Search for 3rd generation superpartners with the ATLAS experiment

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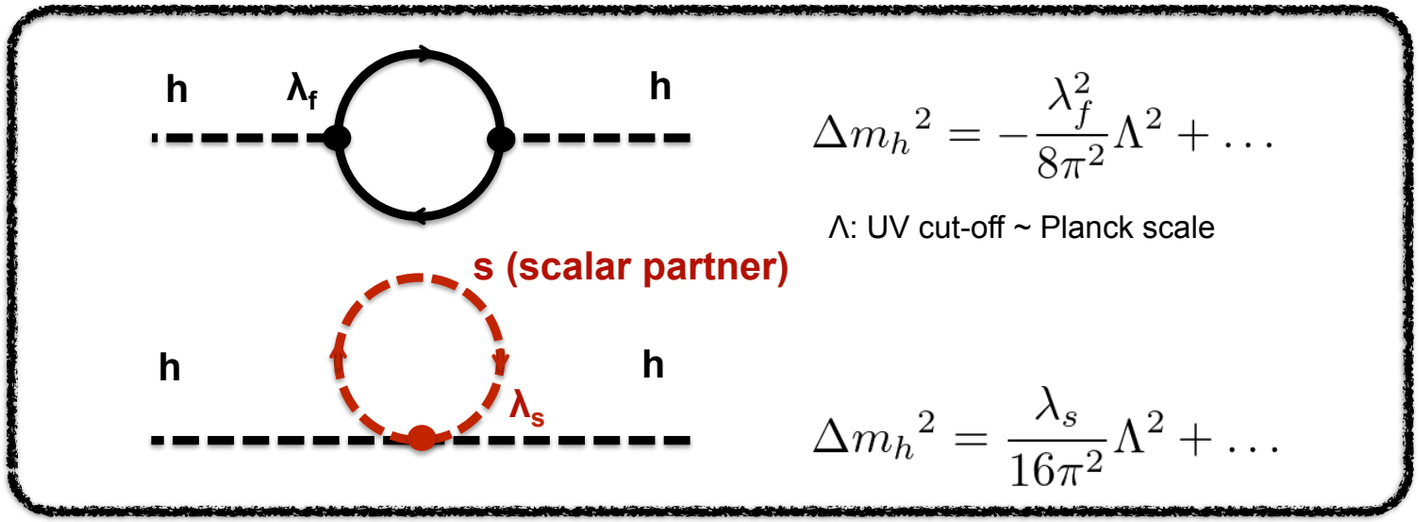
Introduction

The SM of particle physics is incomplete. Supersymmetry can be a new theory solving various problems remained in the SM.

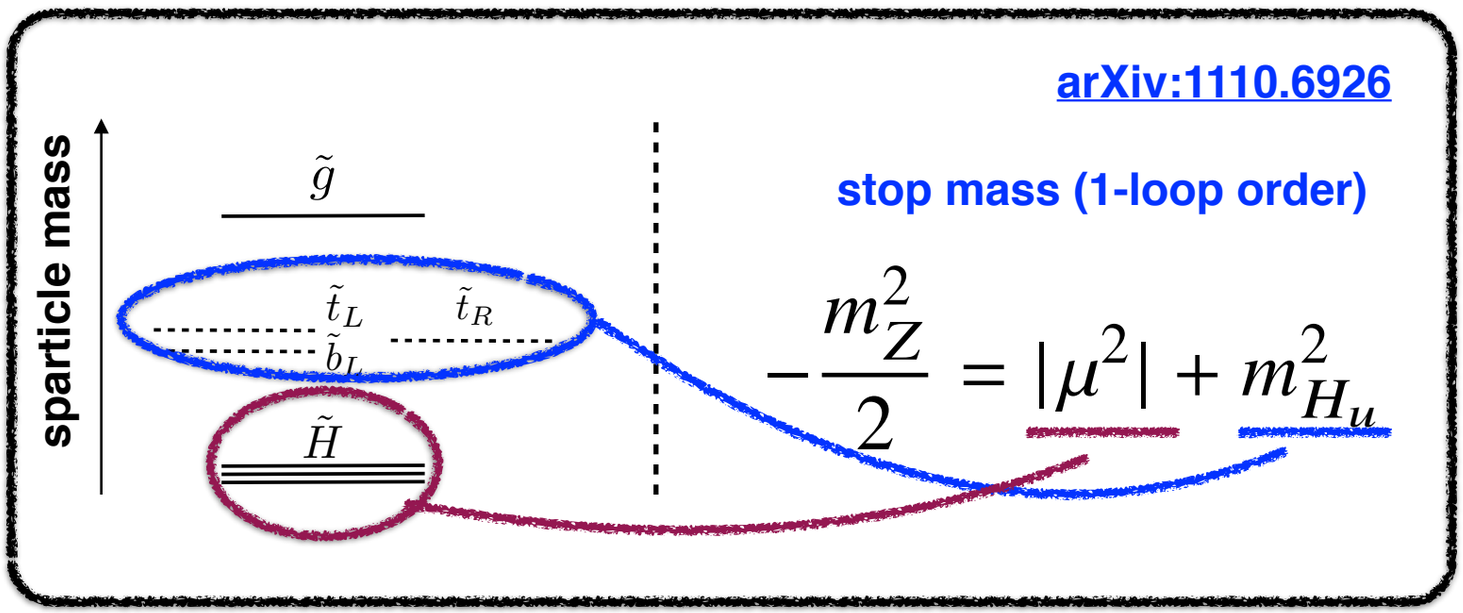
1. Higgs mass divergence at Planck scale due to radiative corrections **(Hierarchy problem)**
   -> $\tilde{t}$ and $\tilde{b}$ are a key **(large Yukawa coupling)**



$$\Delta m_h{}^2 = -\frac{\lambda_f^2}{8\pi^2}\Lambda^2 + \dots$$

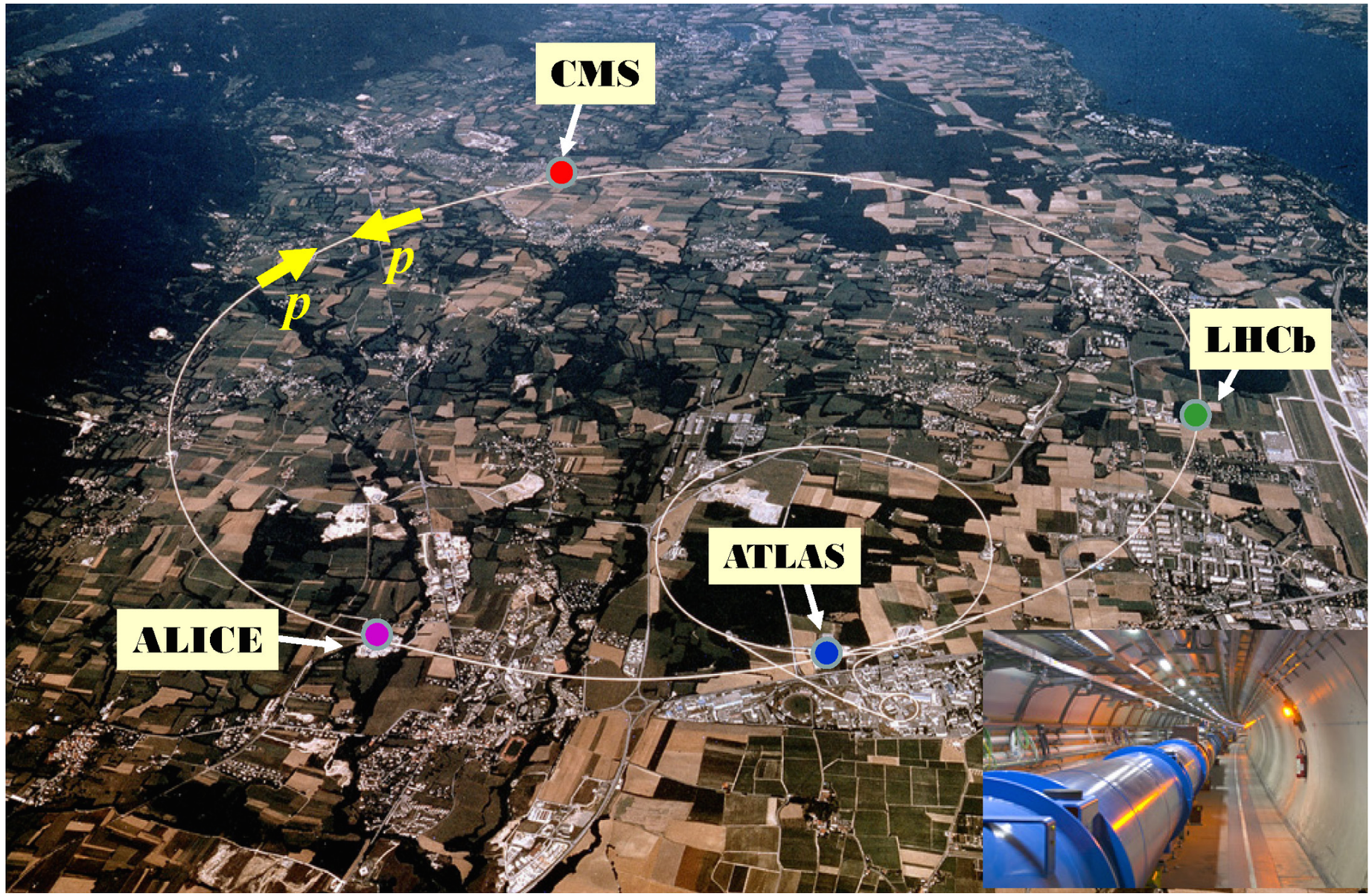
Λ: UV cut-off ~ Planck scale

$$\Delta m_h{}^2 = \frac{\lambda_s}{16\pi^2}\Lambda^2 + \dots$$



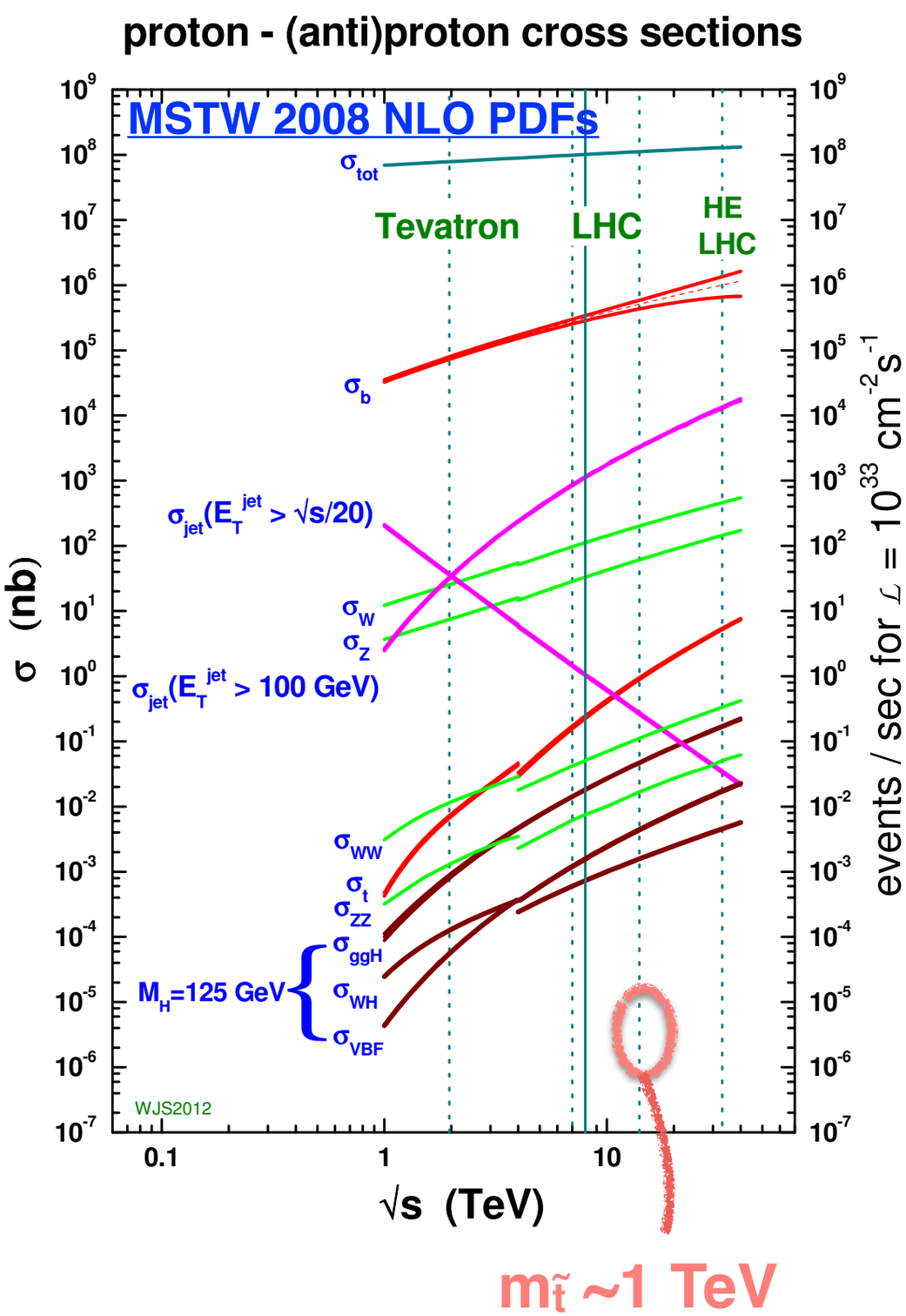
2. **Naturalness** (Natural SUSY) suggests the presence of light 3rd gen. squarks together with the higgsino LSP(s).

Large Hadron Collider (LHC)

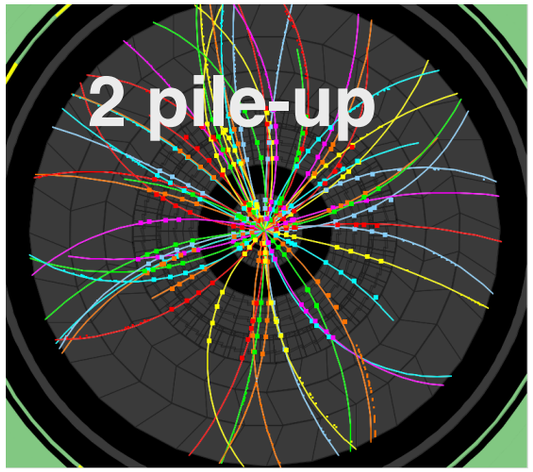


LHC was constructed to perform various searches (Higgs boson and BSM physics) at TeV energy scale.

Challenging environment at LHC

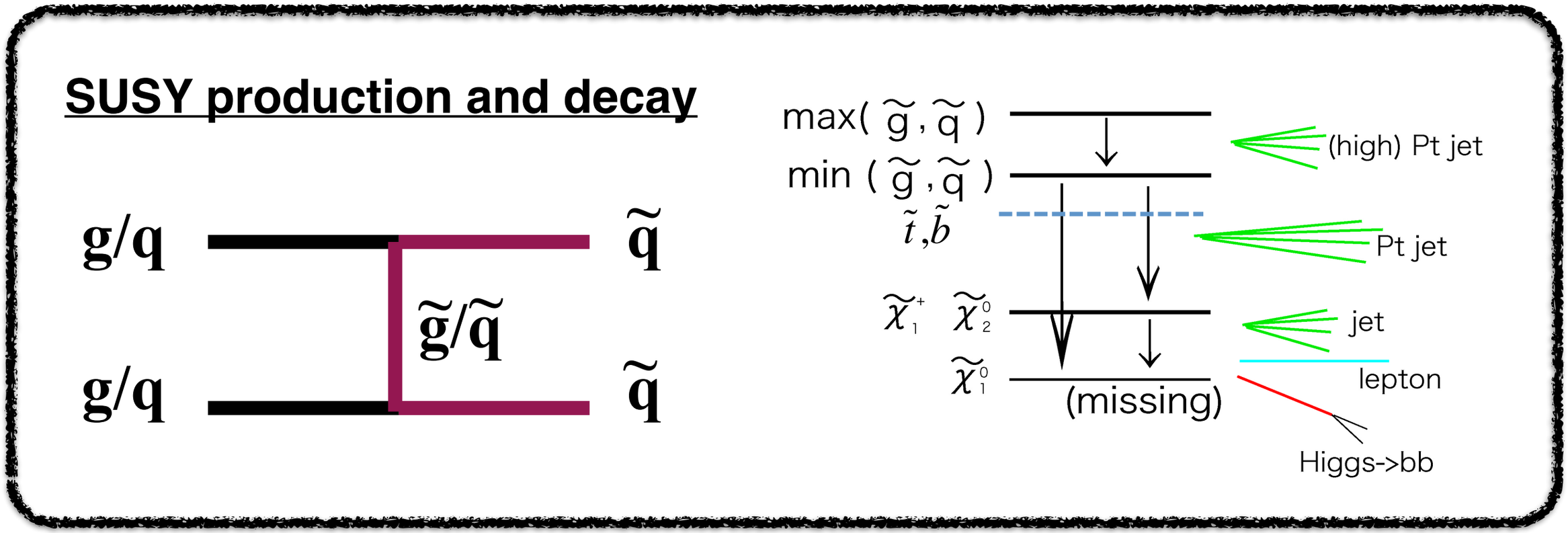


- The cross section for the SUSY is very small.



- As the luminosity increases, number of interactions per crossing (pile-up or μ) and detector occupancy increases.
- Collecting important physics events in this difficult environment is a key at the LHC.

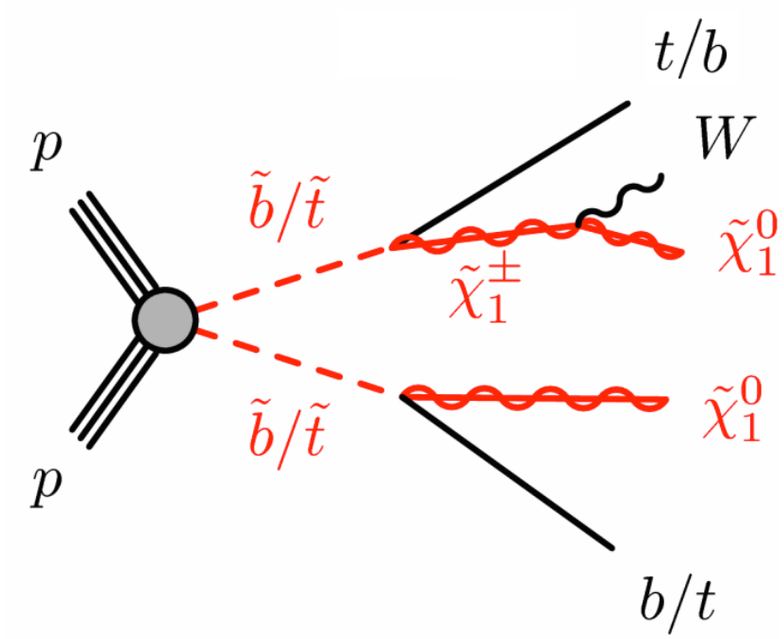
SUSY decay and production at LHC

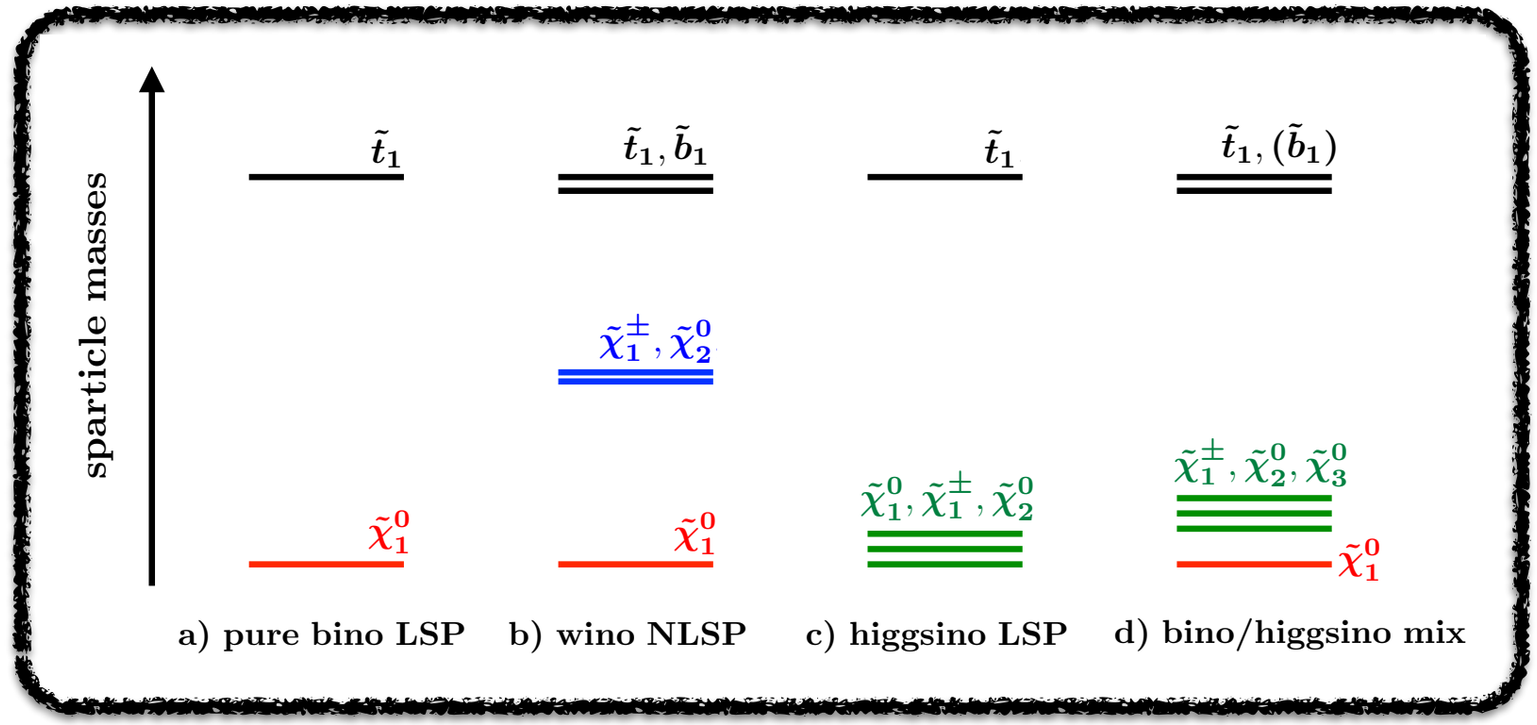


- The stop/sbottom is pair-produced (in RPC scenario) from the gg process if the mass is light ($m_{\tilde{t},\tilde{b}}$ < 1 TeV). As the SUSY mass goes high, the qq contribution gets larger (PDF is very steep).

- The stop/sbottom decays into intermediate states ($\tilde{\chi}_2^0$, $\tilde{\chi}_1^\pm$) if exists, otherwise the stop/sbottom decays directly into the LSP ($\tilde{\chi}_1^0$).

Search strategy

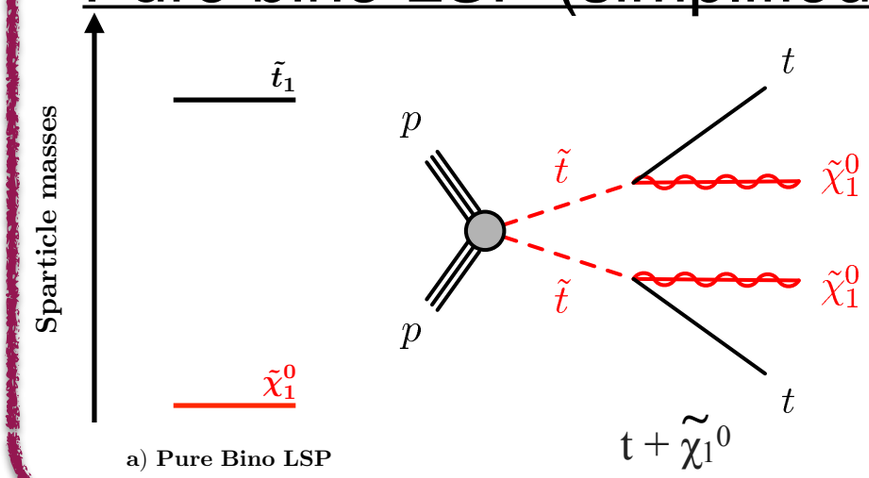


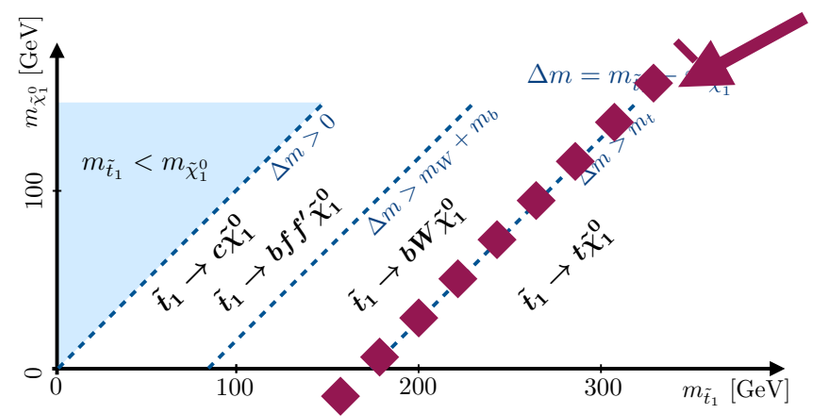


- Various pMSSM (or simplified) models are built to cover the various physics models (GUT, Naturalness, etc…) and the LSP scenarios.
- The event selection is optimized for the various final states, e.g. $t \to t\tilde{\chi}_1^0$, $b\tilde{\chi}_1^{\pm}$, $b \to b\tilde{\chi}_1^0$, $t\tilde{\chi}_1^{\pm}$ …
- Both RPC and RPV stop/sbottom searches are performed in ATLAS. **This talk focuses on RPC scenario**.

Bino LSP models

Pure bino LSP (simplified) model:

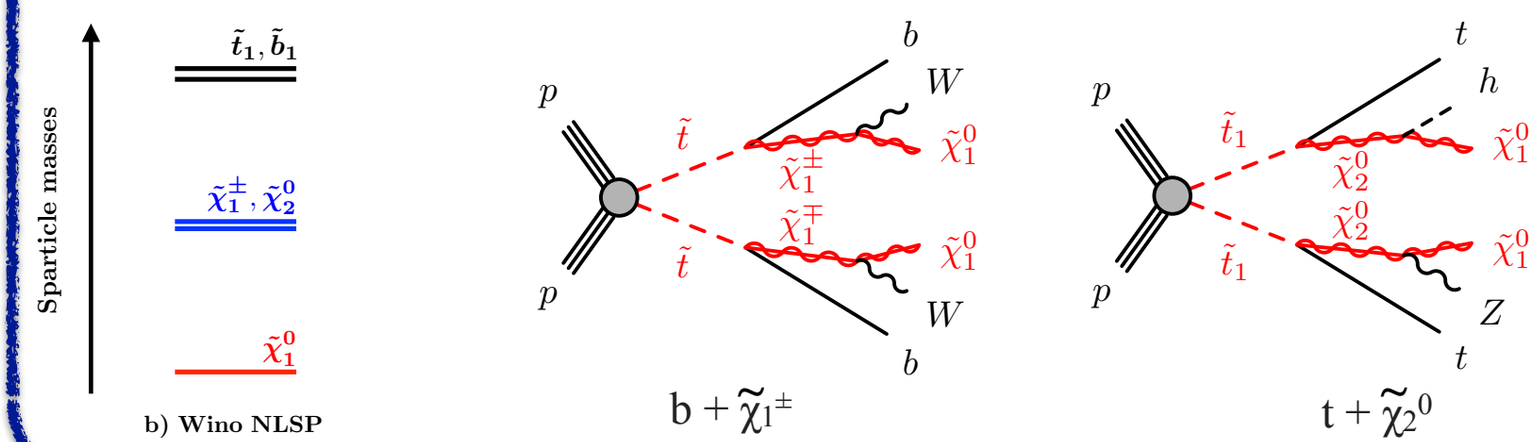




New technique:
BDT and shape-fit

Decay is governed by $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$.

Wino NLSP ($m(\tilde{\chi}_1^{\pm}) \sim 2m(\tilde{\chi}_1^0)$) (pMSSM) model: GUT (cMSSM/mSUGRA)



$b+\tilde{\chi}_1^{\pm}$ signature:
high pT b-jets, jets, and large MET

Higgsino LSP models

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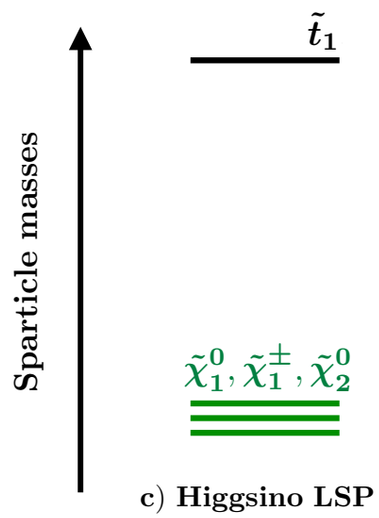
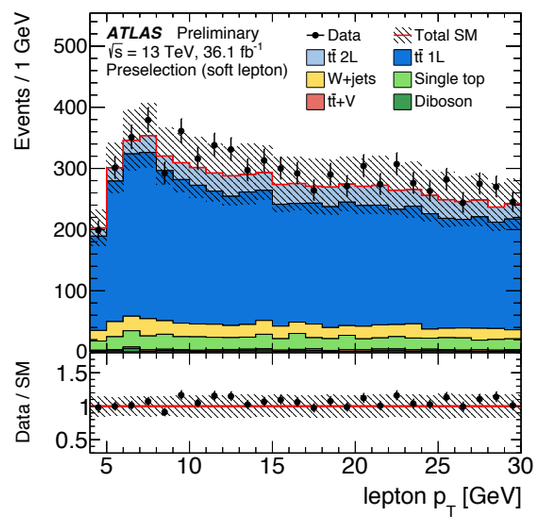
Higgsino LSP (simplified) model: Naturalness





Two benchmark models:

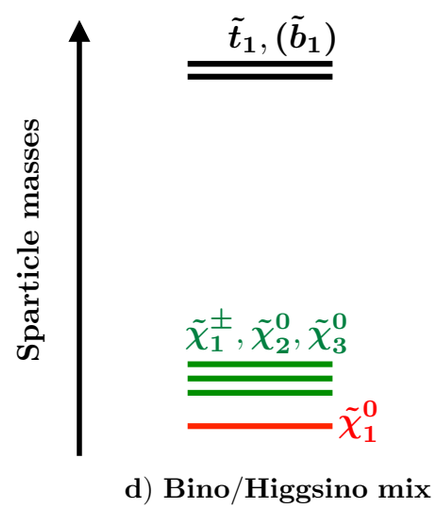
a) $\Delta m(\tilde{\chi}_1^0, \tilde{\chi}_1^\pm)$ = 5 GeV

b) variable $\Delta m(\tilde{\chi}_1^0, \tilde{\chi}_1^\pm)$ = 0-30 GeV

Signature:

Soft-objects and large MET

Well-tempered (pMSSM) model: DM relic density (Ωh2 ~ 1.12)



- Admixture LSP (bino/higgsino) satisfying $M_1 \sim -|\mu|$
- Typical $\Delta m(\tilde{\chi}_1^0, \tilde{\chi}_1^\pm)$ ~ 20-50 GeV
- Interpretation only (no event selection optimized)

Top quark reconstruction

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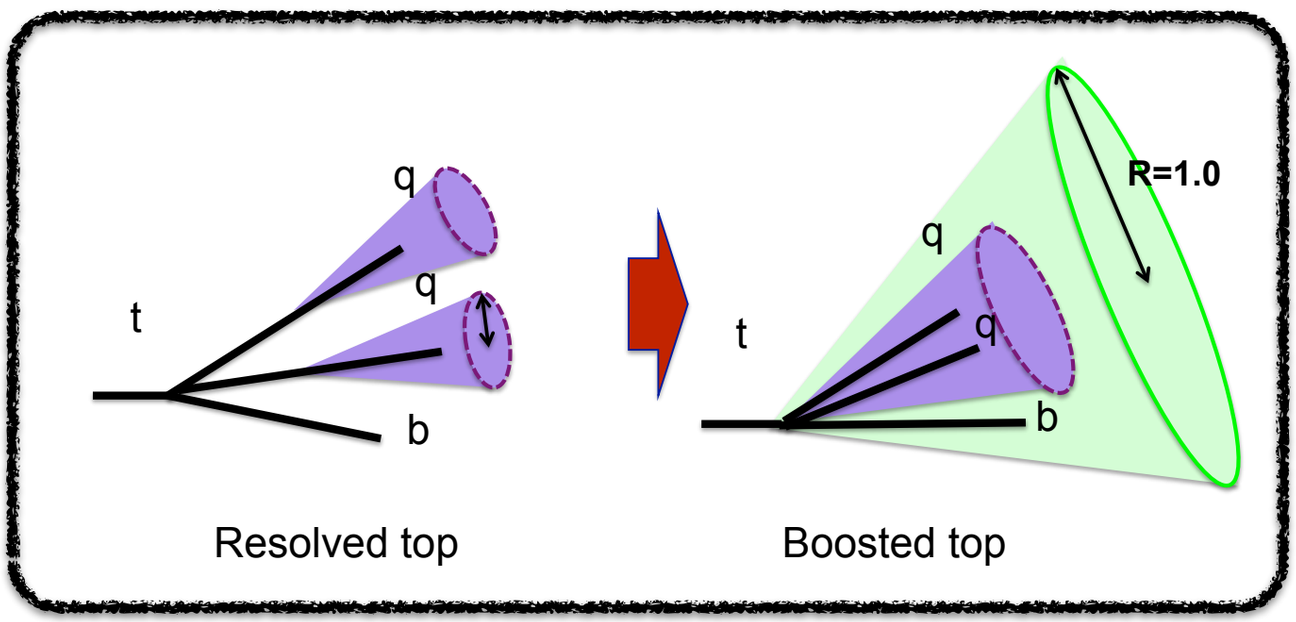
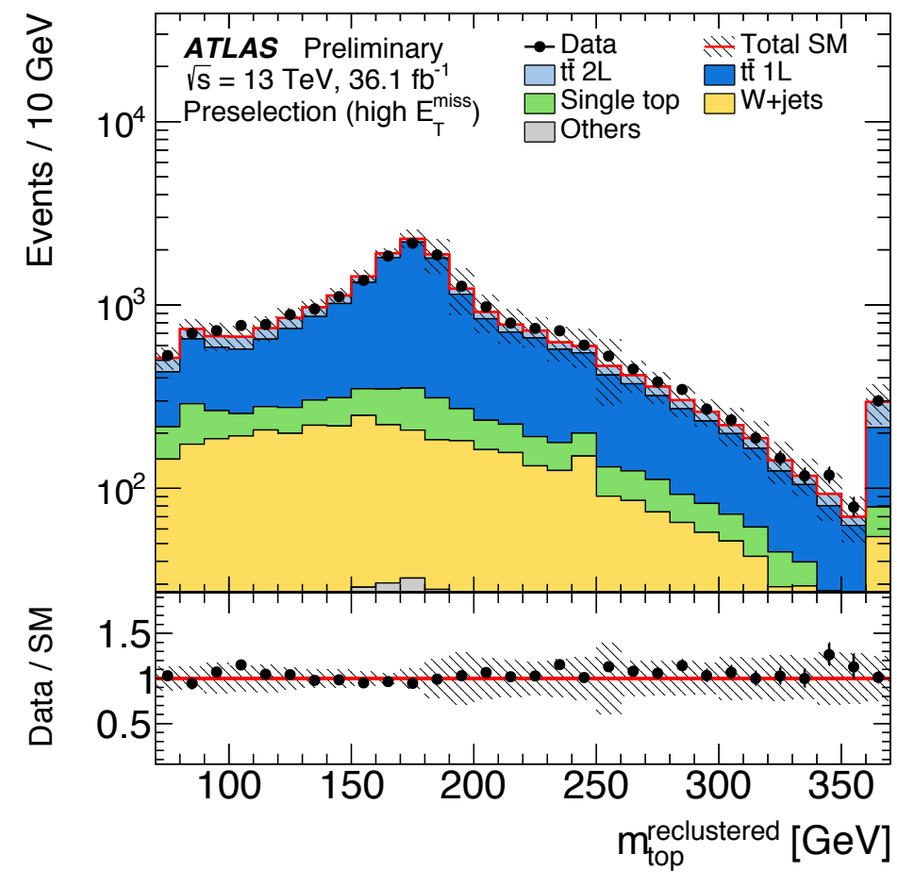
- In the decay of heavy stop, the top quark is highly boosted. As a consequence jets from the top decay tends to form a large radius jet.





- The analysis benefits from reconstructing hadronically decaying top quark ("hadronic top reconstruction").

Background estimate

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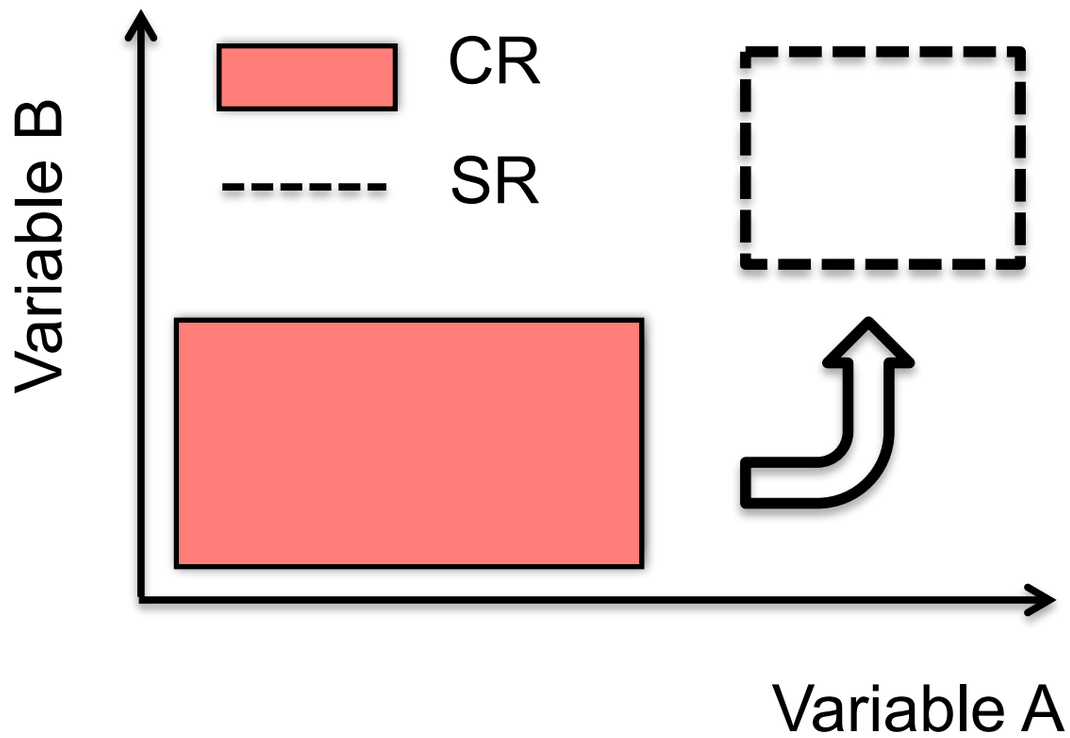

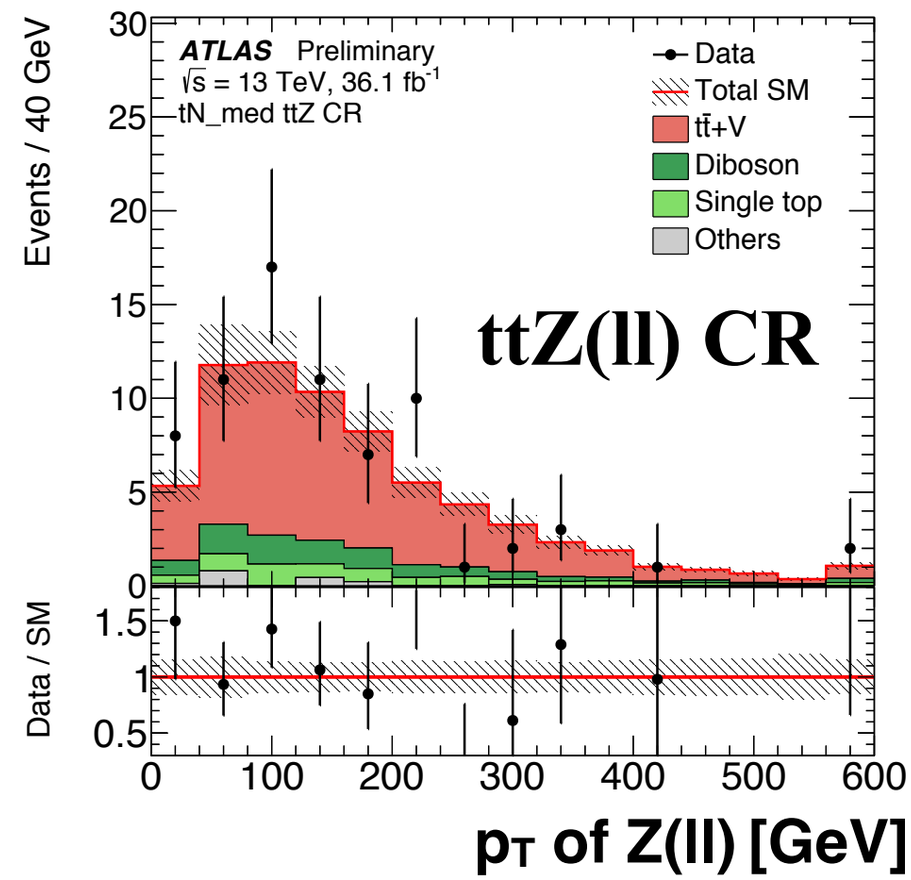

- Use control region (invert one or two SR selections)
- Simulation uncertainties (PS+hadronization, hard-scattering, PDF, …) need to be assessed and propagated when extrapolating the norm to the SR.
- Minor backgrounds are normalized to the SM prediction.

Results: Validation region

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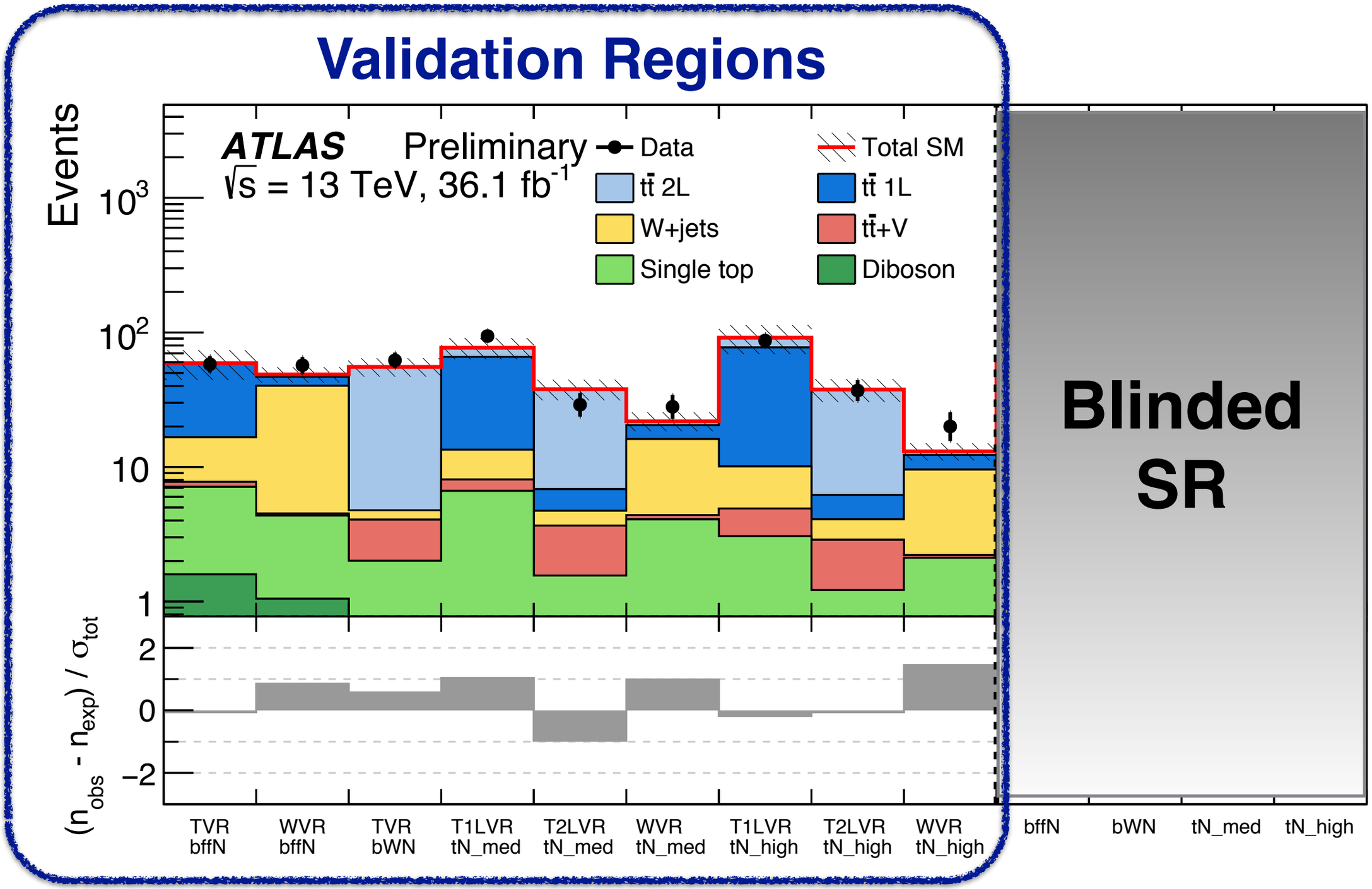

- VRs are monitored while blinding SRs.

Results: Signal region

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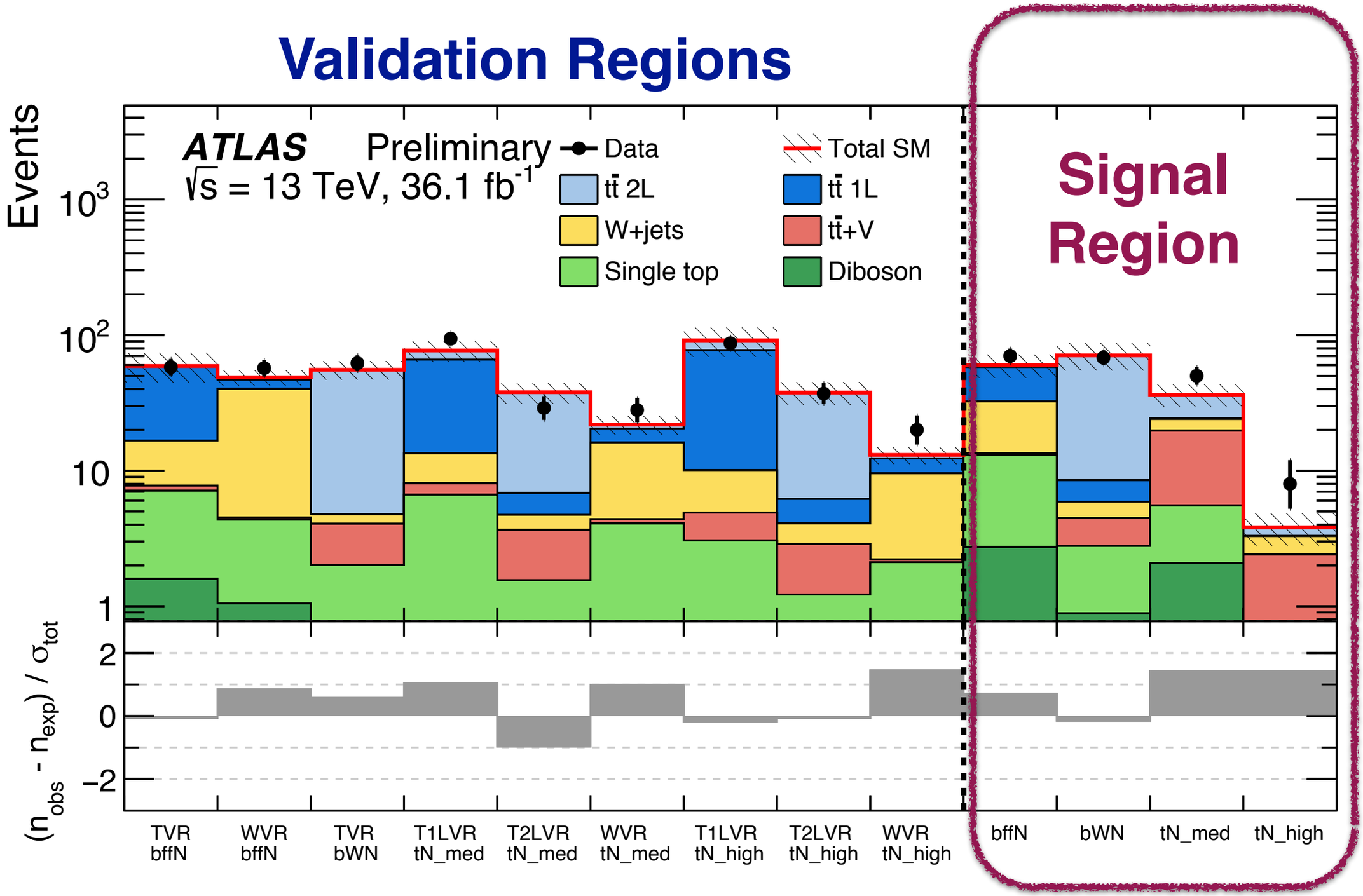

- No significant excess is observed.

Results: Pure Bino LSP

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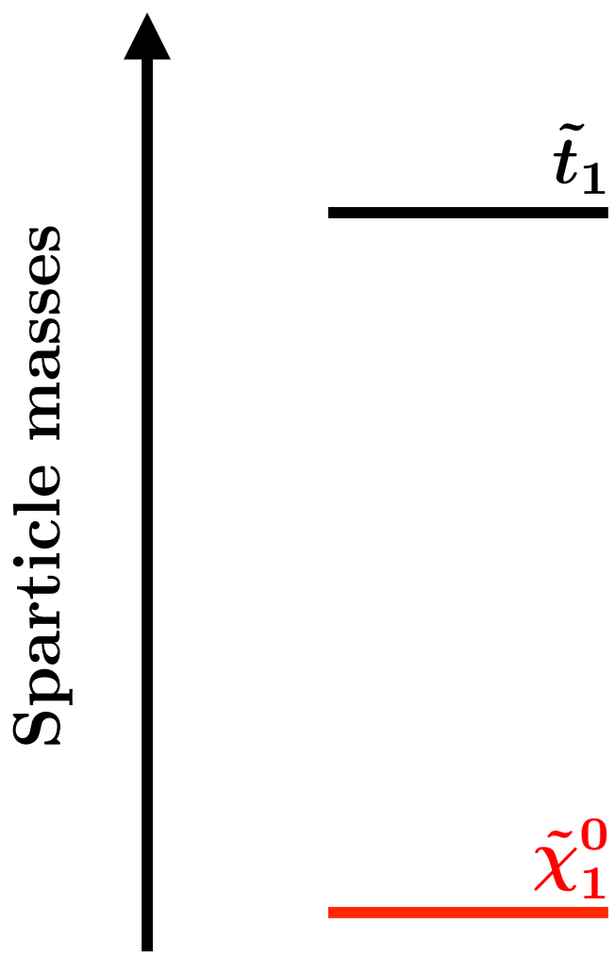
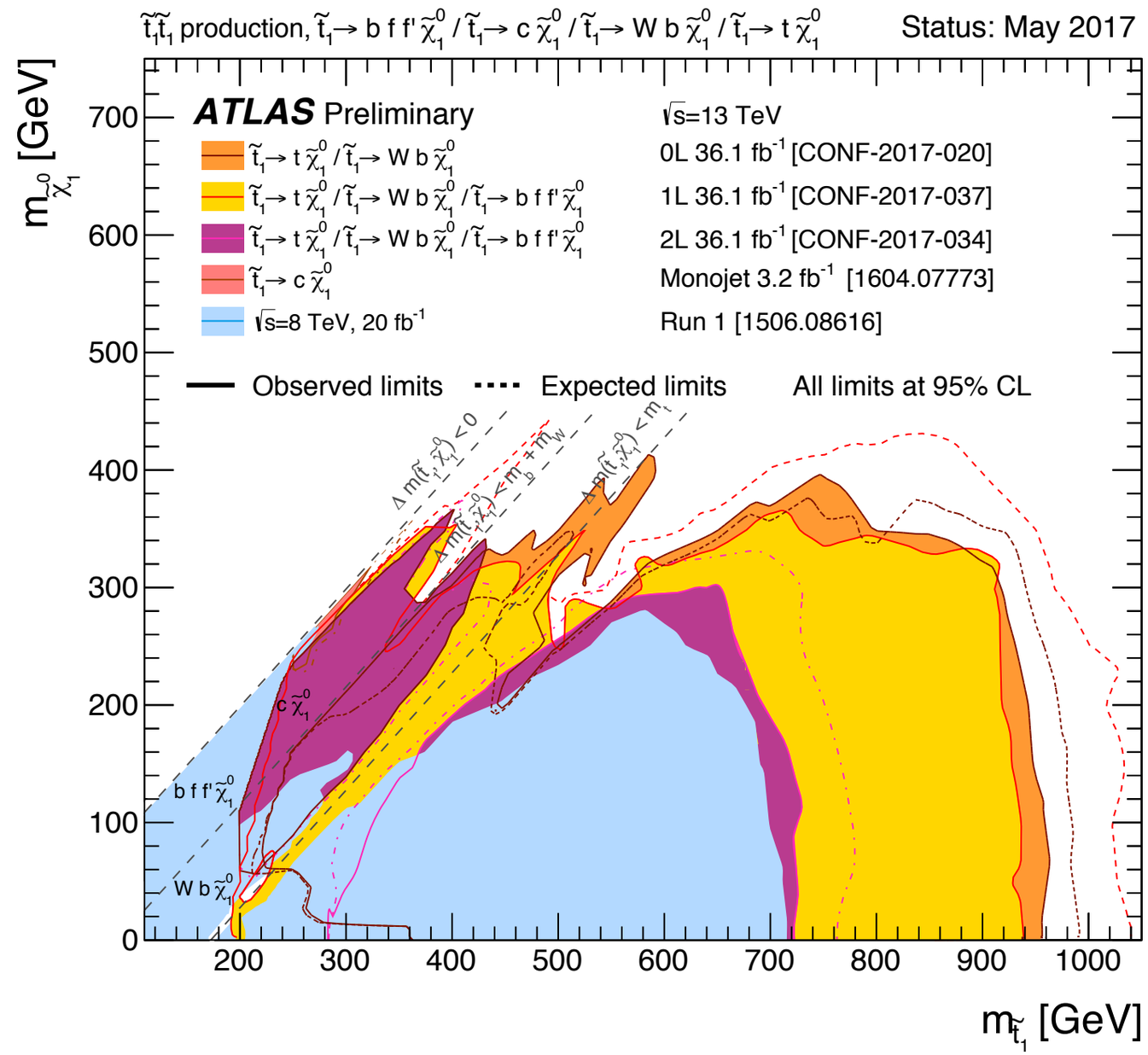
Since there's no significant data excess, exclusion limits are set on $\tilde{t}_1$ and $\tilde{\chi}_1^0$ masses.

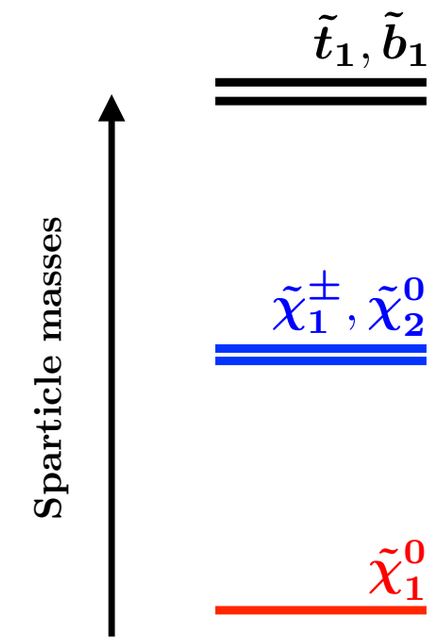


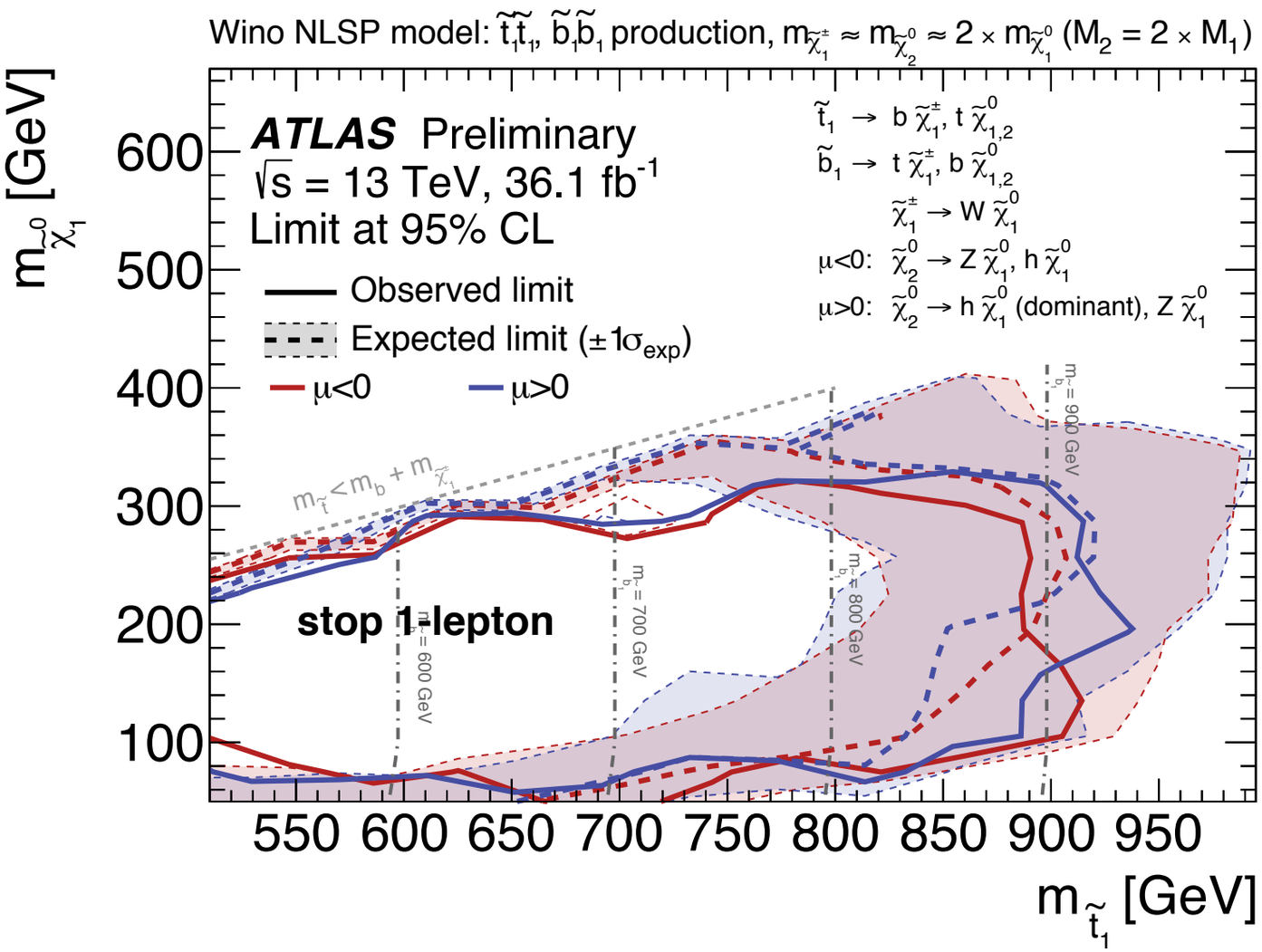
a) Pure Bino LSP

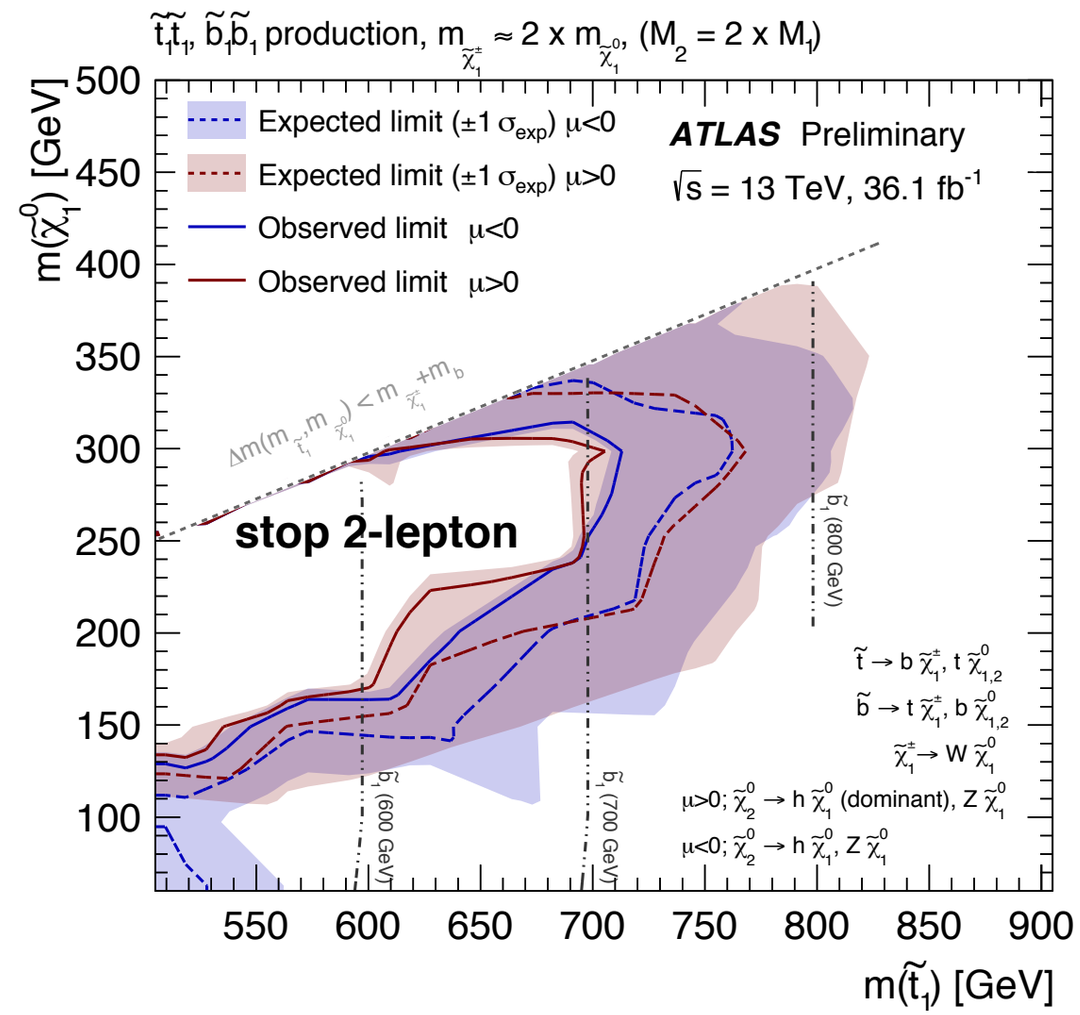


Results: Wino NLSP

Wino NLSP model (pMSSM) with the mass assumption $m(\tilde{\chi}_1^{\pm}) \sim 2m(\tilde{\chi}_1^{0})$. Two contours correspond to μ > 0 and μ < 0.

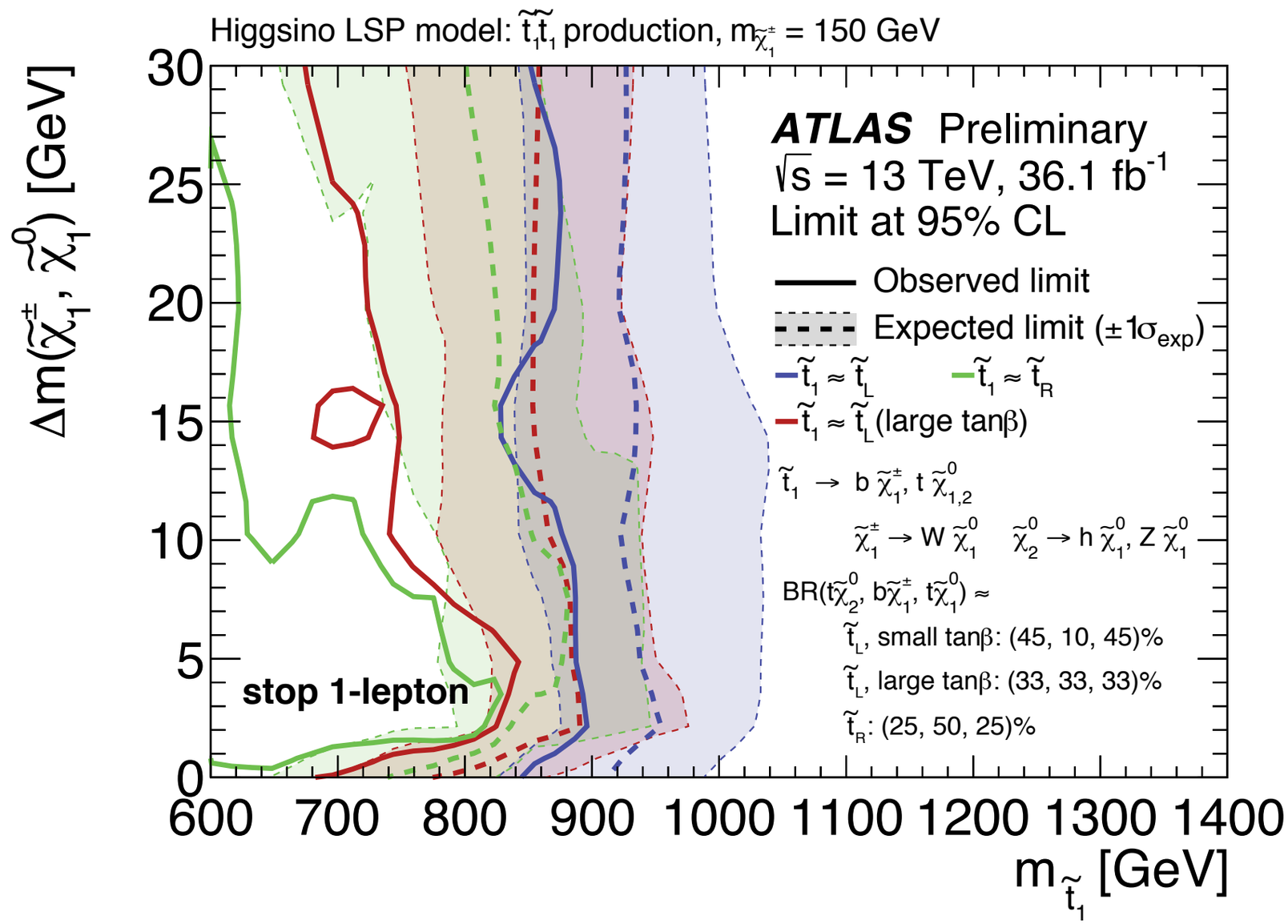


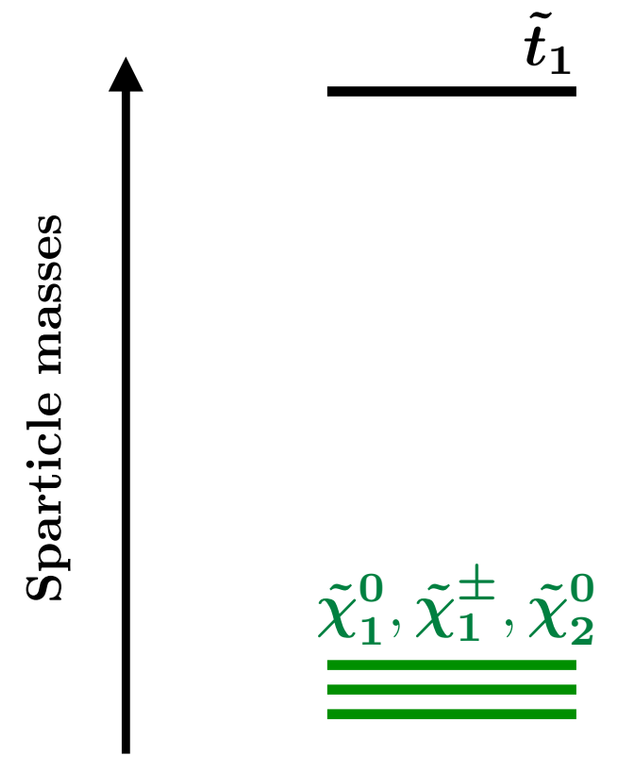




Results: Higgsino LSP

Higgsino LSP model (pMSSM-inspired simplified model) with the assumption $\Delta m(\tilde{\chi}_1^0, \tilde{\chi}_2^0) \sim 2\Delta m(\tilde{\chi}_1^0, \tilde{\chi}_1^\pm)$. Three contours correspond to $\tilde{t}_1 \sim \tilde{t}_R$ and $\tilde{t}_1 \sim \tilde{t}_L$ (w/ large tanβ).

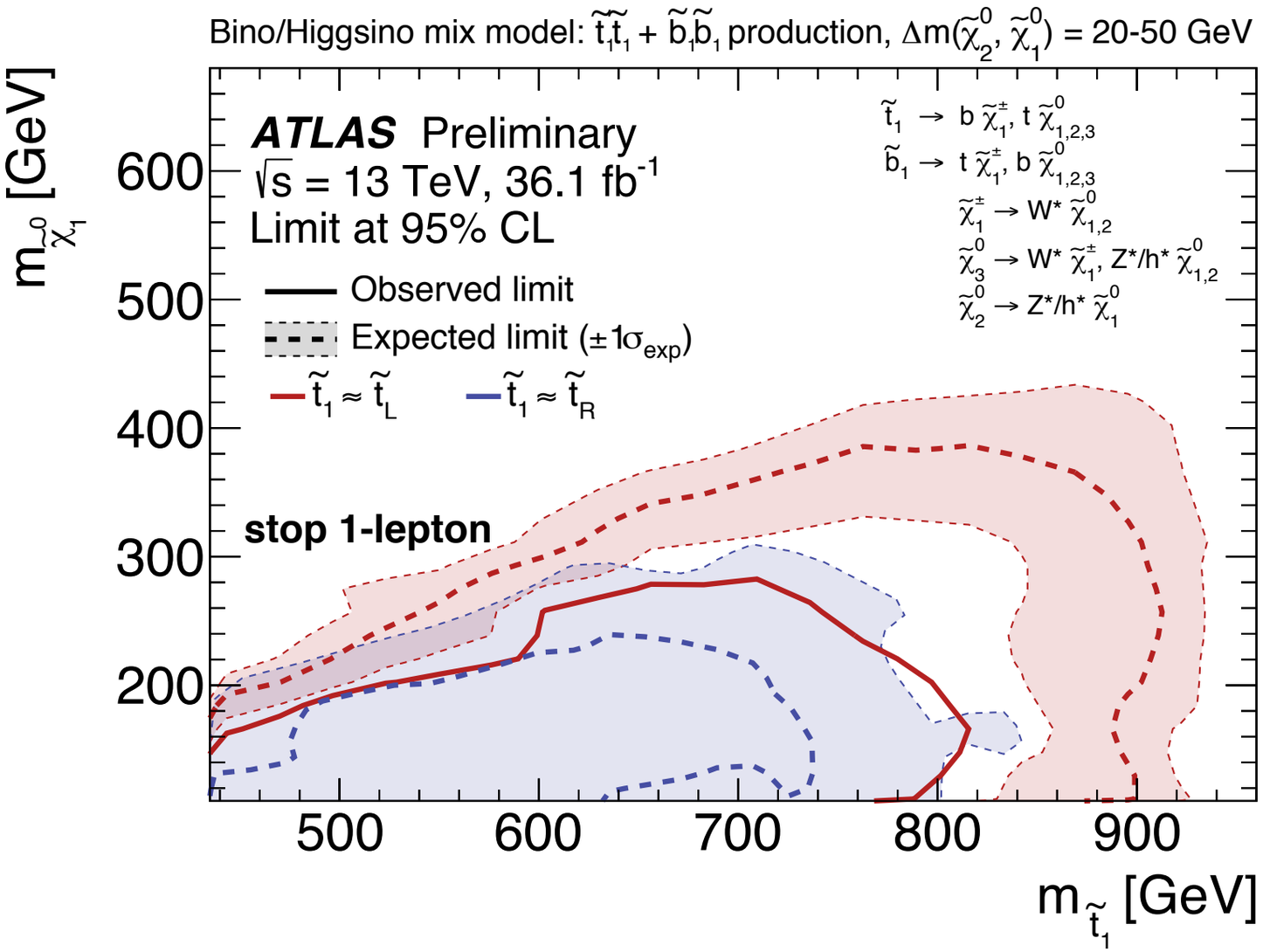


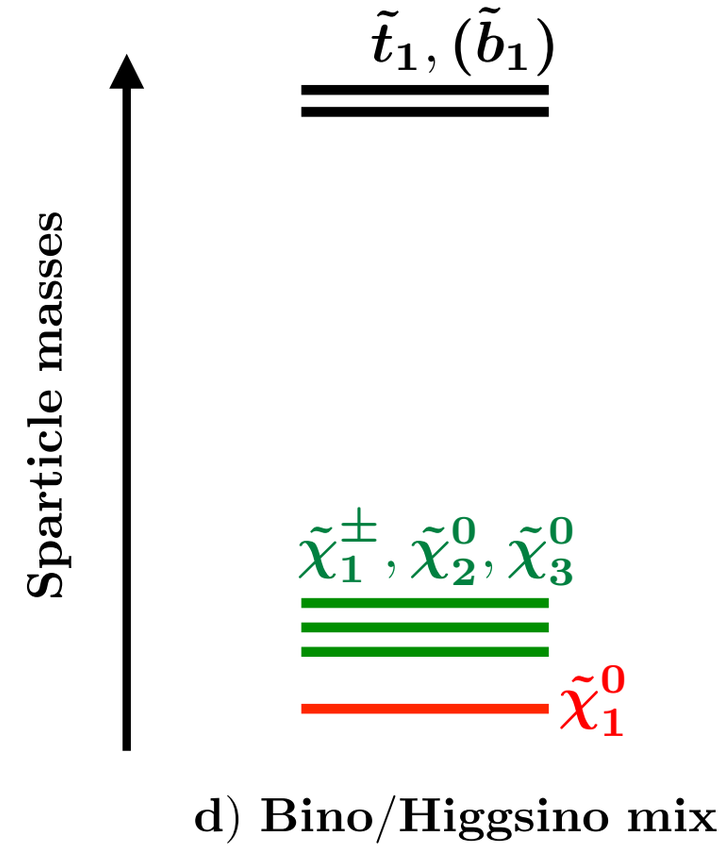


c) Higgsino LSP

Results: Well-tempered LSP

Admixture LSP model (pMSSM) with the assumption $M_1 \sim -|\mu|$ while satisfying DM relic density $\Omega h2 \sim 1.12$. Two contours correspond to $\tilde{t}_1 \sim \tilde{t}_R$ and $\tilde{t}_1 \sim \tilde{t}_L$.





d) Bino/Higgsino mix

Sbottom search:

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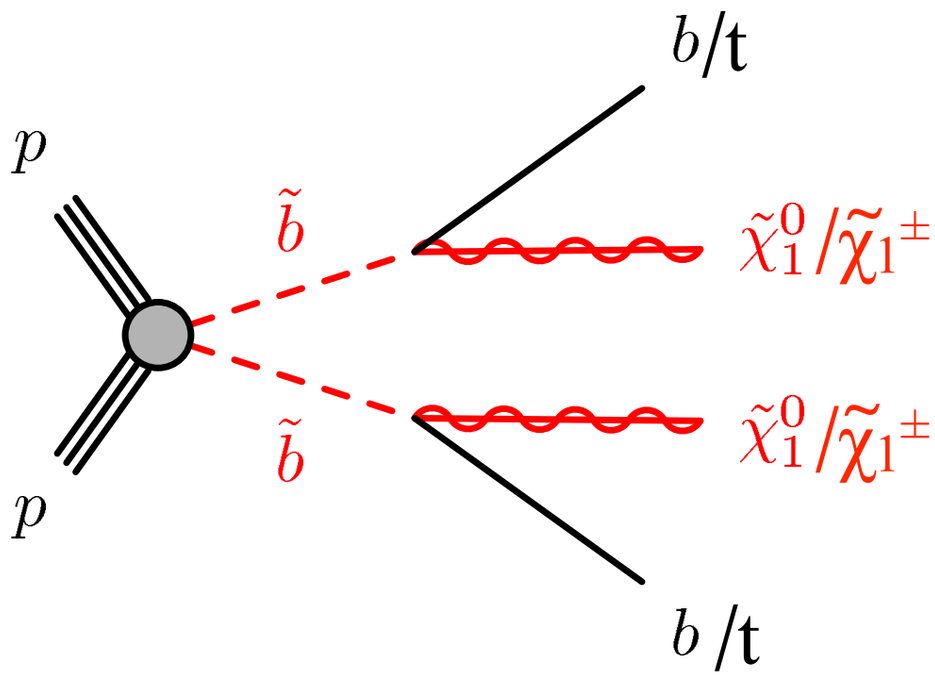
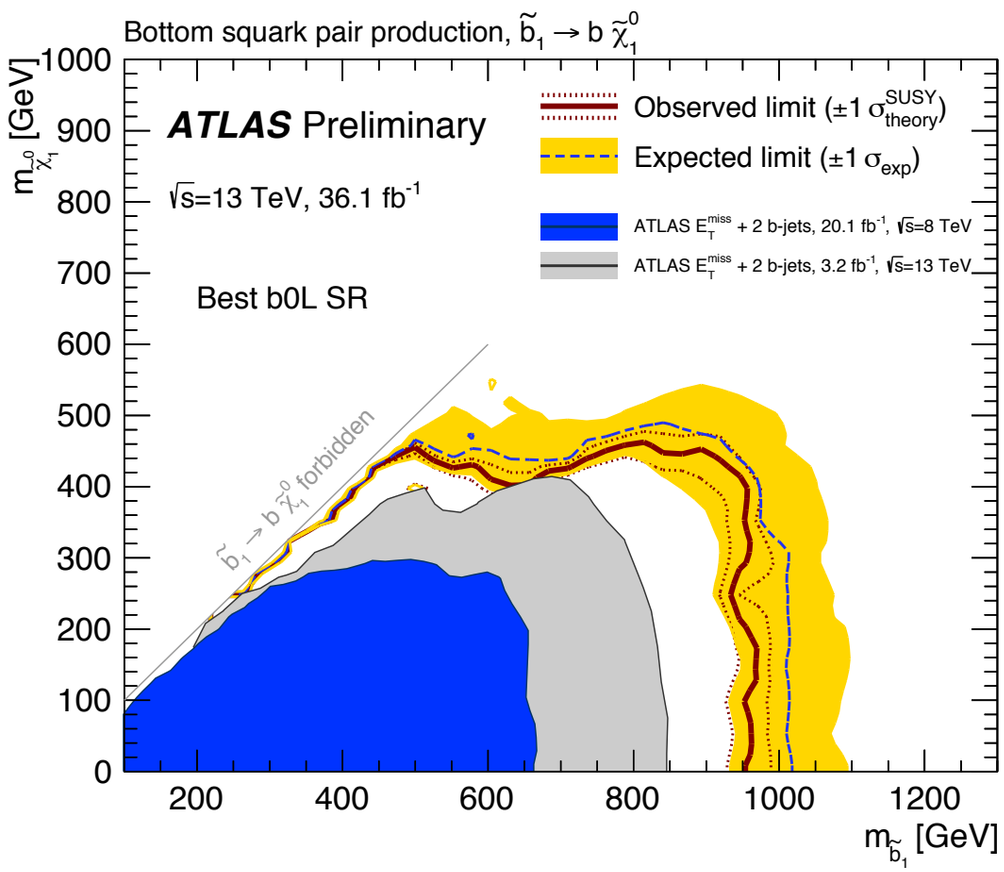
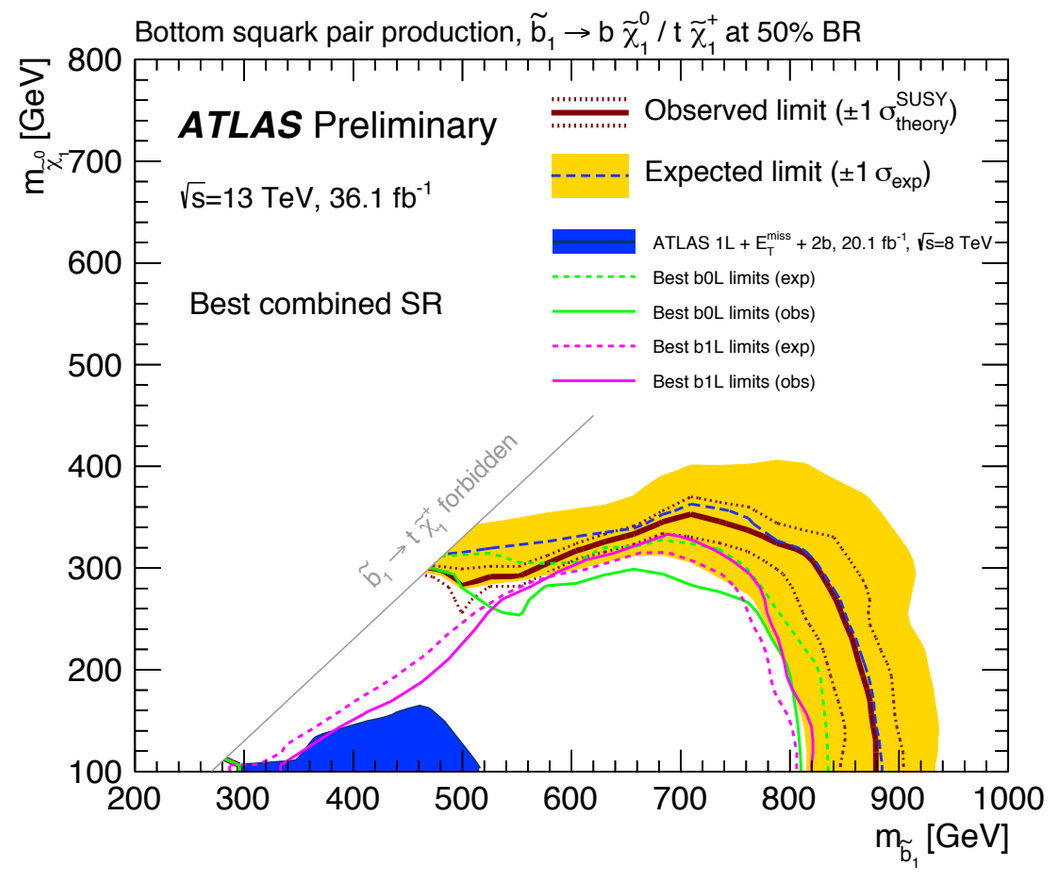


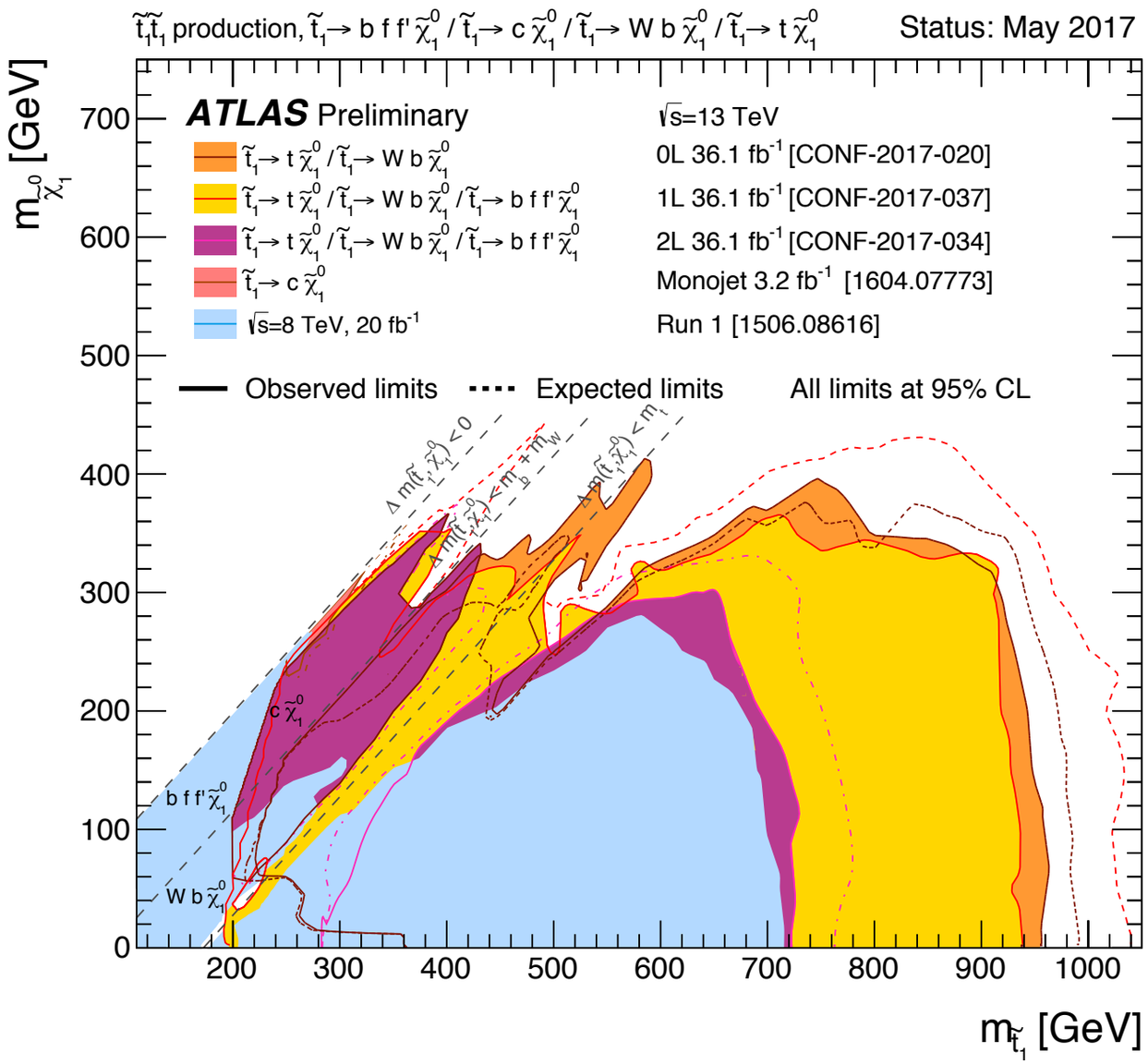
- A dedicated sbottom search ($\tilde{b}$ -> $b\tilde{\chi}_1^0/t\tilde{\chi}_1^\pm$) with 2b-quark and large MET final state.
- Z+jets is a main background estimated by the data-driven method.





Conclusion

- Many new results from ATLAS for 3rd generation squark searches are presented based on full 2015+2016 data (36 fb^{-1}).

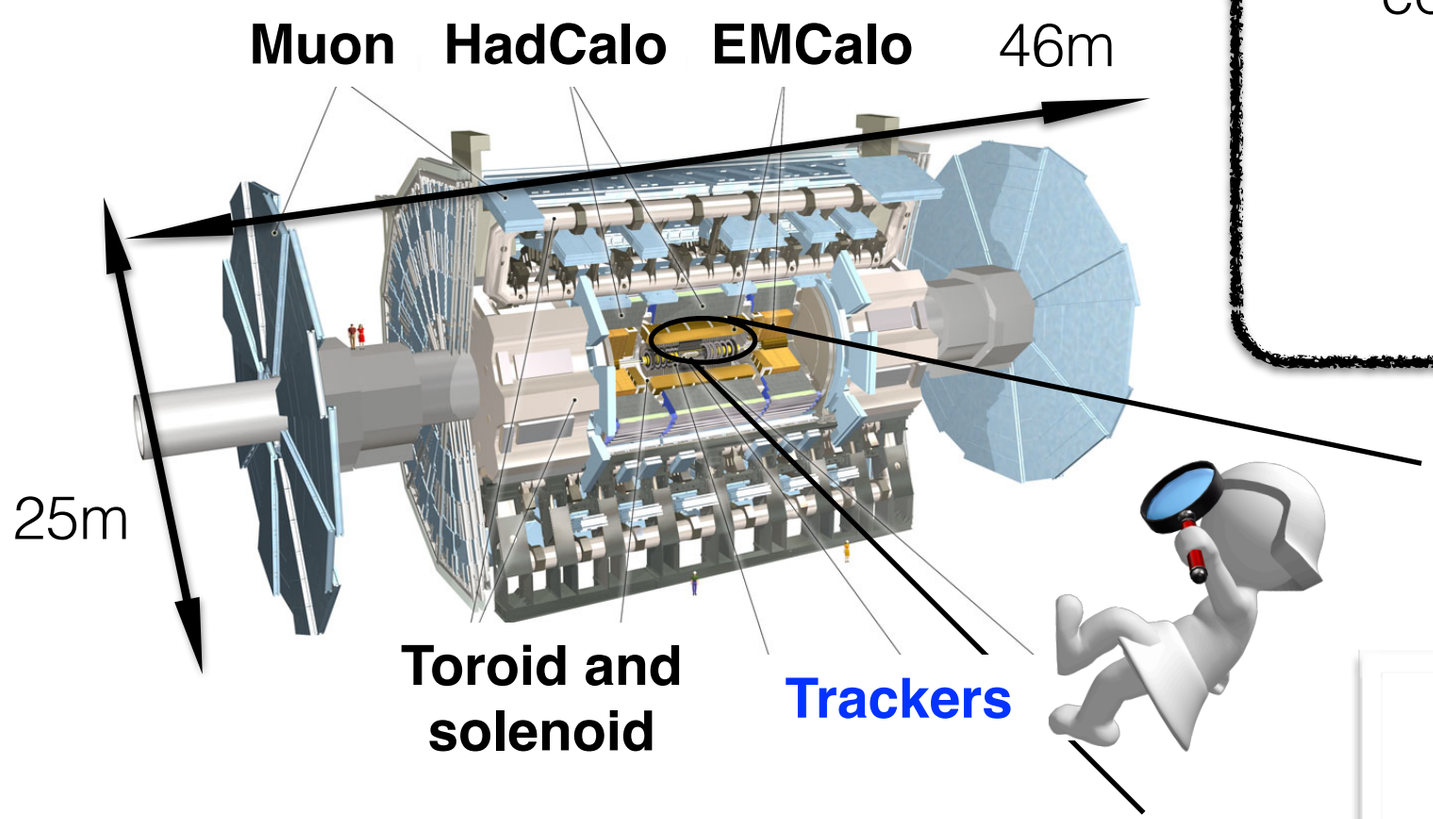


- No significant excesses this time around…

- Stringent constraints obtained on various pMSSM and simplified models.

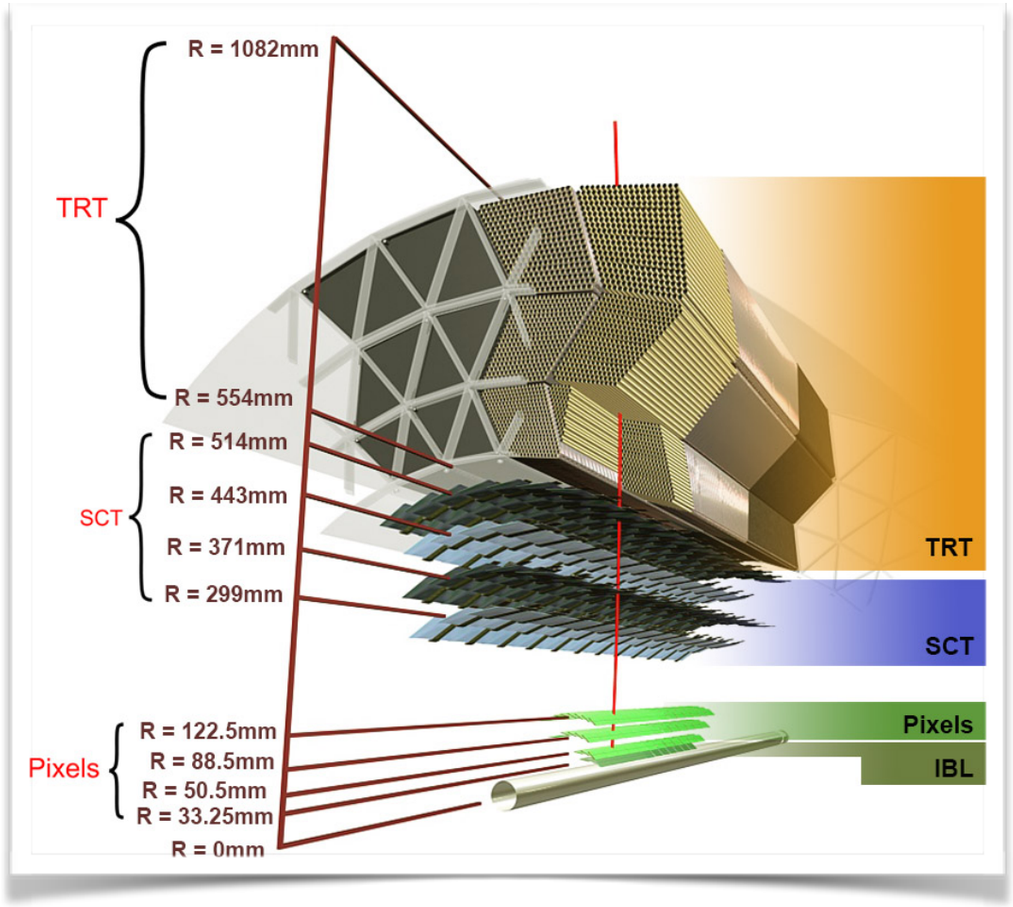
Backup

ATLAS detector



- ATLAS is a multipurpose detector composed of:
  - inner trackers
  - solenoid magnet
  - calorimeters
  - spectrometer (and toroid)

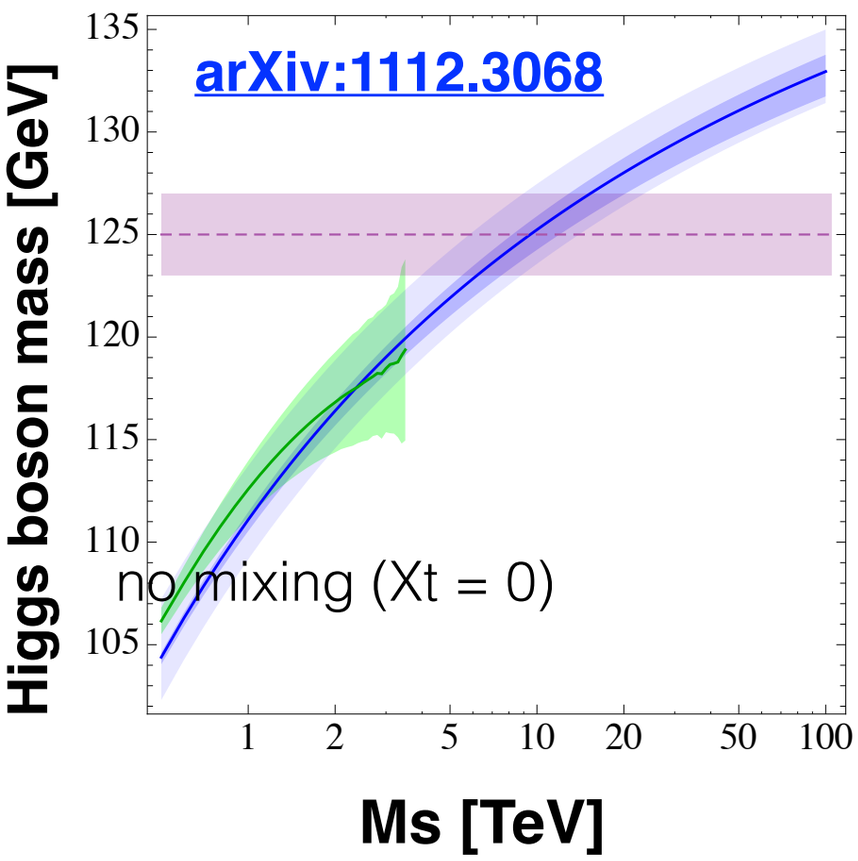
ATLAS Inner detector

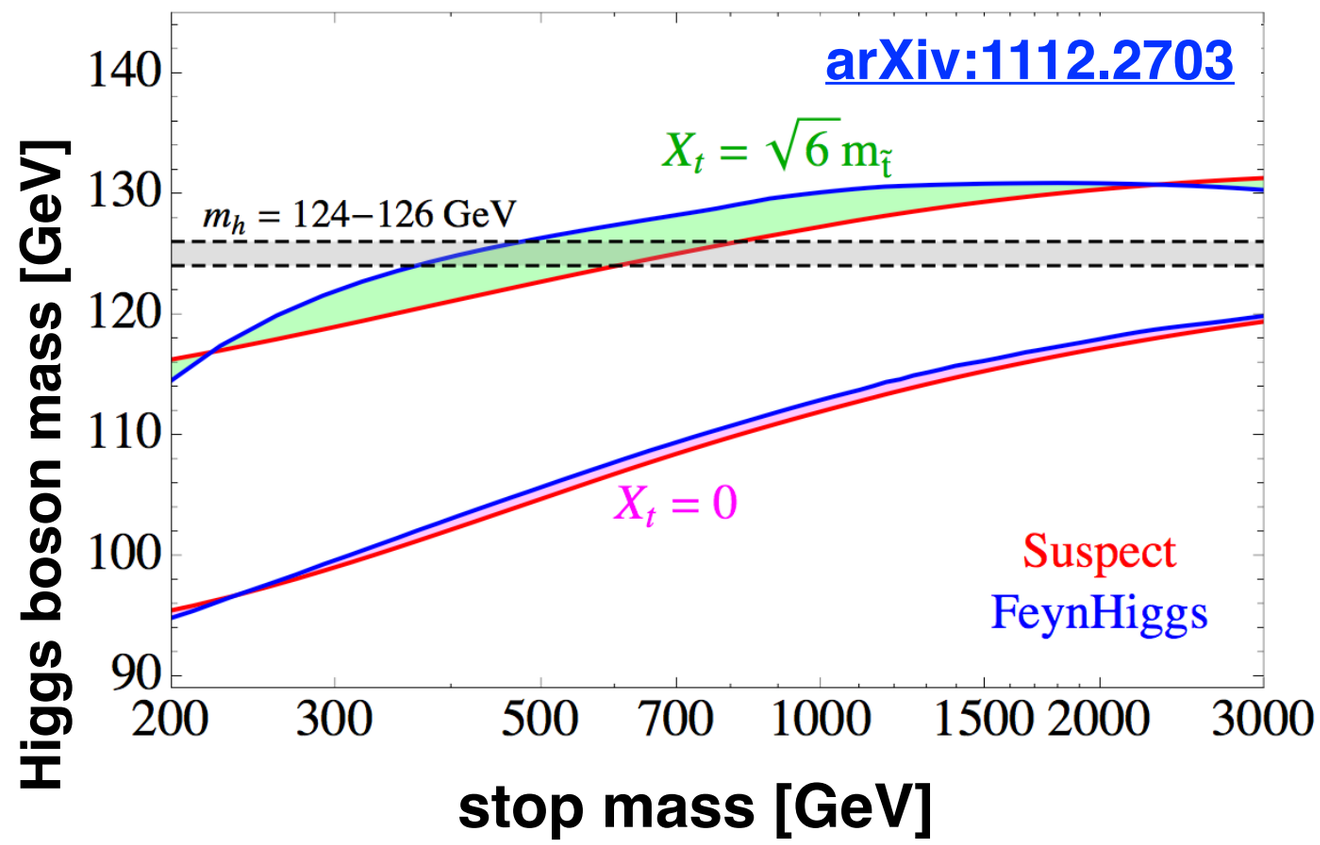


- Inner detector composed of **Pixel, SCT, and TRT**, plays a key role in track reconstruction in the dense environment.
- Calorimeter composed of **EM and Hadronic calo**, measures energy deposit of e/gamma and hadrons.
- Spectrometer reconstructs muons.

What does the Higgs mass of 125GeV indicate?

Naively squark mass scale (MS) is ~10 TeV.





But the scalar top quark (stop) is special, one can make the stop mass much lighter, < 1 TeV with large $\tilde{t}_R$ - $\tilde{t}_L$ mixing ($X_t = \sqrt{6}\, m_{\tilde{t}}$). -> My current research

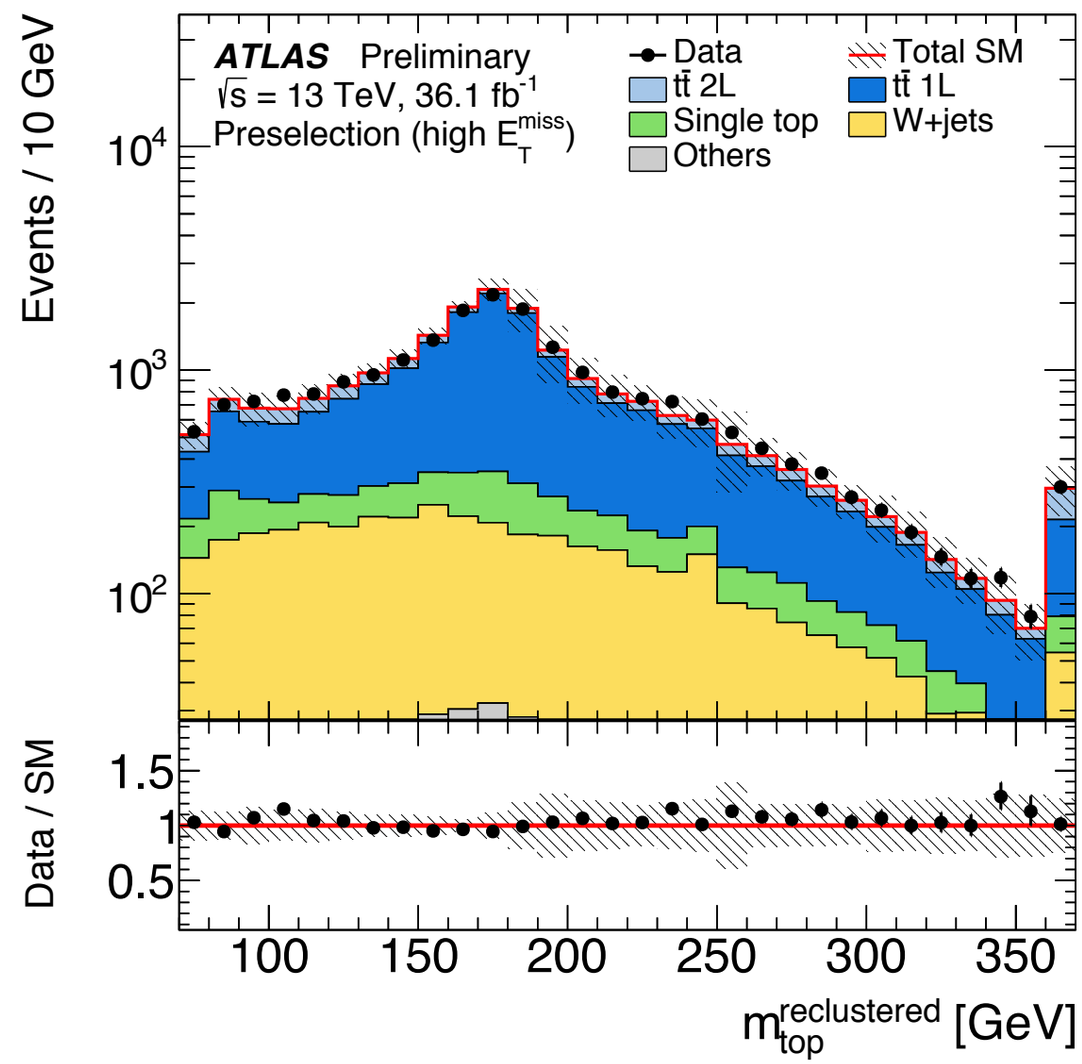
pMSSM model parameters

Scenario	Wino NLSP	Higgsino LSP	Bino/higgsino mix
Models	pMSSM	simplified	pMSSM
Mixing parameters		$X_t/M_S \sim \sqrt{6}$	
$\tan\beta$	20	20 or 60	20
M_S [TeV]	0.9-1.2	1.2	0.7-1.3
M_3 [TeV]	2.2	2.2	1.8
Scanned mass parameters	(M_1, m_{q3L})	$(\mu, m_{q3L}/m_{tR})$	$(M_1, m_{q3L}/m_{tR})$
Electroweakino masses [TeV]	$\mu = \pm 3.0$	$M_2 = M_1 = 1.5$	$M_2 = 2.0$
	$M_2 = 2M_1 \ll \lvert\mu\rvert$	$\mu \ll M_1 = M_2$	$M_1 \sim -\mu$, $M_1 < M_2$
Additional requirements	–	–	$0.10 < \Omega h^2 < 0.12$
	–	–	$\Delta < 100$
Sbottom pair production	considered	–	considered
$\tilde{t}_1$ decay modes and their BR [%]	$\tilde{t}_1 \sim \tilde{t}_L$	(a) / (b) / (c)	(a) / (b)
$\tilde{t}_1 \to t\tilde{\chi}_1^0$	< 5	$\sim 25/\sim 45/\sim 33$	$< 10/< 10$
$\tilde{t}_1 \to b\tilde{\chi}_1^\pm$	~ 65	$\sim 50/\sim 10/\sim 33$	$\sim 50/\sim 10$
$\tilde{t}_1 \to t\tilde{\chi}_2^0$	~ 30	$\sim 25/\sim 45/\sim 33$	$\sim 20/\sim 40$
$\tilde{t}_1 \to t\tilde{\chi}_3^0$	–	–	$\sim 20/\sim 40$
$\tilde{b}_1$ decay modes and their BR [%]	$\tilde{b}_1 \sim \tilde{t}_L$	–	$\tilde{b}_1 \sim \tilde{b}_L$
$\tilde{b}_1 \to b\tilde{\chi}_1^0$	< 5	–	< 5
$\tilde{b}_1 \to t\tilde{\chi}_1^\pm$	~ 65	–	~ 85
$\tilde{b}_1 \to b\tilde{\chi}_2^0$	~ 30	–	< 5
$\tilde{b}_1 \to b\tilde{\chi}_3^0$	–	–	< 5

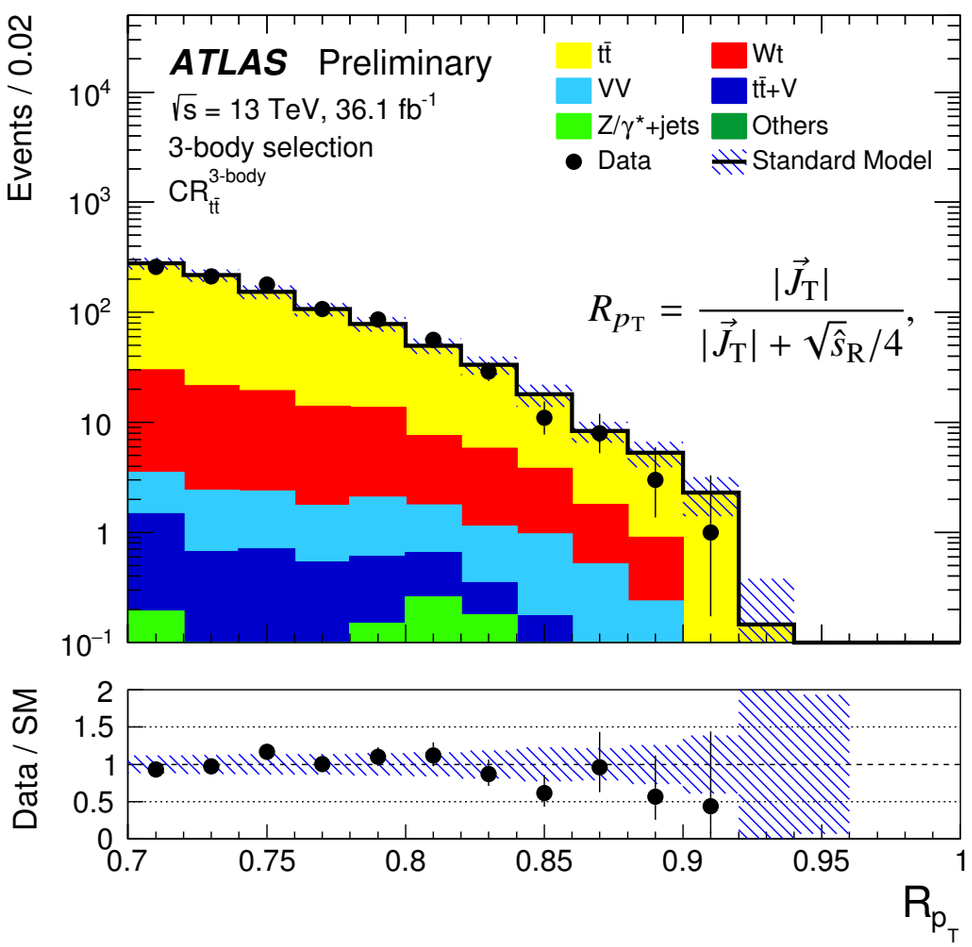
Discriminating variables

- Had top reconstruction:
  a key discriminant in stop1-lepton (t+χ10).
- Various MT2 variables (aMT2 or MT2ll):
  discriminating signal from ttbar events.

Mass of hadronic top-quark



Super-razor variable (RpT)

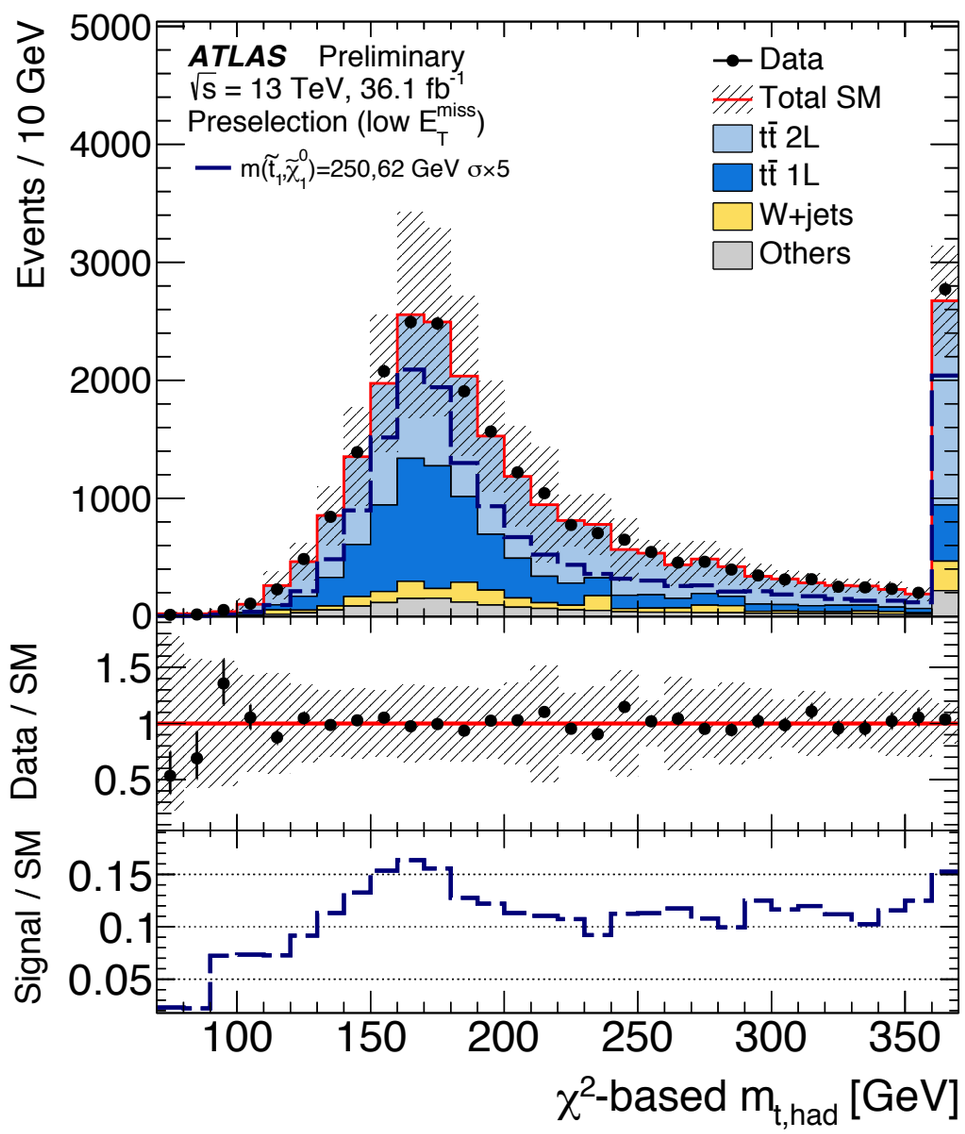


- **Super-razor variables: [arXiv:13104827] kinematic variables defined in super-razor (approximate boost) frame.**

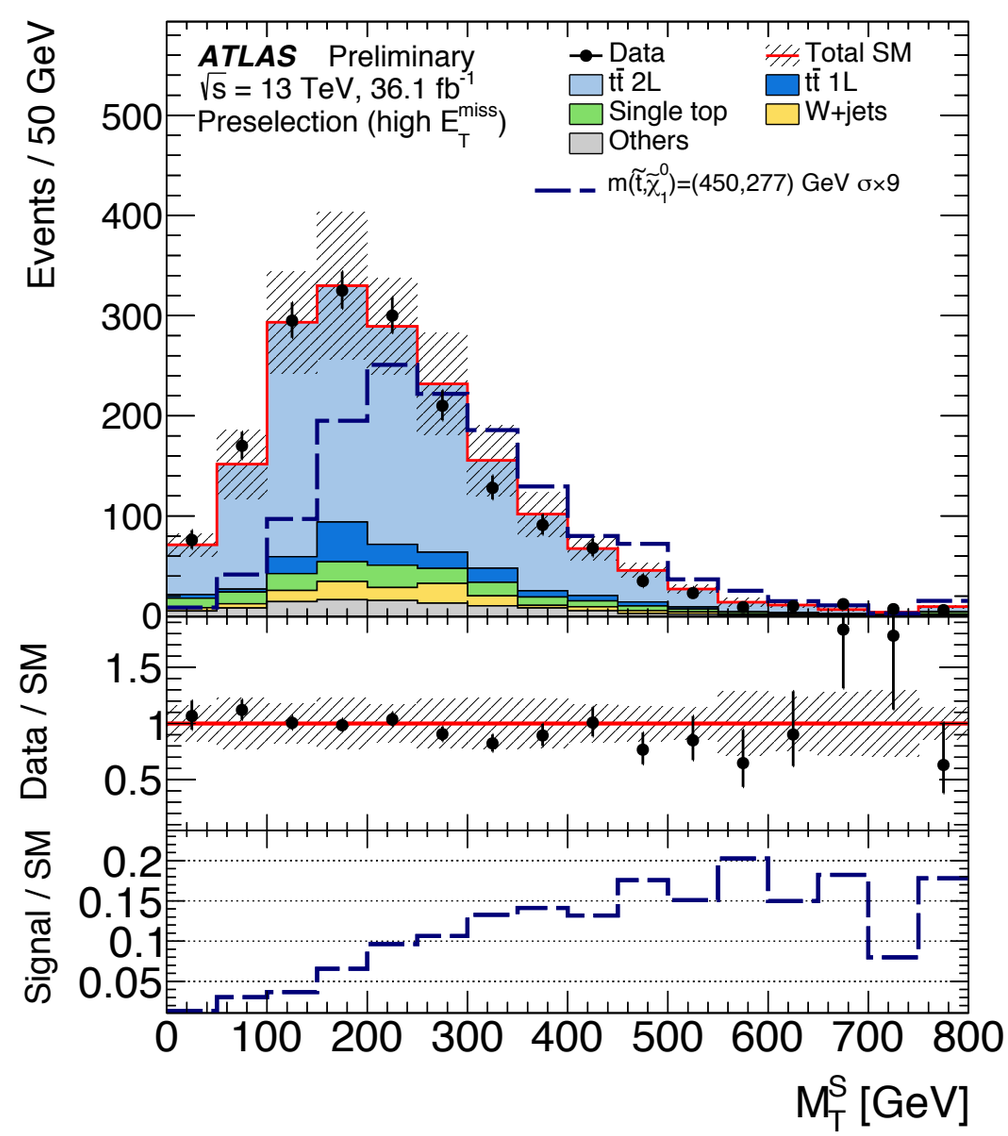
Discriminating variables for BDT

- Additional discriminating variables (e.g. RJ Rec: [arXiv:1607.08307]) for the BDTs targeting the compressed t+χ10 region.

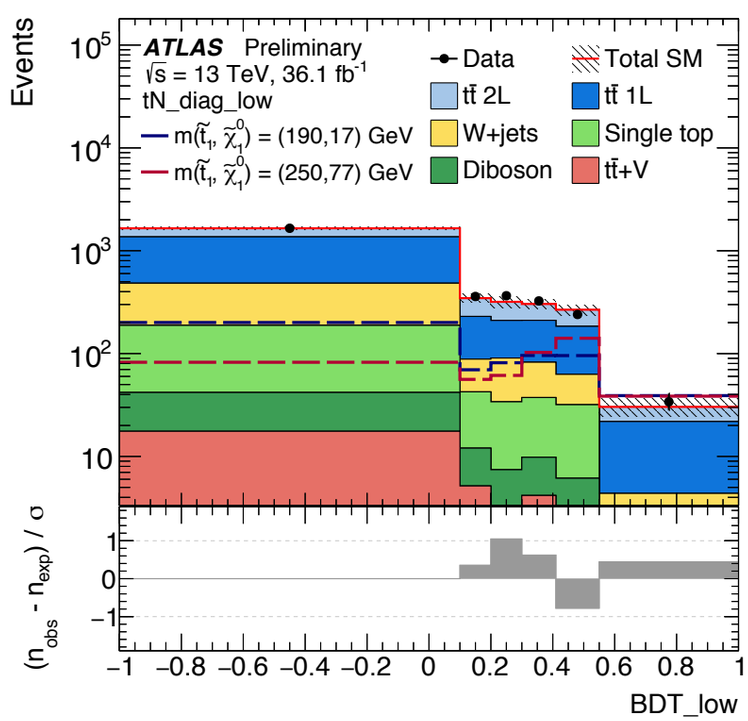
χ2-based hadronic top rec

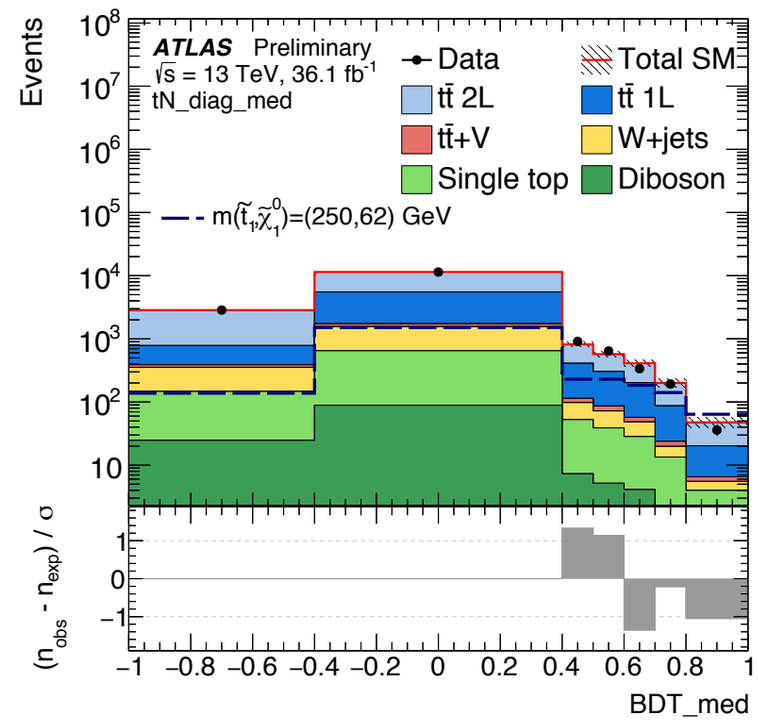


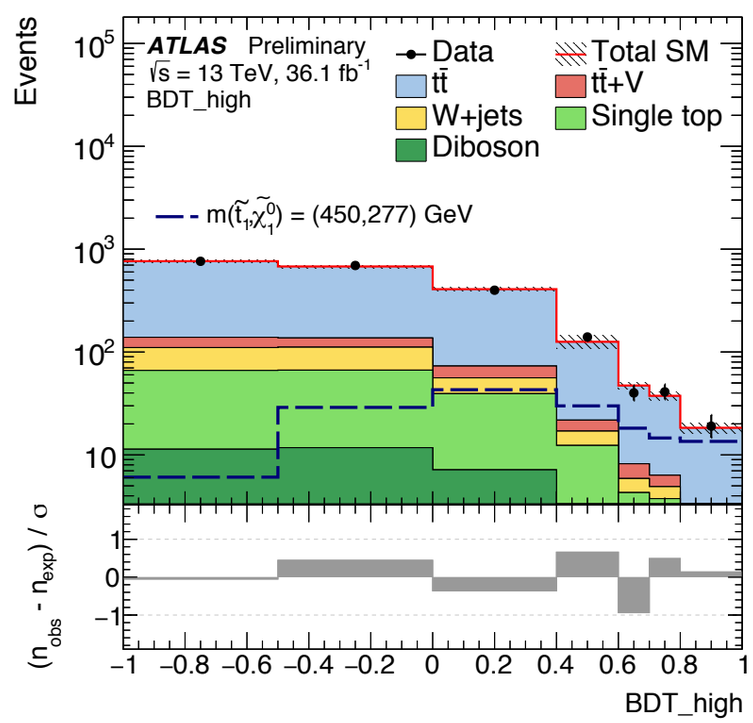
RJR variable: MTS



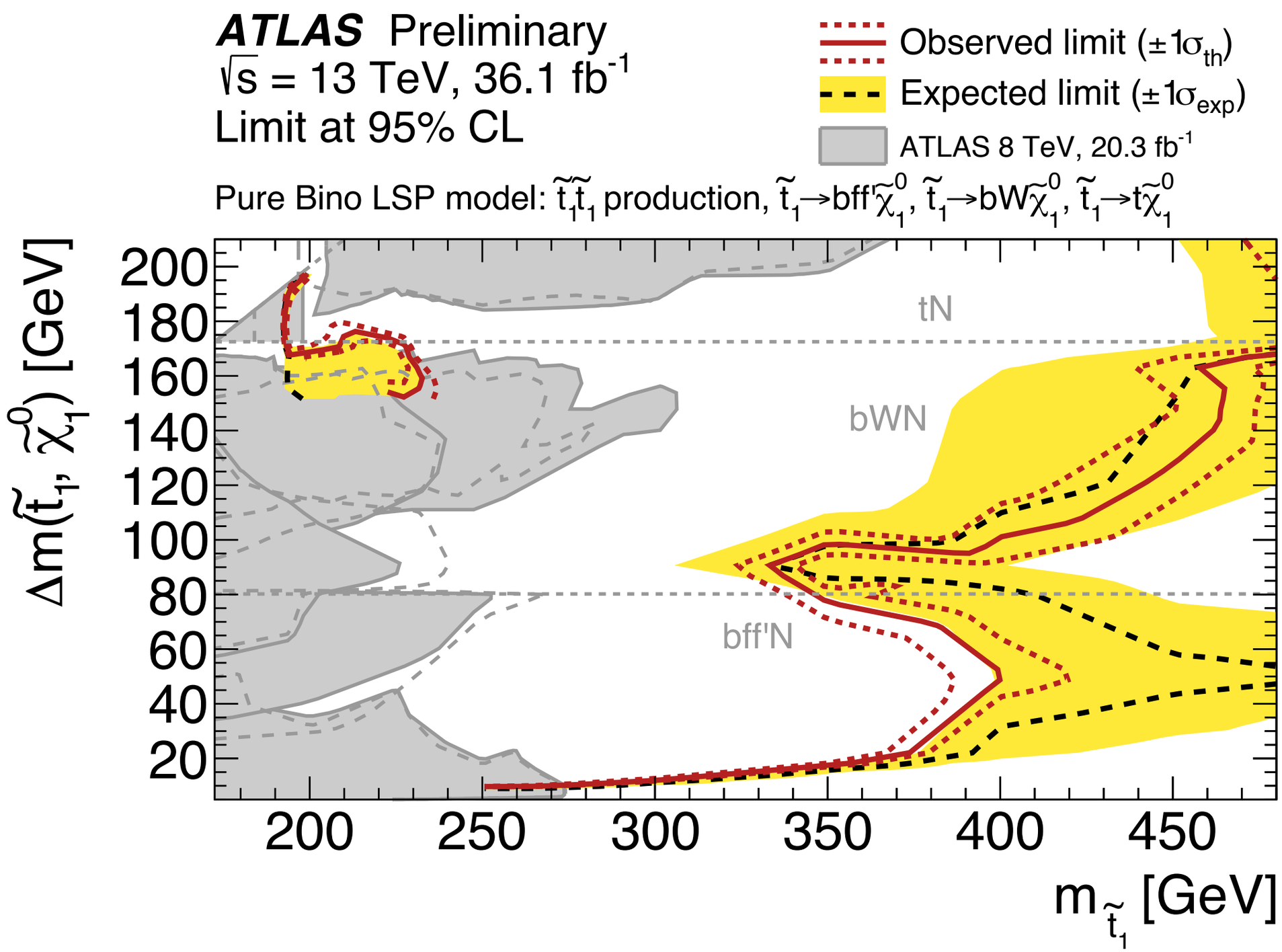
Results: Pure Bino LSP scenario (BDT)



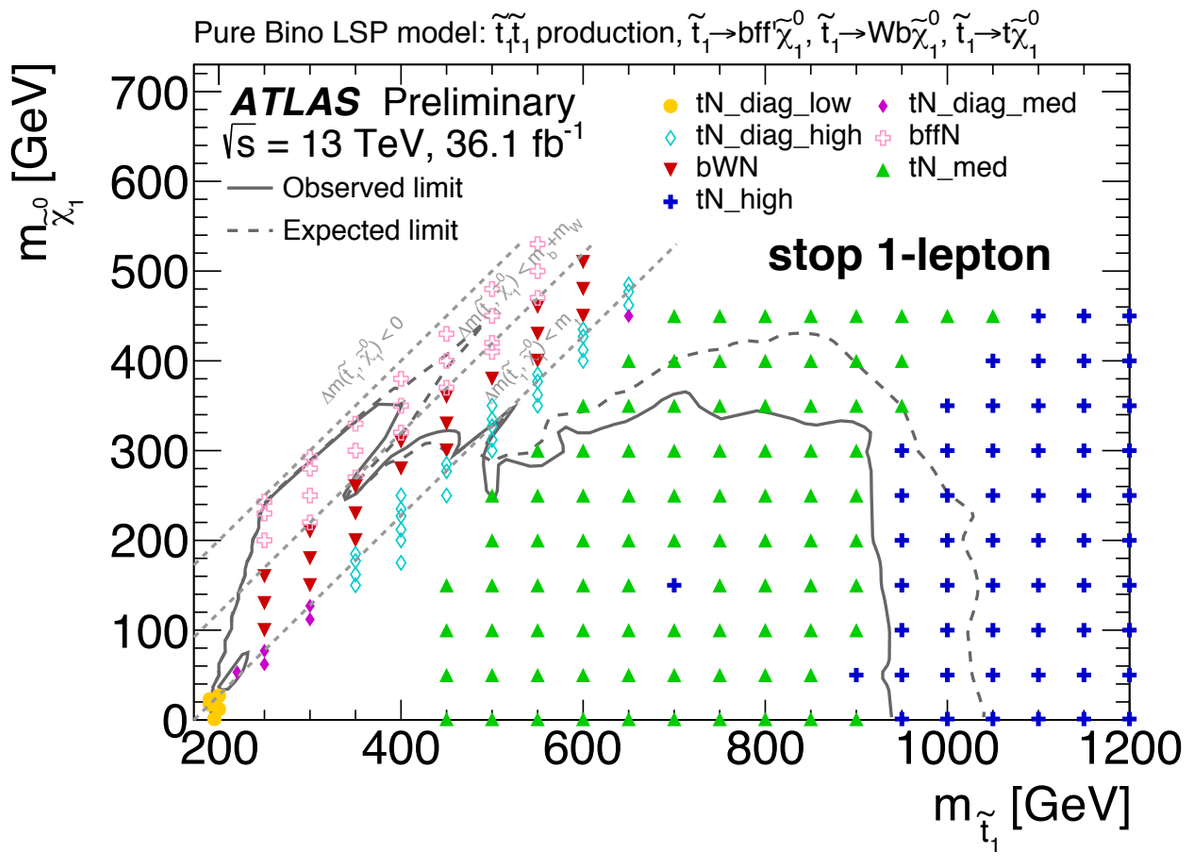


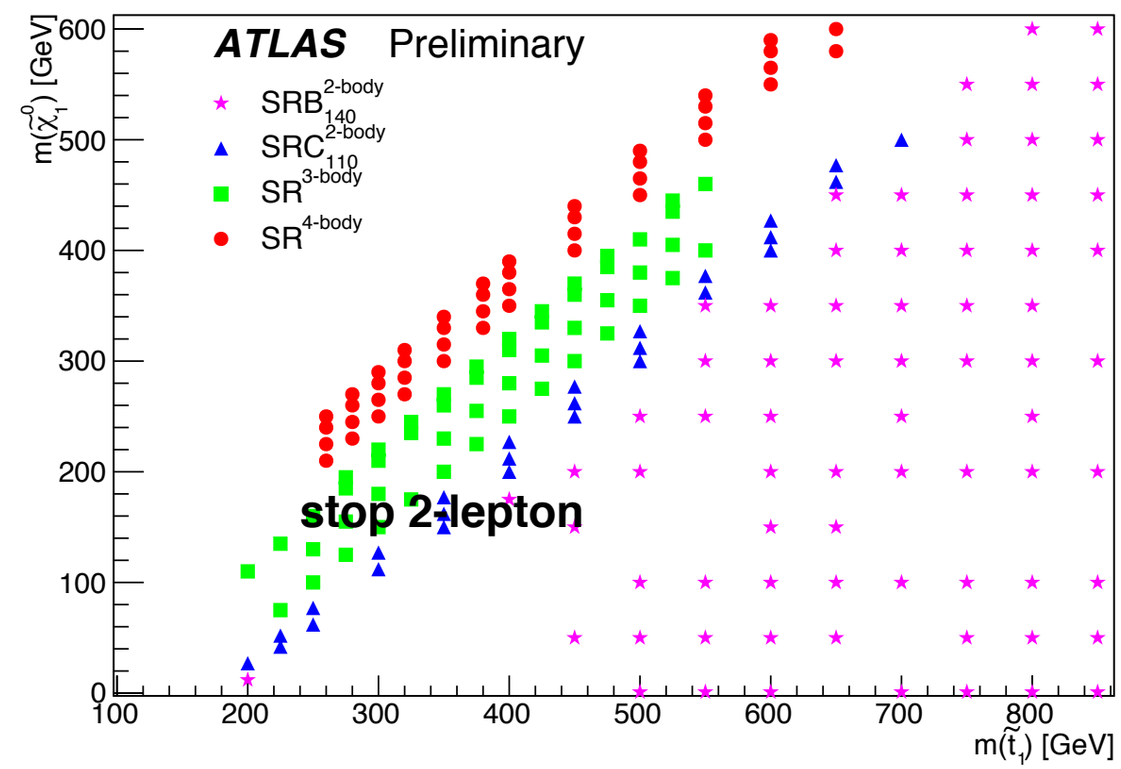


Results: Pure Bino LSP scenario (Low mass zoom)

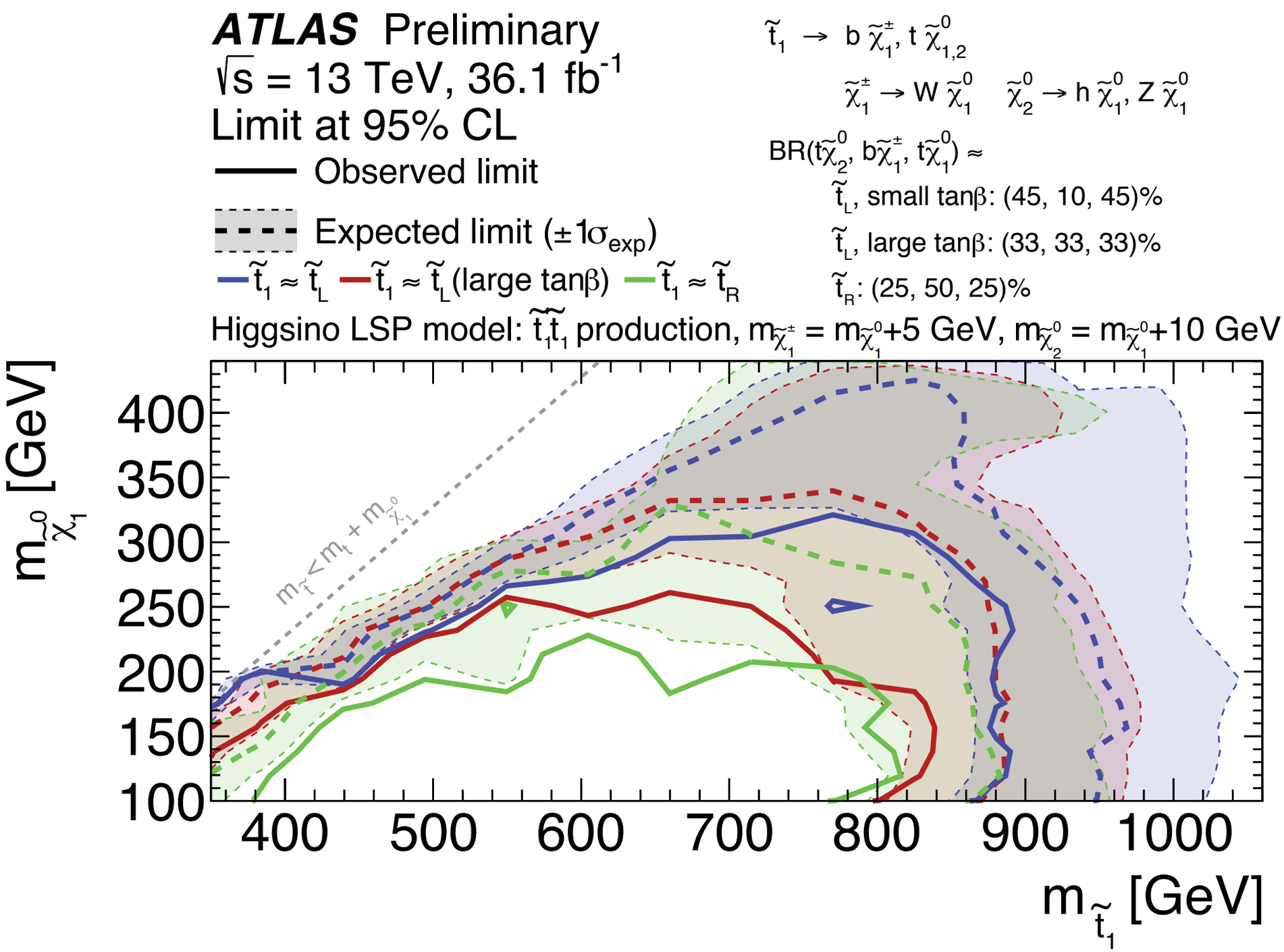


Results: Pure Bino LSP scenario (SR map)

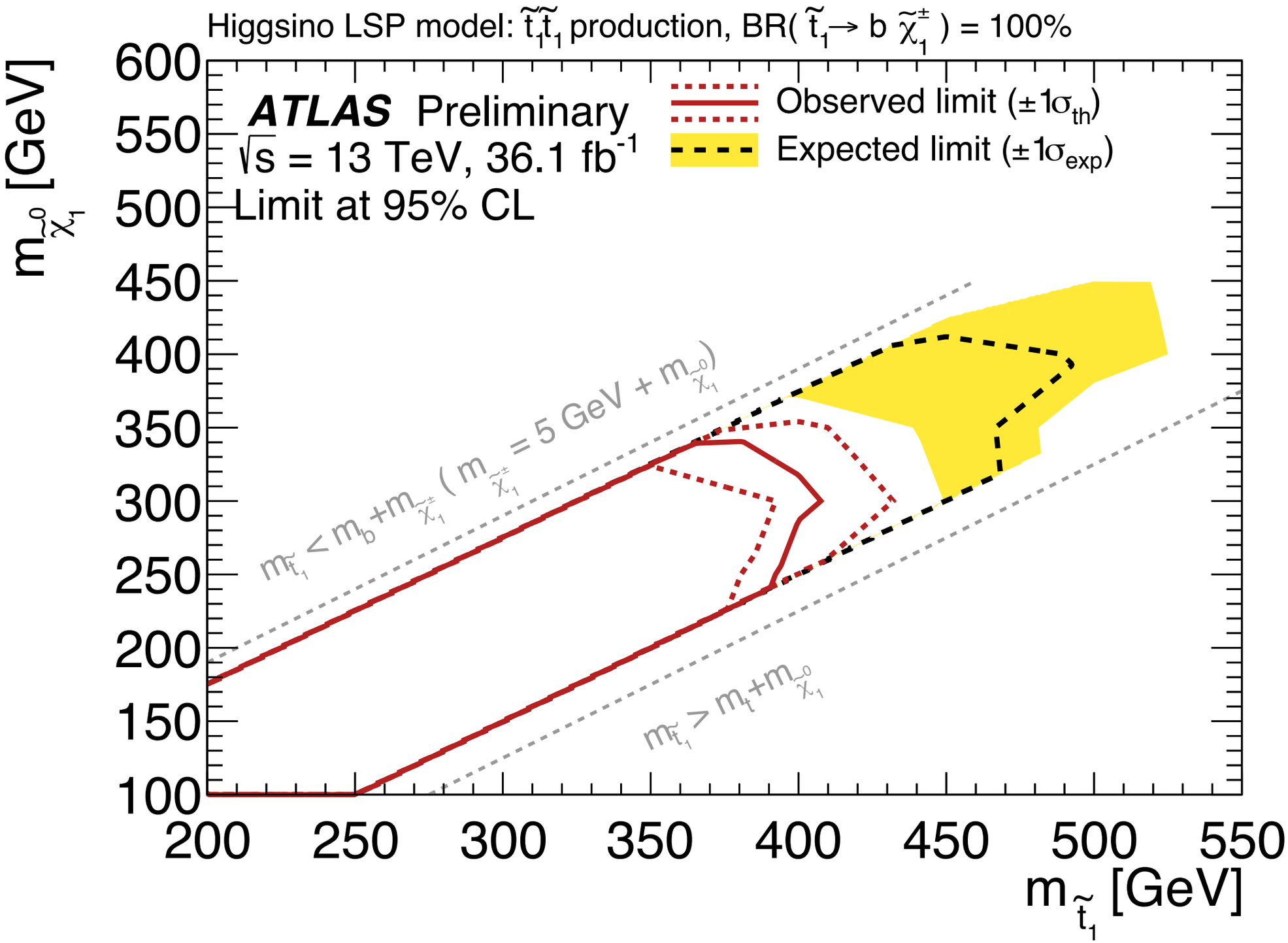




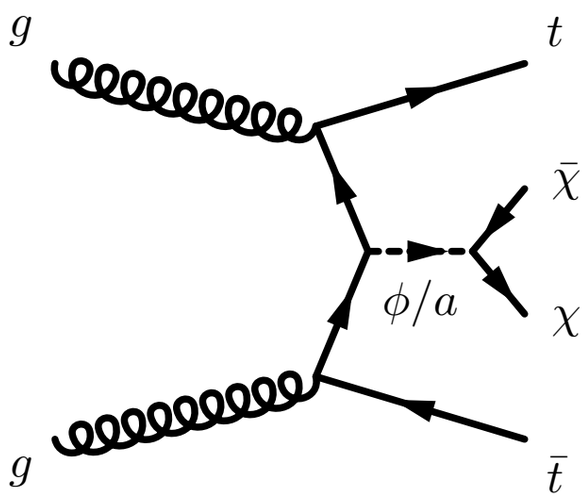
Results: Higgsino LSP fixed Δm=5GeV



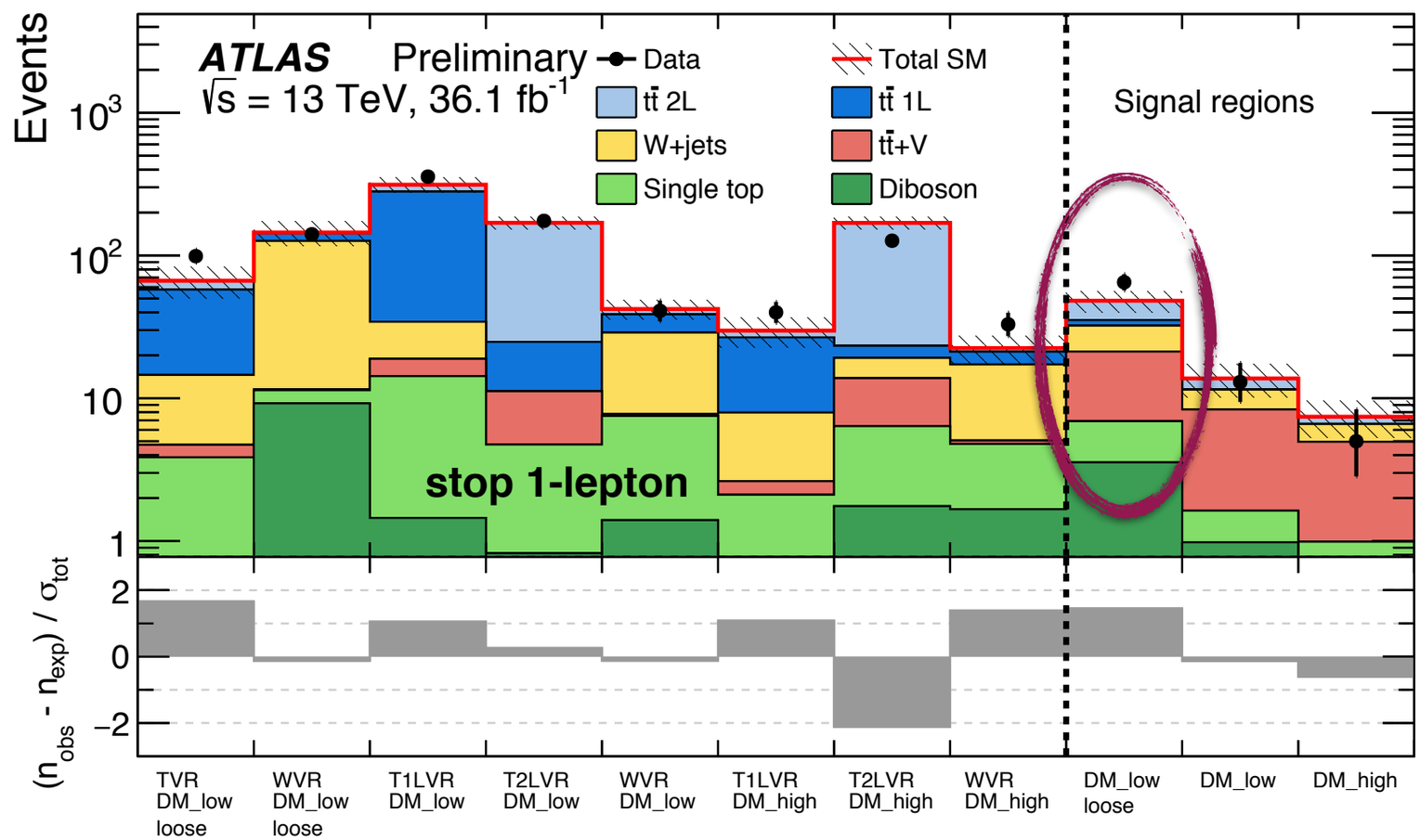
Results: Higgsino LSP diagonal region

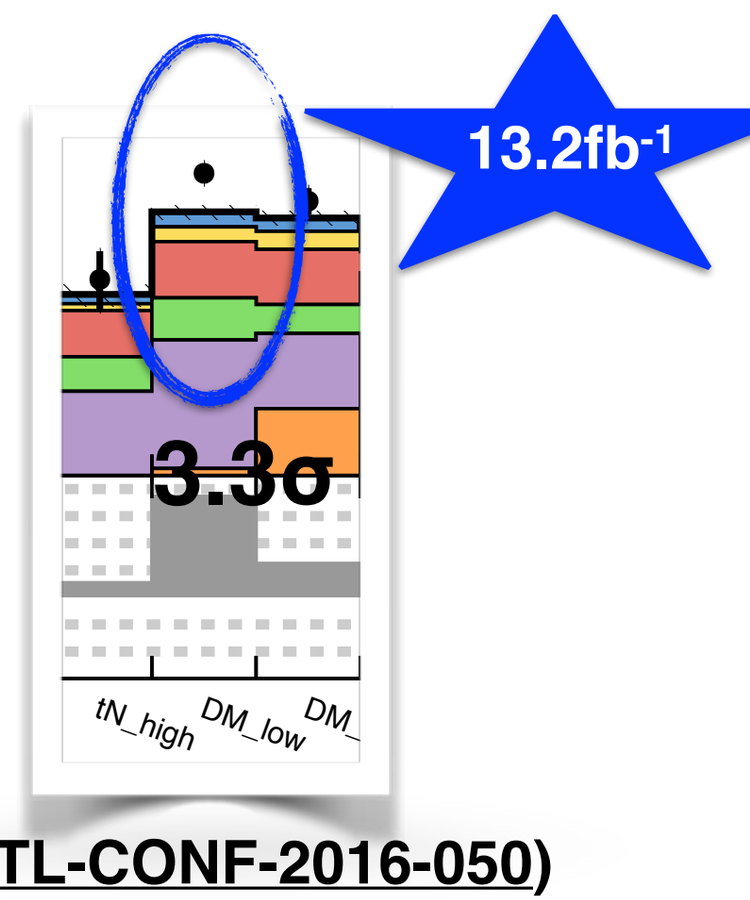


Results: Spin-0 mediator model (DM+ttbar)



- Spin-0 mediator model is studied, exploiting the similarity of the final state: ttbar+MET (1-lepton).
- There *was* mild excess in DM_low(_loose) in 13.2 fb-1
- No longer significant with full 2015+2016 data (1.5σ).





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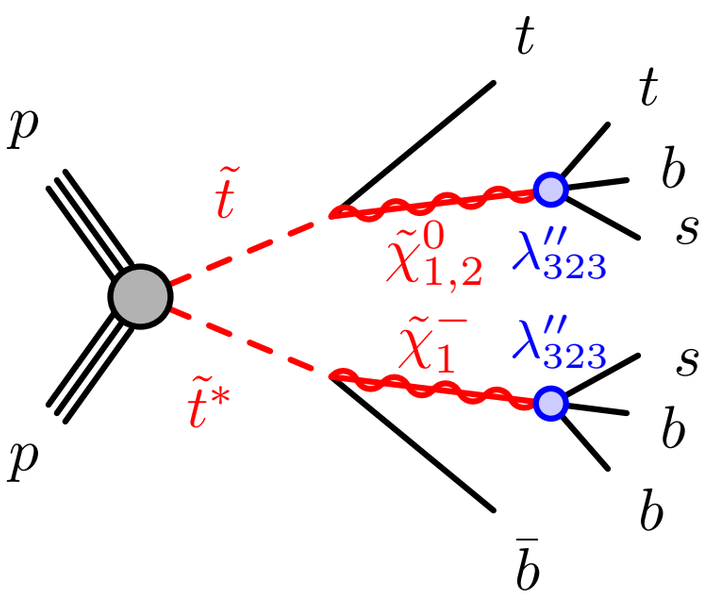
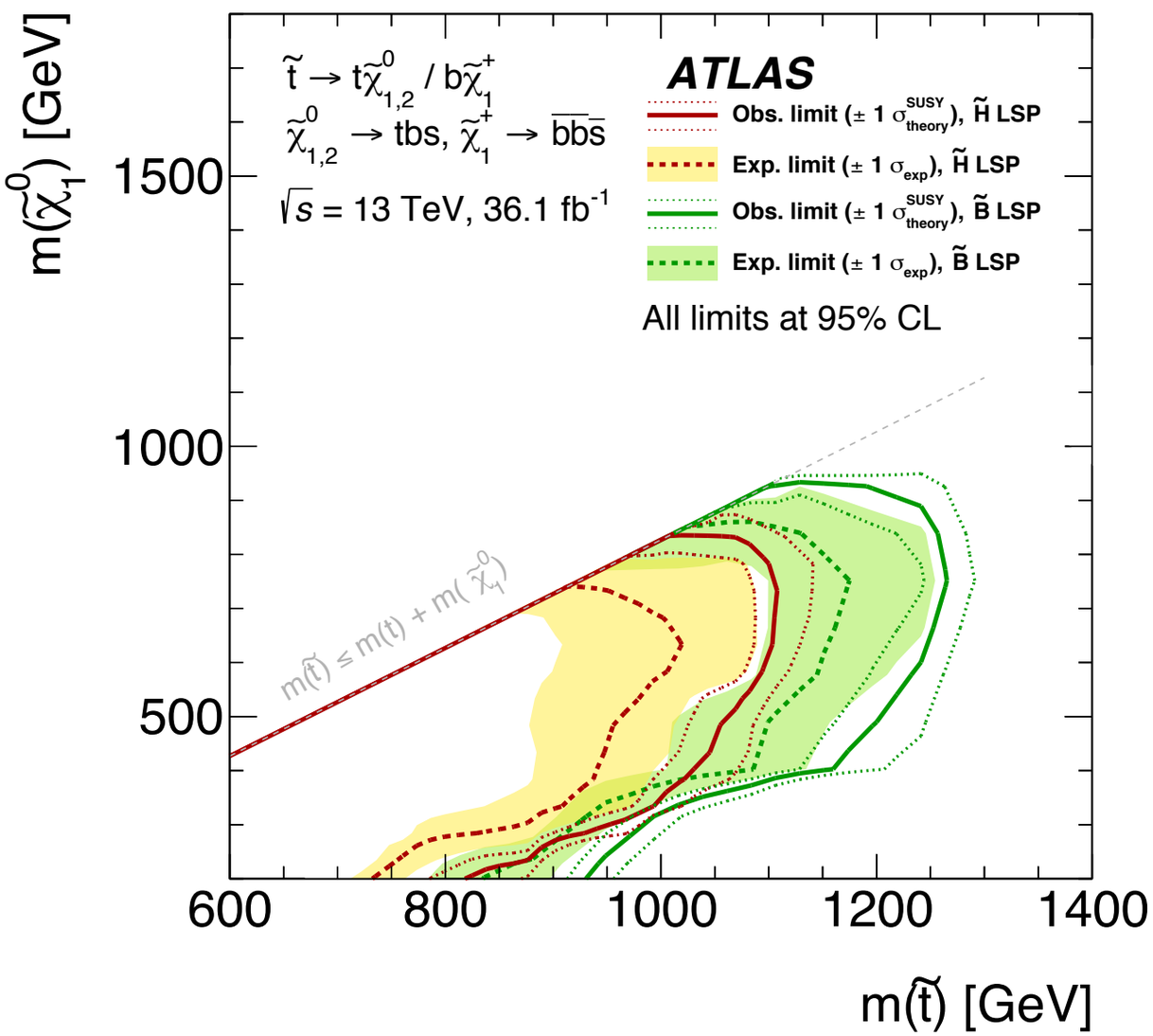
RPV stop 1L search

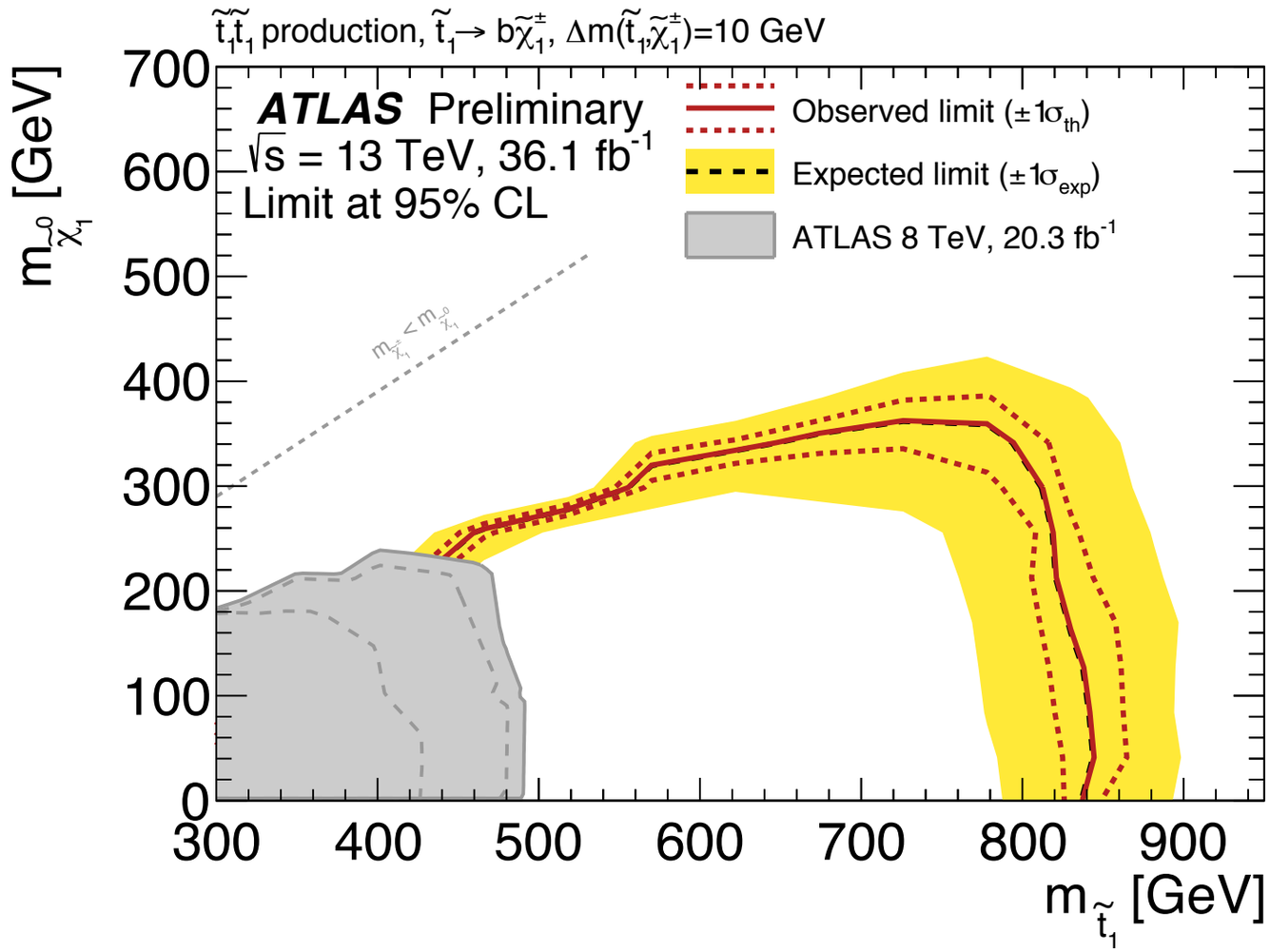


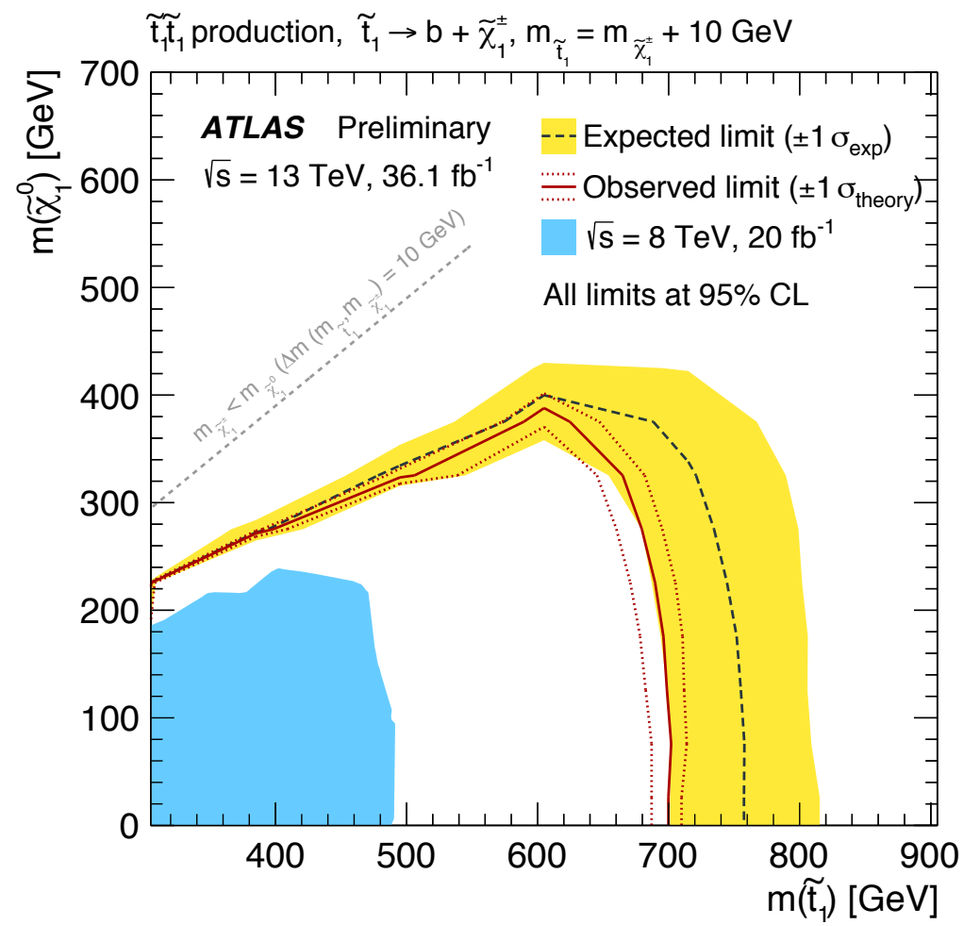
- In RPV models, LSP decays further into quarks, leading to multijets (up to >= 12 jets!) and a lepton (from semi-leptonic top-quark decay) final state.

- Higgsino LSP (with t1 ~ tR) and Bino LSP scenarios considered.
- mt1 up to 1250 GeV (1100 GeV) is excluded for the bino LSP (higgsino LSP) scenario.



Results: Compressed b+chargino





Results: Spin-0 mediator model