	0.12 ± 0.03	0.03 ± 0.01
MC W+jets yield	0.03 ± 0.03	$0.01^{+0.02}_{-0.01}$
$N^{\rm limit}_{\rm BSM}$ exp (95% CL)	$6.4^{+3.0}_{-1.9}$	$3.9^{+2.4}_{-0.5}$
$N^{\rm limit}_{\rm BSM}$ obs (95% CL)	4.0	3.9
$\sigma^{\rm vis}_{\rm BSM}$[fb]	0.11	0.11

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UNCERTAINTIES

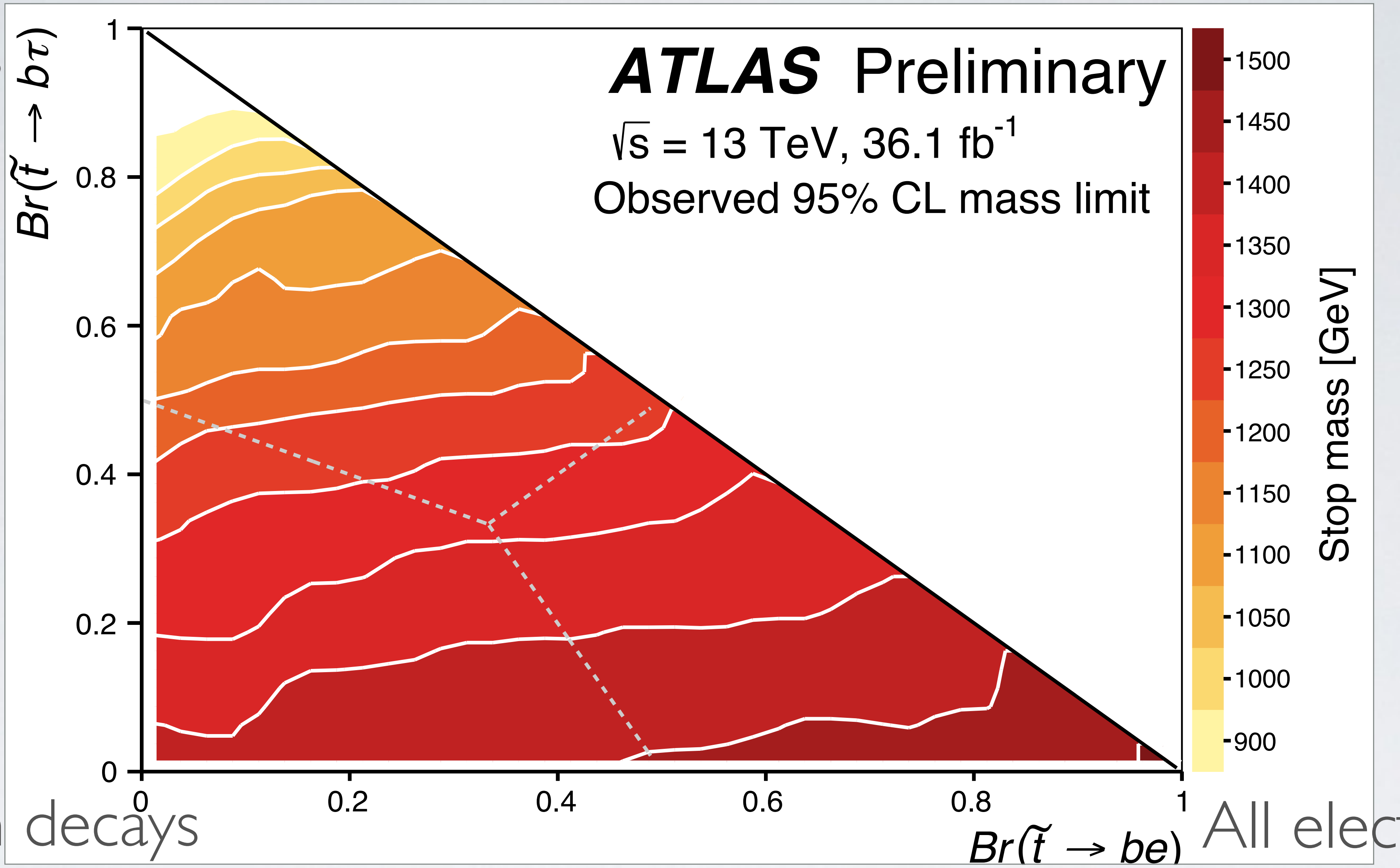
- MC statistical and theoretical uncertainties dominate
- Theoretical uncertainties are applied to background normalization factors
  - Derived by comparing ratio of SR/CR yields in nominal and "test" case:
    - scaling ISR and FSR up and down
    - comparing different parton shower and generator simulations
    - Modeling of Wt/ttbar interference (see Christian Herwig's talk)

Source \ Region	SR800	SR1100
Experimental uncertainty		
b-tagging	3%	5%
Jet energy resolution	2%	10%
Jet energy scale	1%	3%
Electrons	1%	4%
Muons	1%	3%
Theoretical modeling uncertainty		
MC statistics	8%	17%
$t\bar{t}$	8%	45%
single-top	21%	22%
Z+jets	2%	4%
diboson	4%	3%
$t\bar{t}+W/Z$	1%	1%
W+jets	1%	1%

- CP uncertainties are generally minor
  - Jet energy resolution and *b*-tagging are the most significant, as expected

OBSERVED LIMITS

All tau decays
$b\tau b\tau$

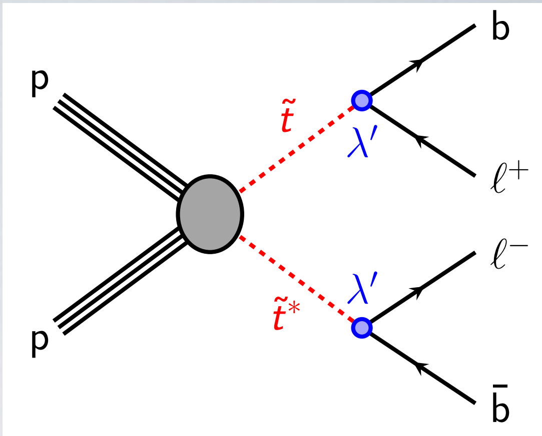


All muon decays
$b\mu b\mu$

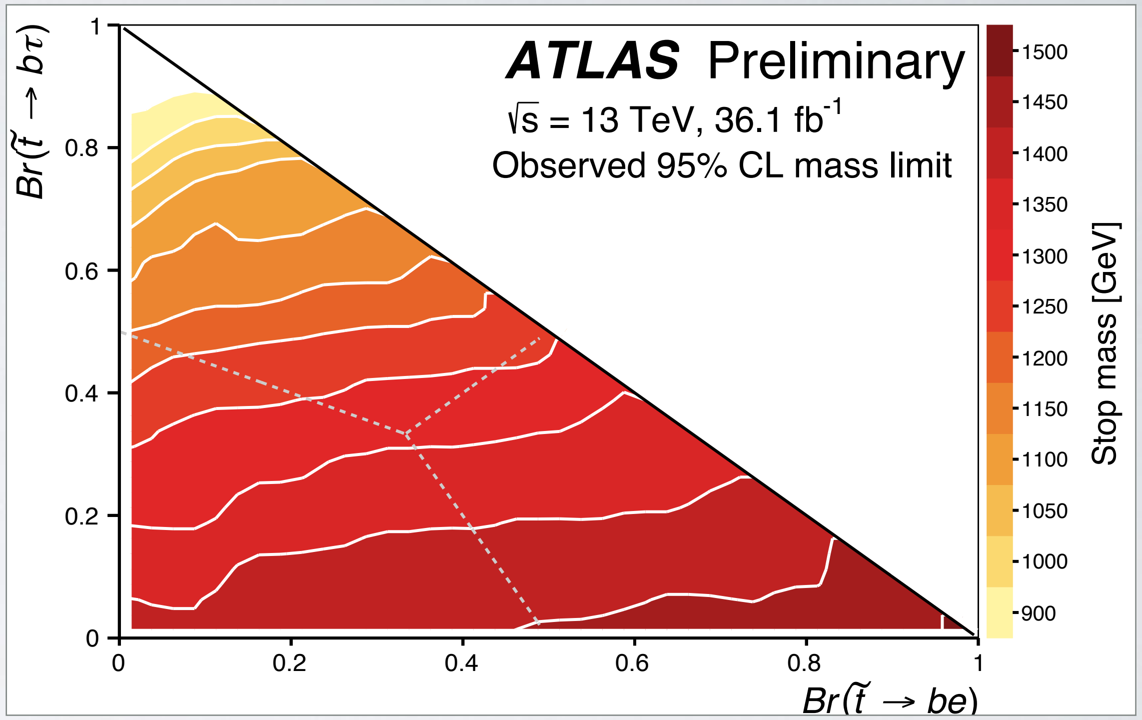
All electron decays
$bebe$

Stop masses from 900 GeV to 1.5 TeV have been excluded for BR($\tilde{t}\rightarrow be$)+ BR($\tilde{t}\rightarrow b\mu$)>10%

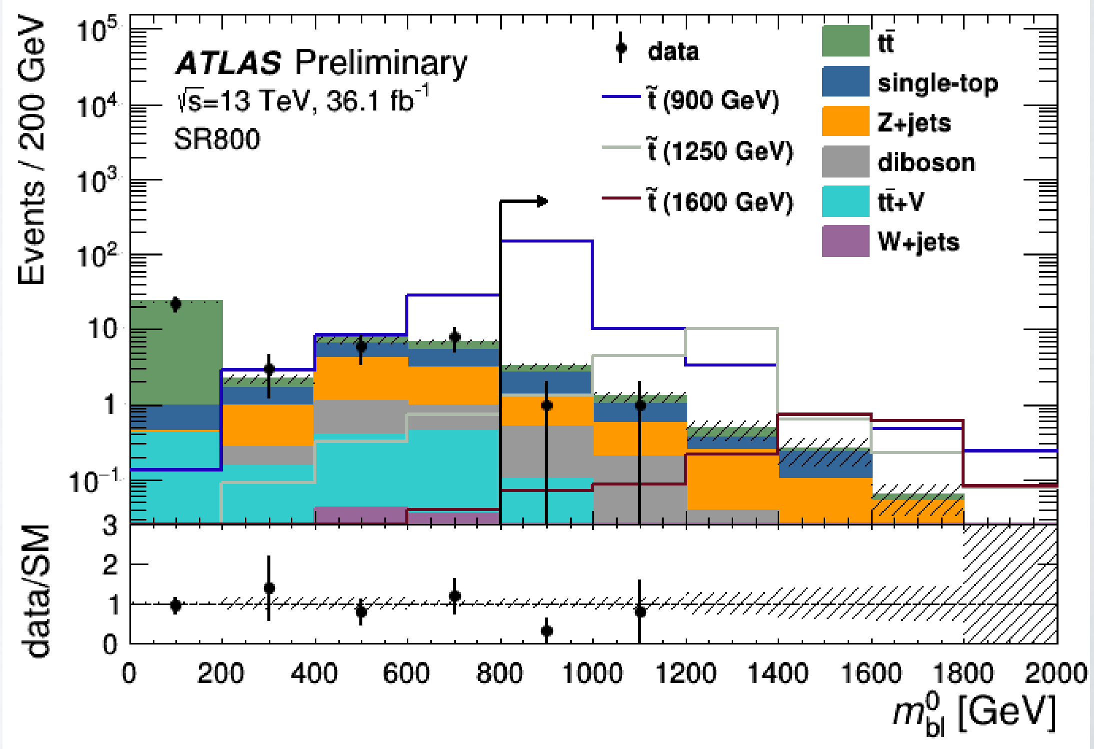
CONCLUSION



- We have presented a search for stop pair production which decays via an RPV coupling to a lepton and a *b*-quark



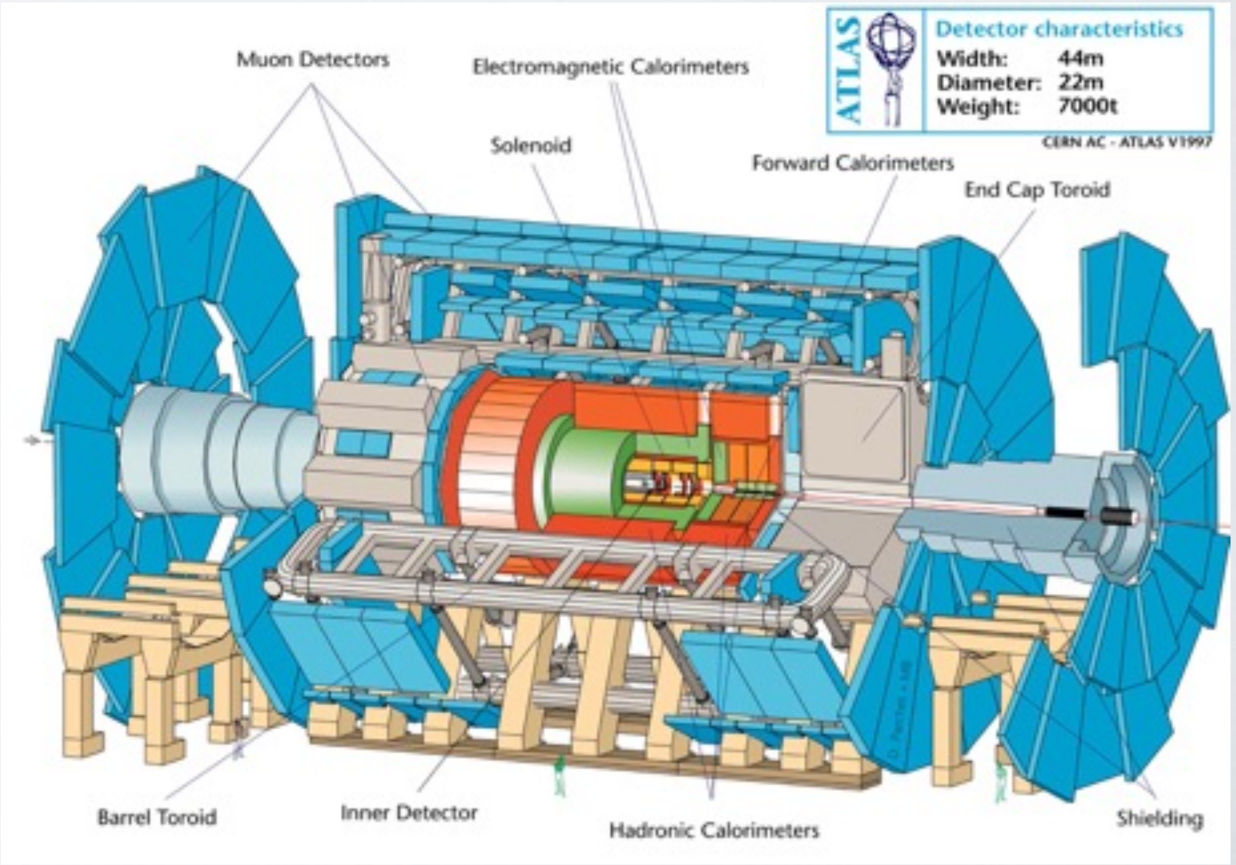
- With the absence of an observed signal, strong limits have been set on the stop mass for branching ratios of at least 10% to *be* or *b*μ



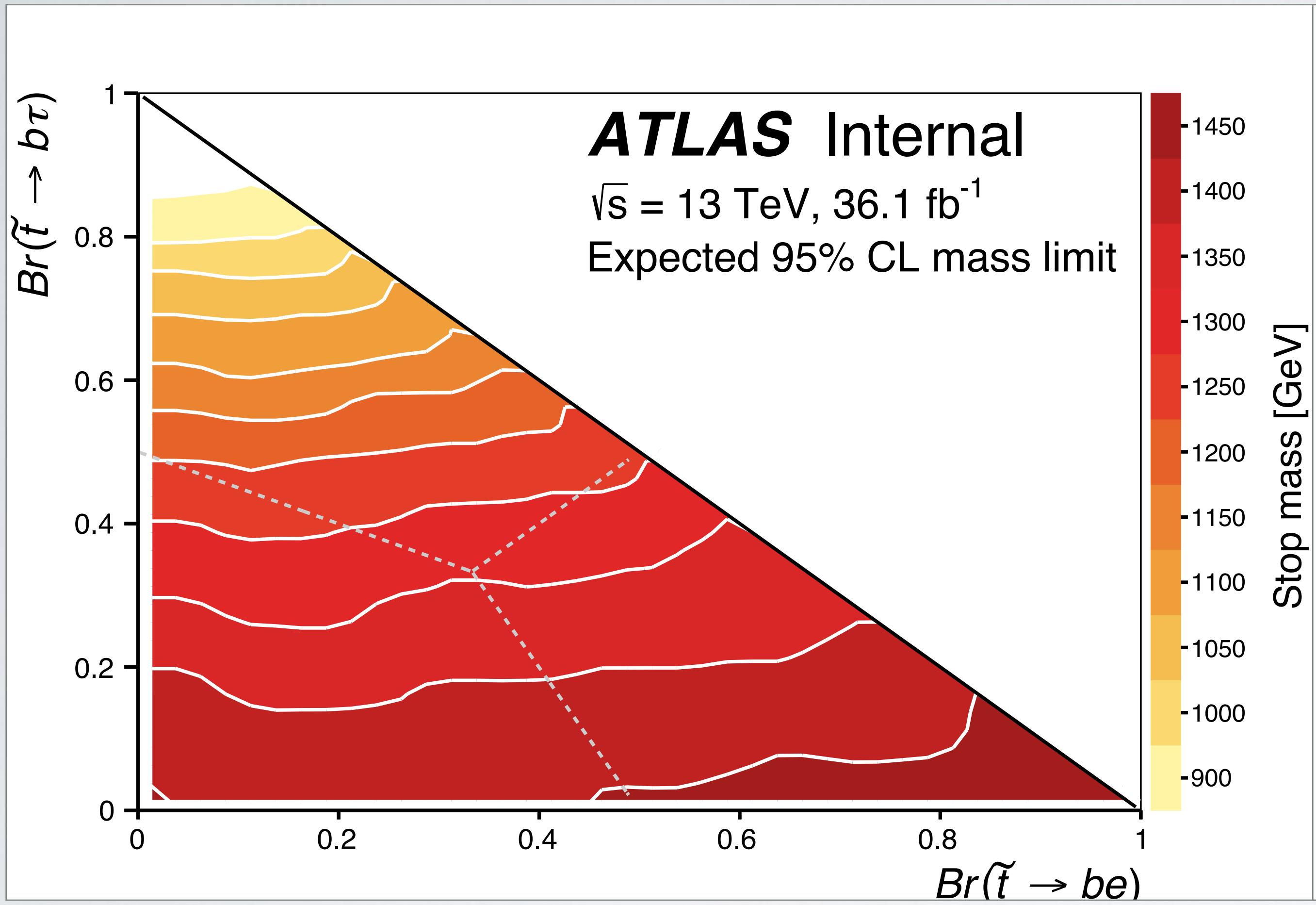
BACKUP

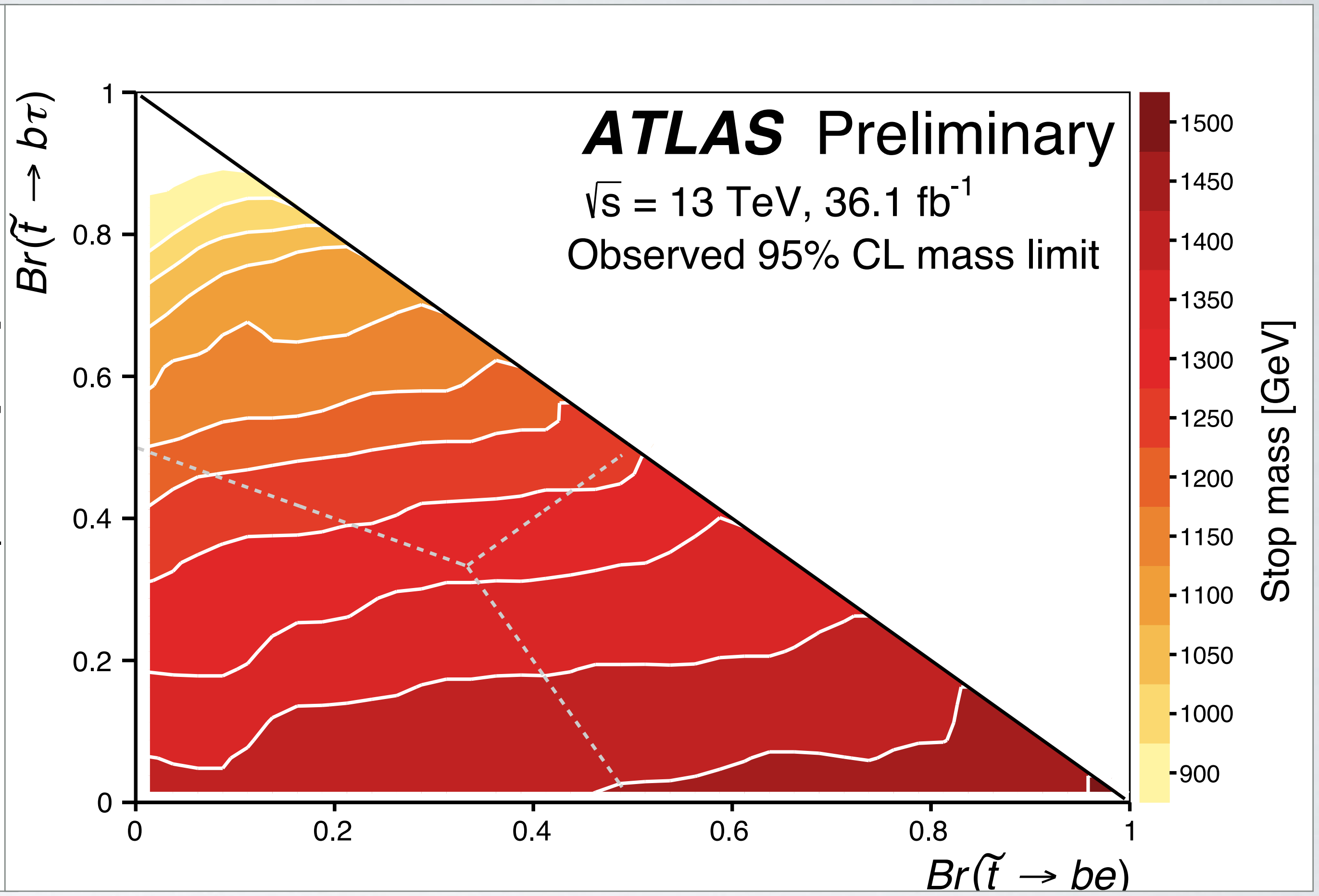
THE ATLAS DETECTOR

- Muon identification
  - Momentum resolution 5% at 500 GeV
- Electron identification
  - Energy resolution 1% at 100 GeV
- Anti-k_t jets with R=0.4
  - Energy resolution 8% at 100 GeV
- B-jet identification
  - 40% efficient at 500 GeV
- Triggers
  - Single electron and single muon triggers 93-98% efficient



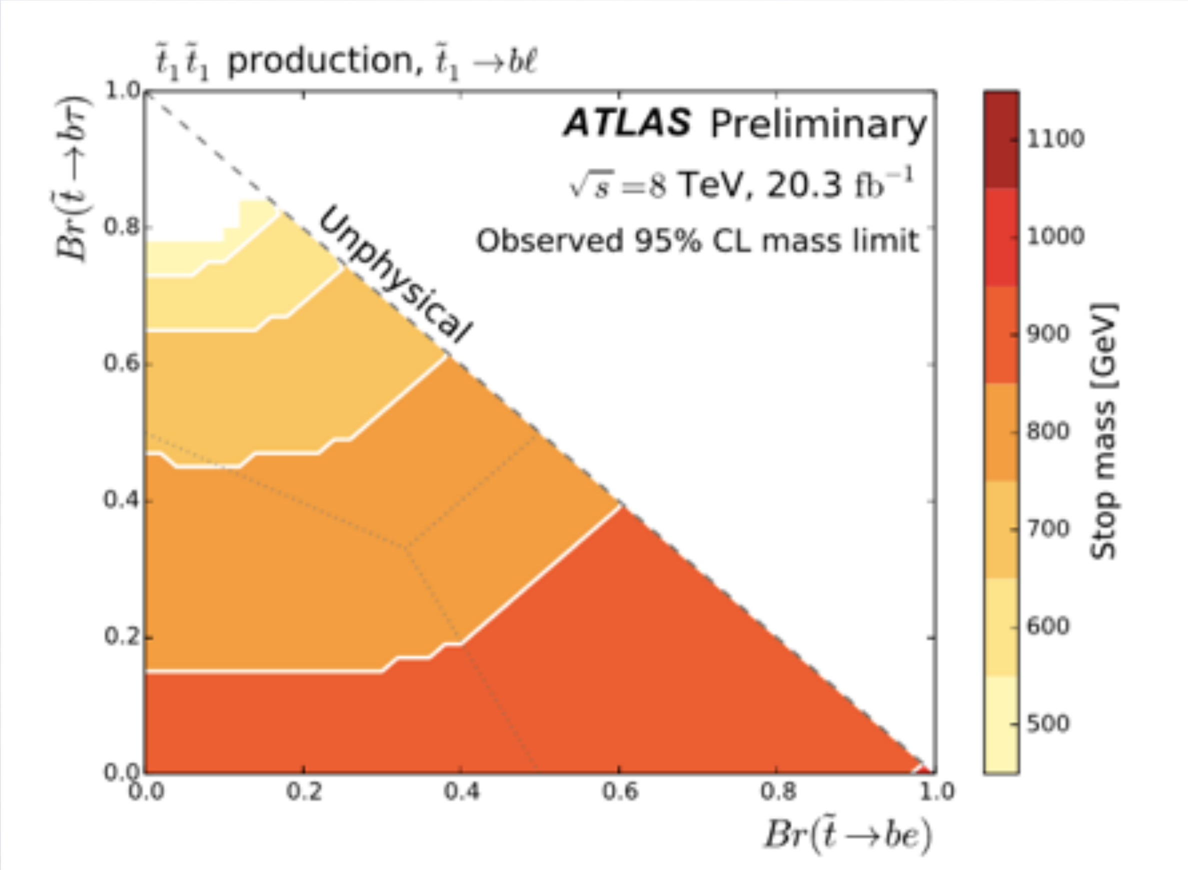
EXPECTED AND OBSERVED LIMITS

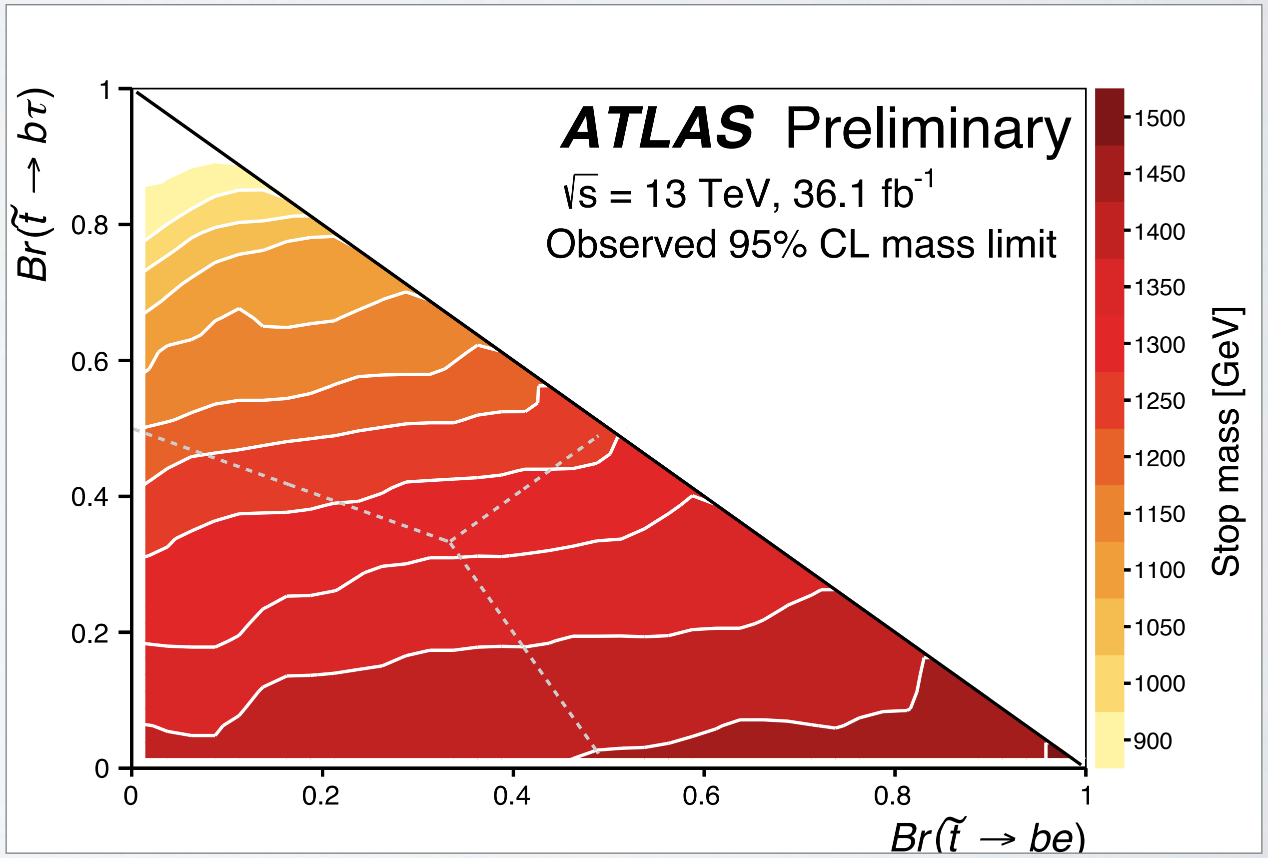




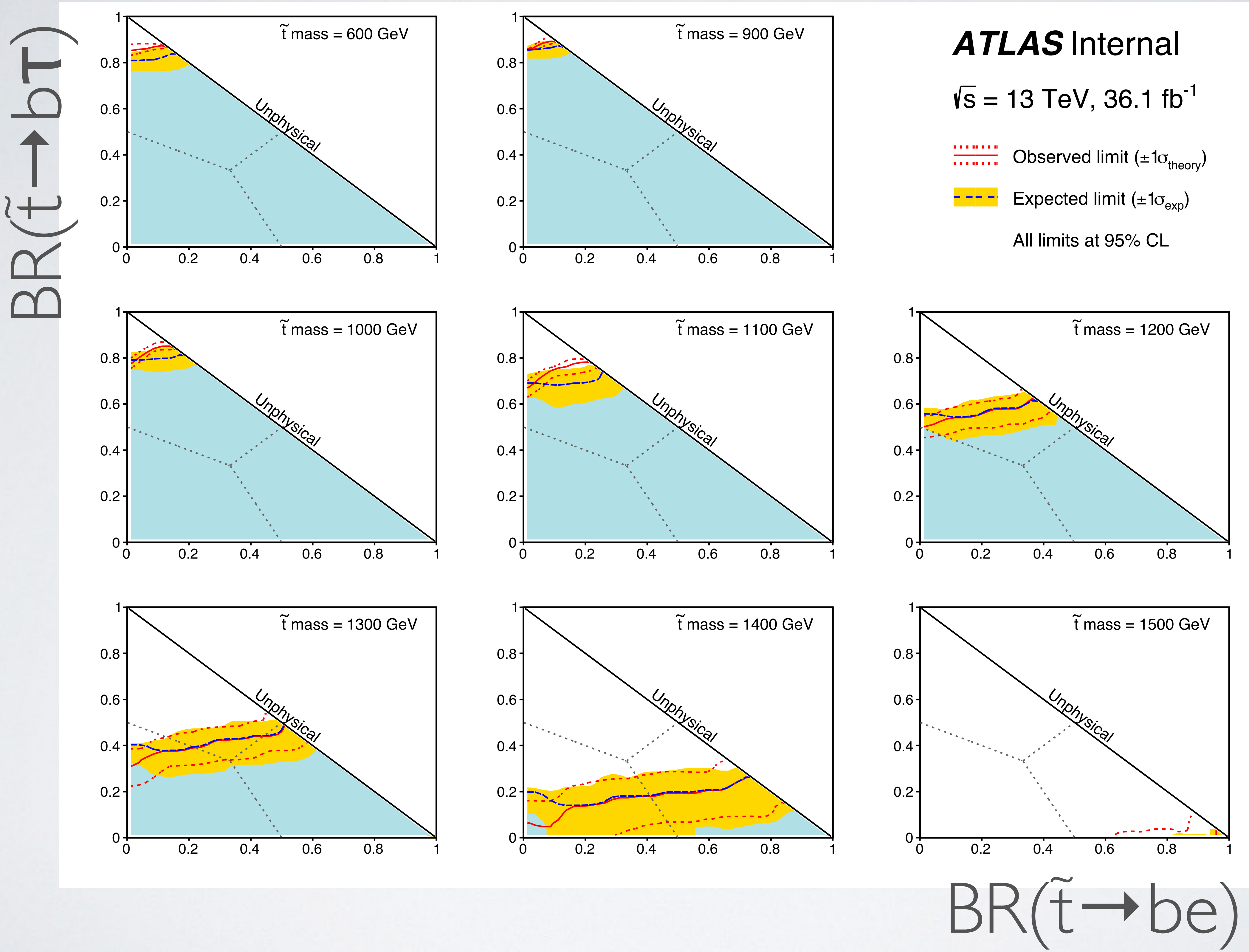
COMPARISON TO RUN1 LIMITS

- Stop mass limits at a given BR have increased from Run1 by at least 300 GeV

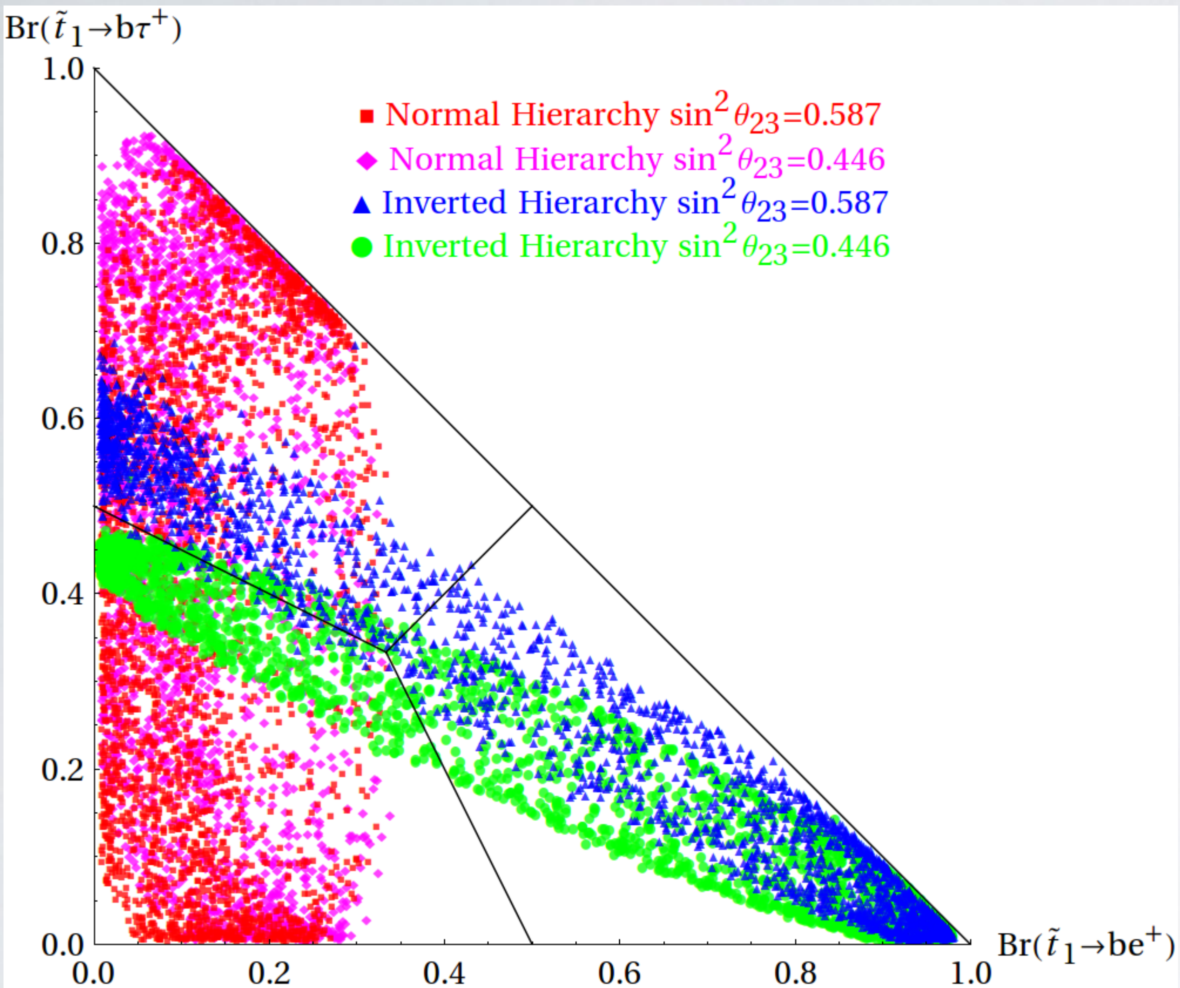


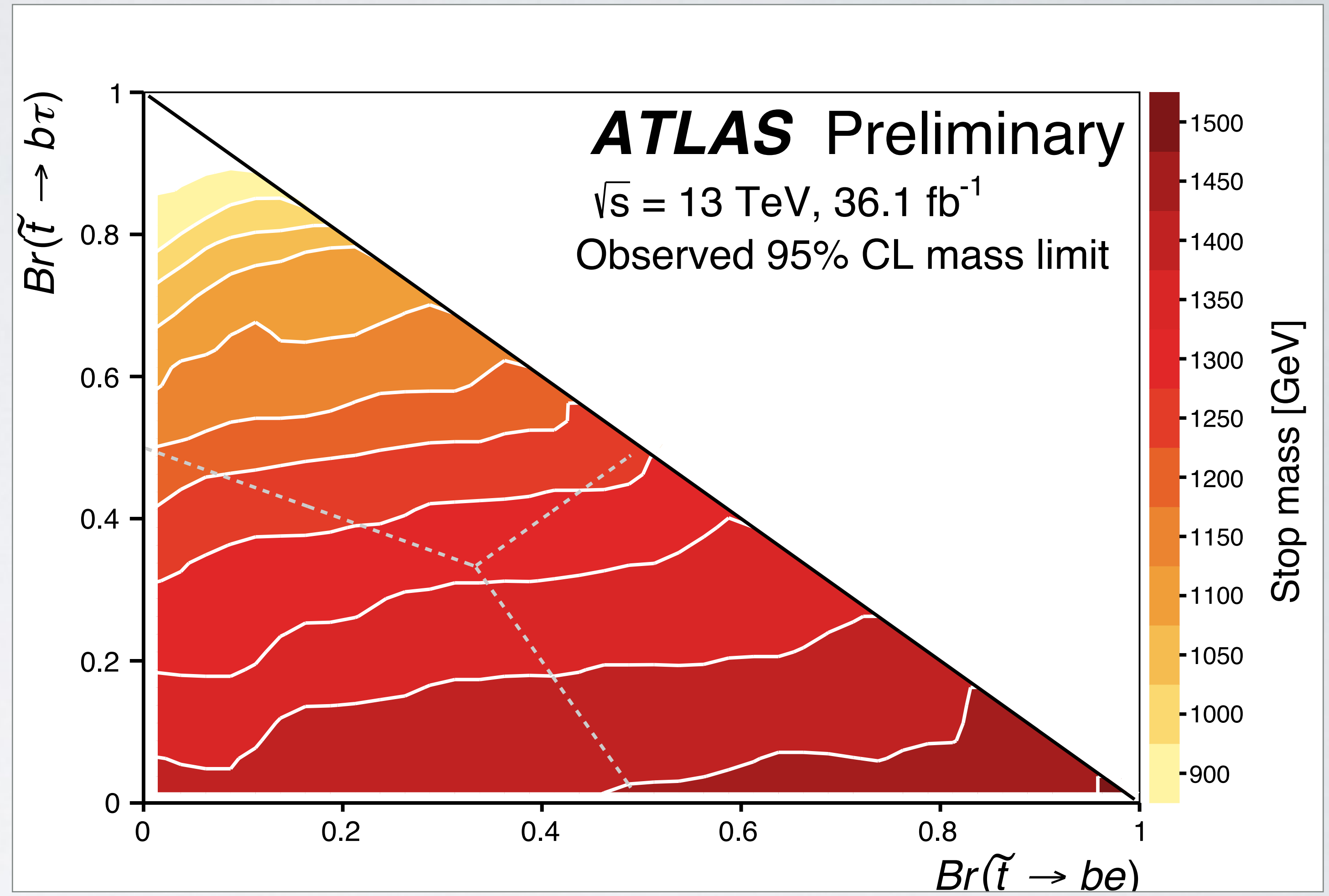


OBSERVED LIMITS



NEUTRINO MASS HIERARCHY





arXiv:1402.5434

The relative branching ratios to each lepton flavor are related to the neutrino hierarchy.

STOP MIXING ANGLE

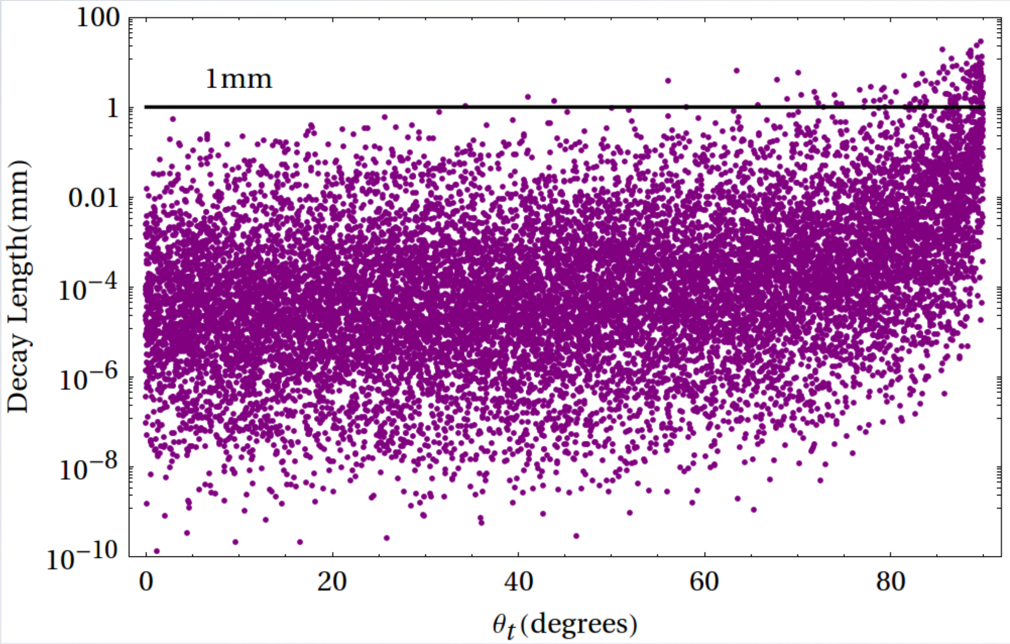


FIG. 1. Stop LSP decay length in millimeters versus stop mixing angle. The decay length increases sharply past 80°, where the stop is dominantly right-handed, due to the suppressed right-handed stop decays, Eq. (47).

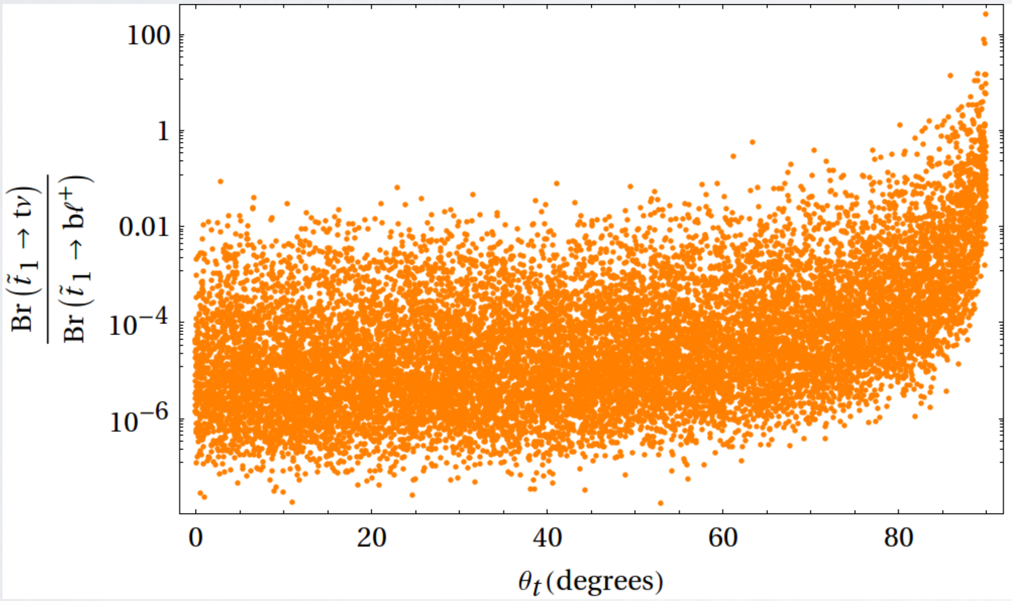


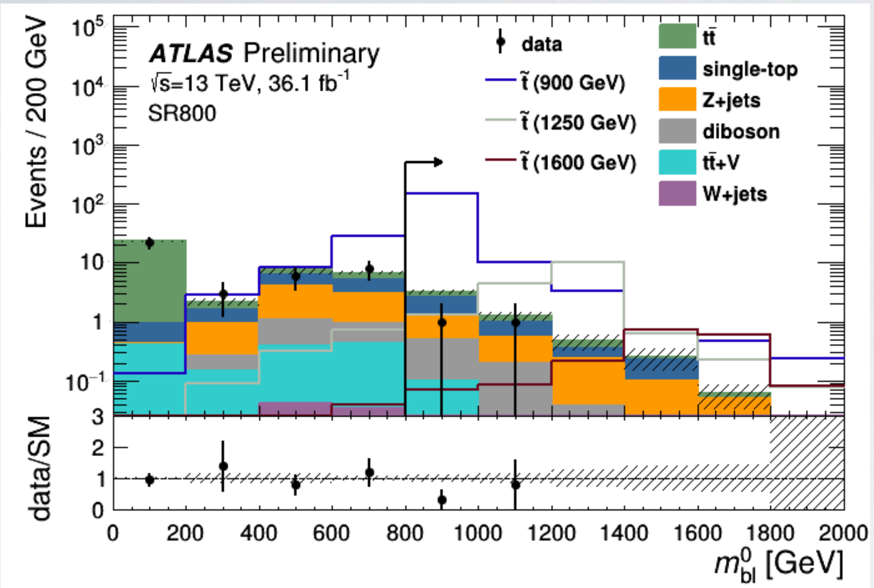
FIG. 2. $\frac{\mathrm{Br}(\tilde{t}_1 \to t\nu)}{\mathrm{Br}(\tilde{t}_1 \to b\ell^+)}$ versus stop mixing angle, where $\mathrm{Br}(\tilde{t}_1 \to b\ell^+) \equiv \sum_{i=1}^{3} \mathrm{Br}(\tilde{t}_1 \to b\ell_i^+)$. For the admixture stop, the branching ratio to $b\ell^+$ is dominant and the branching ratio to $t\nu$ is insignificant for LHC purposes. For a mixing angle greater than about 80°, corresponding to a mostly right-handed stop, the branching ratio to $t\nu$ can be significant.

When stop mixing angle θ_t<80° (in other words, unless the stop is dominantly right-handed) the stop LSPs in this model:

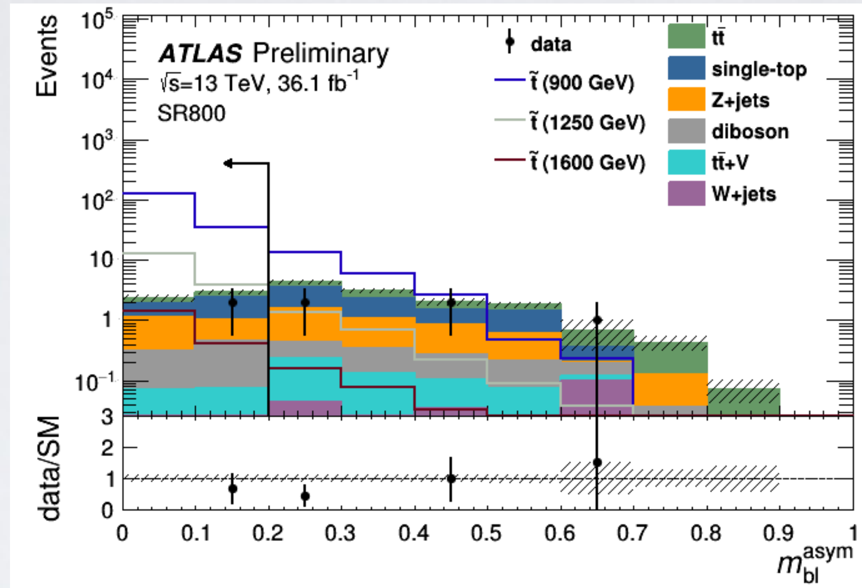
- decay promptly (Fig 1).
- preferentially decay to a lepton and a b-quark (Fig 2).

arXiv:1402.5434

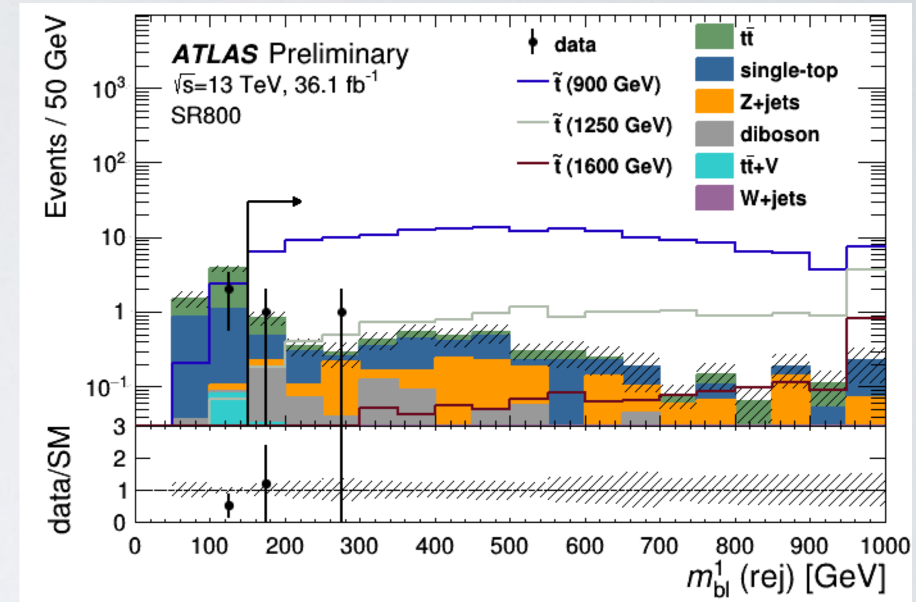
UNBLINDED SR DISTRIBUTIONS



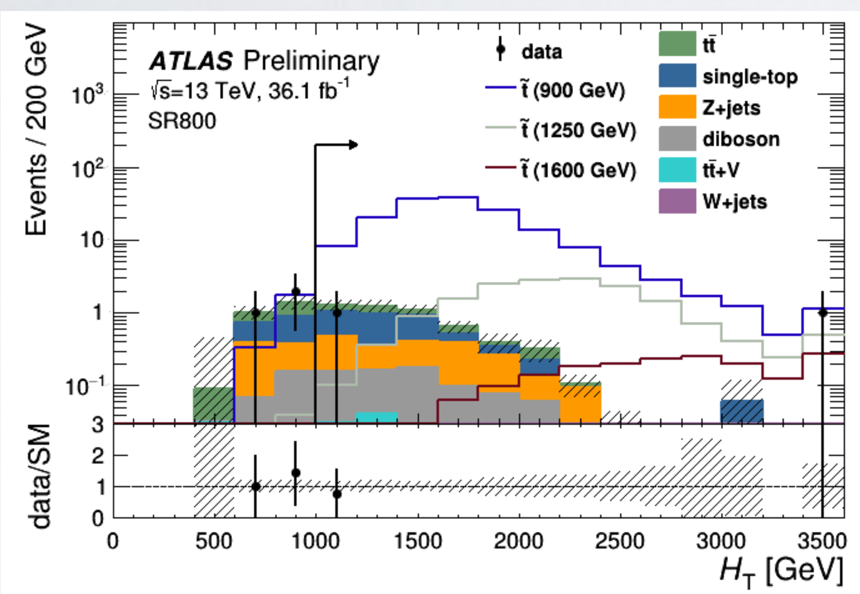
(a) $m^0_{b\ell}$



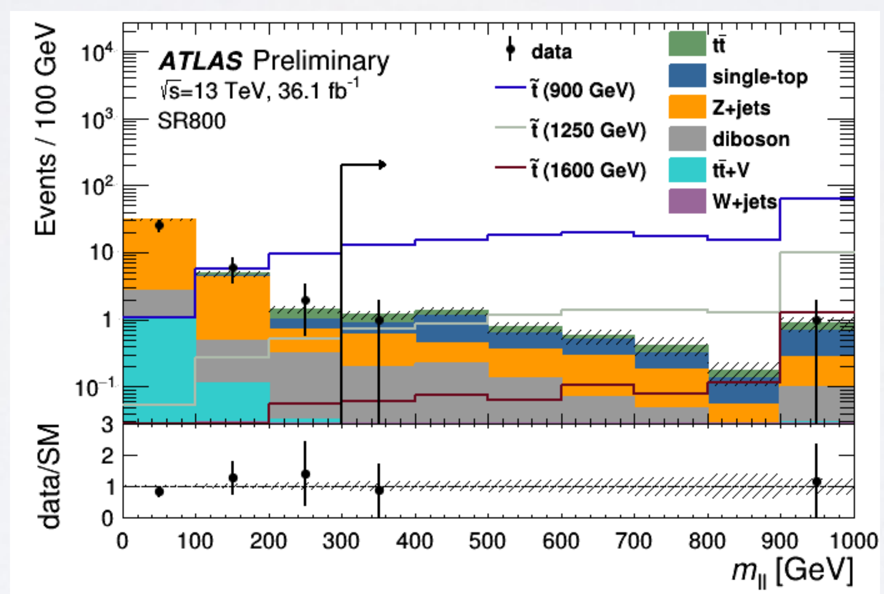
(b) $m^{\mathrm{asym}}_{b\ell}$



(e) $m^1_{b\ell}$(rej)

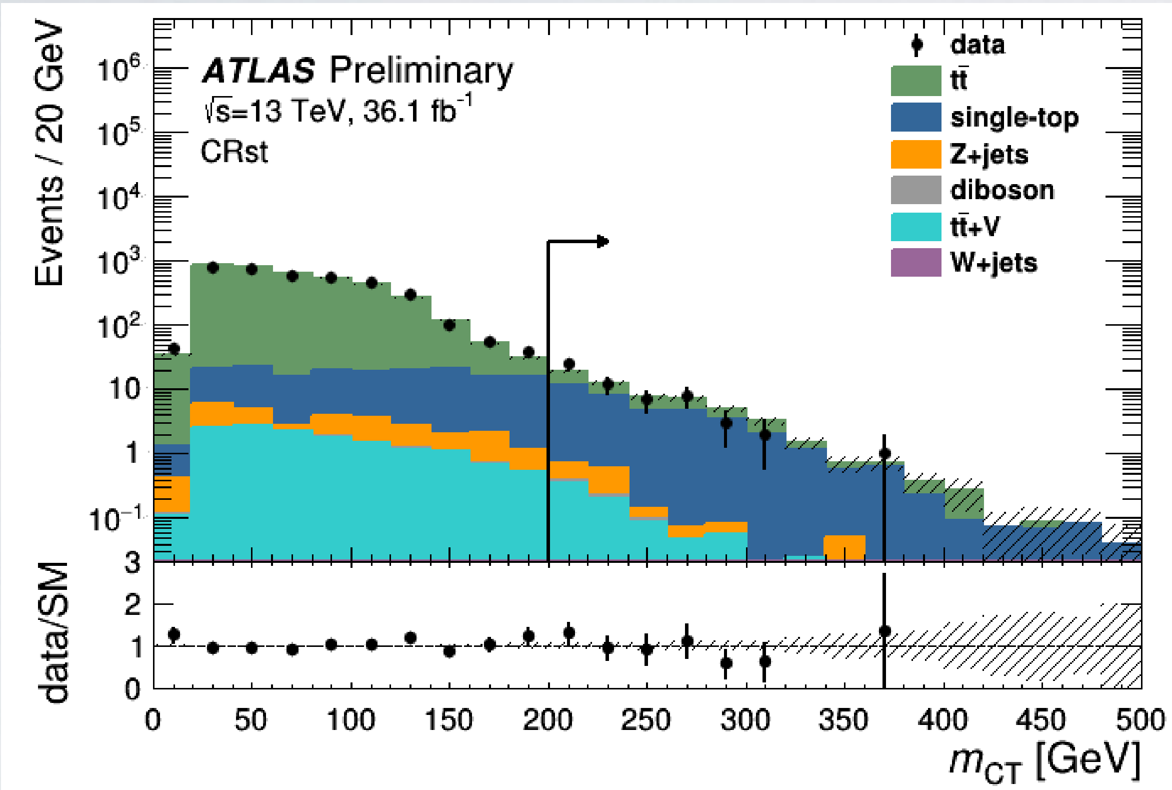


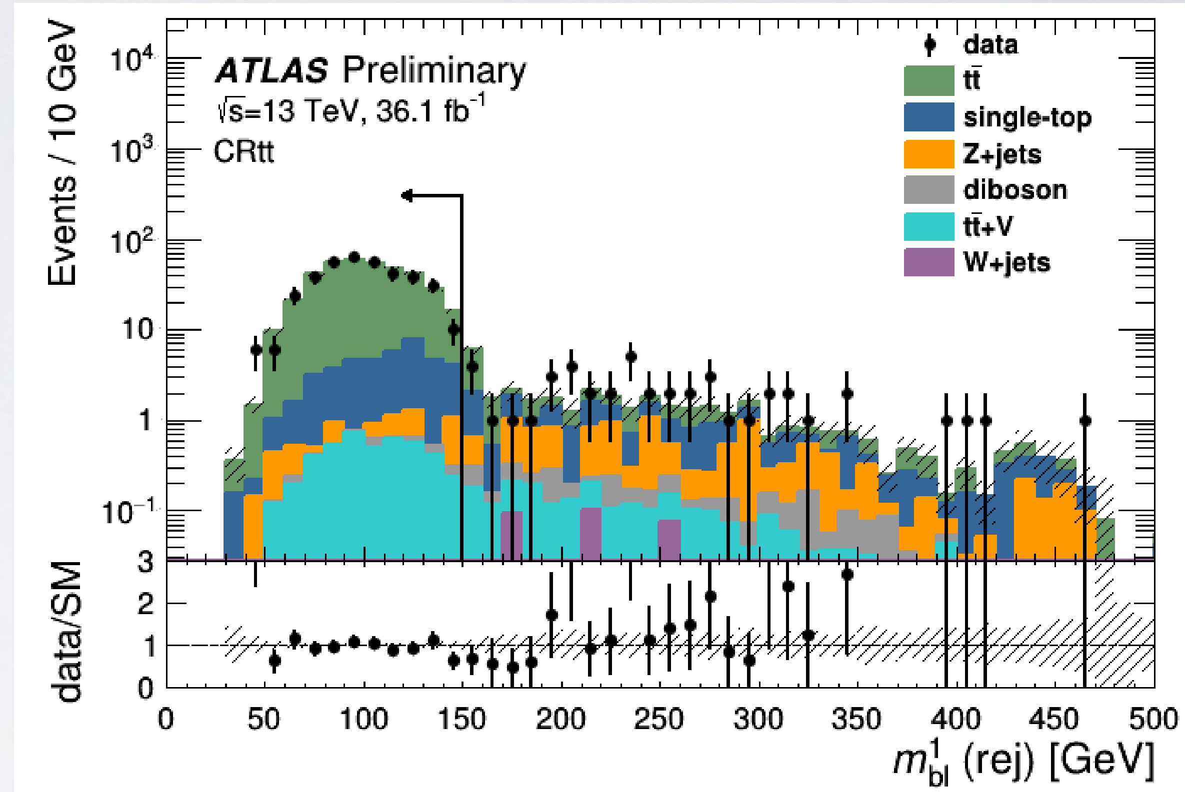
(c) H_{T}



(d) $m_{\ell\ell}$

CR DISTRIBUTIONS





Normalization factors:

single top: 1.10 ± 0.27

ttbar: 0.94± 0.06

Drell-Yan: 1.22 ± 0.18

SIGNAL CUTFLOW

Selection	800 GeV yield (rel. eff.)	1200 GeV yield (rel. eff.)	1500 GeV yield (rel. eff.)
Total	1022	57	9
Production filter	737 (72.0%)	42.6 (73.8%)	6.9 (74.7%)
Event quality	737 (100.0%)	42.6 (100.0%)	6.9 (100.0%)
Trigger	705 (95.7%)	41.0 (96.3%)	6.7 (96.3%)
Jet cleaning	704 (99.9%)	40.9 (99.8%)	6.7 (99.8%)
Muon cleaning	704 (100.0%)	40.9 (100.0%)	6.6 (100.0%)
2 signal ℓ	385 (54.7%)	21.7 (53.0%)	3.5 (52.2%)
Trigger matching	385 (99.8%)	21.6 (99.8%)	3.5 (99.8%)
Opposite-charge leptons	375 (97.5%)	20.9 (96.8%)	3.3 (96.5%)
2 signal jets	363 (96.9%)	20.6 (98.2%)	3.3 (98.7%)
1 b-tagged jet	285 (78.5%)	14.3 (69.6%)	2.0 (62.3%)
$m_{b\ell}^{\mathrm{asym}} < 0.2$	245 (85.8%)	12.2 (85.3%)	1.8 (86.3%)
$H_{\mathrm{T}} > 1000$ GeV	228 (92.9%)	12.1 (99.4%)	1.8 (99.7%)
$m_{\ell\ell} > 300$ GeV	199 (87.6%)	11.5 (94.6%)	1.7 (96.4%)
$m_{b\ell}^{1}(\mathrm{rej}) > 150$ GeV	195 (97.8%)	11.4 (99.4%)	1.7 (99.9%)
$m_{b\ell}^{0} > 800$ GeV	81.2 (41.6%)	10.7 (93.4%)	1.6 (96.3%)
$m_{b\ell}^{0} > 1100$ GeV	4.4 (2.3%)	8.4 (73.6%)	1.5 (89.5%)

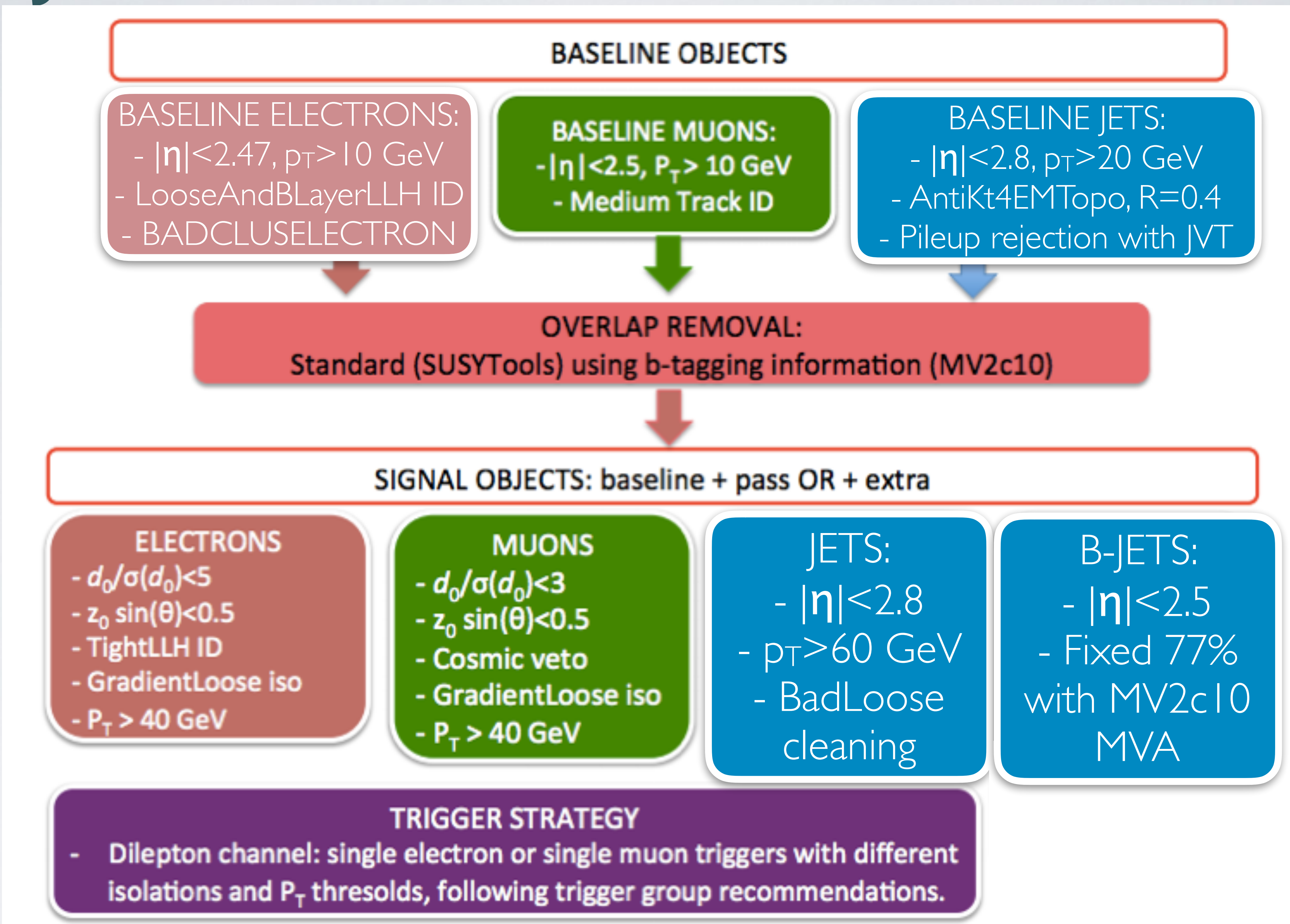
Table 5: Full list of event selections and MC generator-weighted yields and efficiencies in the inclusive SR800 and SR1100 signal regions for several signal samples of varying $\tilde{t}$ mass, assuming $Br(\tilde{t} \to be) = Br(\tilde{t} \to b\mu) = Br(\tilde{t} \to b\tau) = 1/3$. The production filter applies a loose trigger requirement and requires at least two electrons or muons of uncalibrated $p_{\mathrm{T}} > 9$ GeV and $|\eta| < 2.6$. The relative efficiencies for the $m_{b\ell}^{0} > 1100$ GeV requirement are with respect to the $m_{b\ell}^{1}(\mathrm{rej}) > 150$ GeV requirement.

DISCRIMINATING VARIABLES

- $m_{b\ell}^{acc1}$: to probe $m_{\tilde{t}}$
- $m_{b\ell}^{asym}$: should be small if both $b\ell$ pairs reconstruct $m_{\tilde{t}}$
- $H_T = p_T^{lep1} + p_T^{lep2} + p_T^{jet1} + p_T^{jet2}$: should be large with such heavy stops
- $m_{\ell\ell}$: to reject Drell-Yan background
- $m_{b\ell}^{rej2}$: to reject mis-paired top background, when a rejected pairing reconstructs a top
- m_{cT}: contransverse mass of the two leading jets; to reject $t\bar{t}$ events which have a kinematic endpoint at ~135 GeV. For this variable we require exactly 2 b-tagged jets.

$$m_{CT}^2(j_1, j_2) = [E_T(j_1) + E_T(j_2)]^2 - \left[\vec{P}_T(j_1) - \vec{P}_T(j_2)\right]^2$$

OBJECT & EVENT SELECTION



- Event selection: two signal leptons with pT > 40 GeV and two signal jets with pT > 60 GeV

CR AND VR DEFINITIONS

Region	N_b	$m^0_{b\ell}$ [GeV]	$m^1_{b\ell}$(rej)[GeV]	H_{T} [GeV]	$m_{\ell\ell}$ [GeV]	m_{CT} [GeV]
CRtt	≥ 1	[200,500]	< 150	[600,800]	> 300	$< 200^*$
CRst	$= 2$	[200,500]	< 150	< 800	> 120	> 200
CRZ	≥ 1	> 700	–	> 1000	[76.2,106.2]	–
VR$m^0_{b\ell}$	≥ 1	> 500	< 150	[600,800]	> 300	–
VR$m^1_{b\ell}$(rej)	≥ 1	[200,500]	> 150	[600,800]	> 300	–
VRH_{T}	≥ 1	[200,500]	< 150	> 800	> 300	–
VRZ	$= 0$	[500,800]	> 150	> 1000	> 300	–

+ $m_{b\ell}^{asym} \leq 0.2$ for all regions

*only for events with ==2 b-tagged jets