Searches for **direct pair production of stops** in final states containing **taus or H/Z bosons** with the ATLAS detector

A. Miucci on behalf of the ATLAS collaboration

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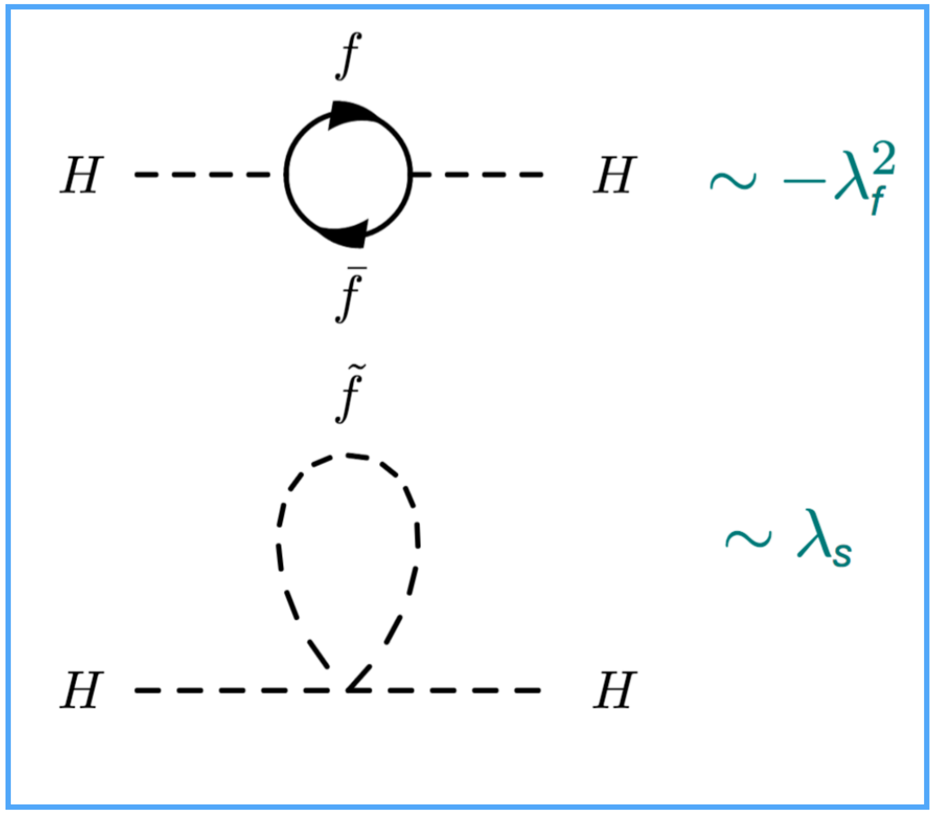
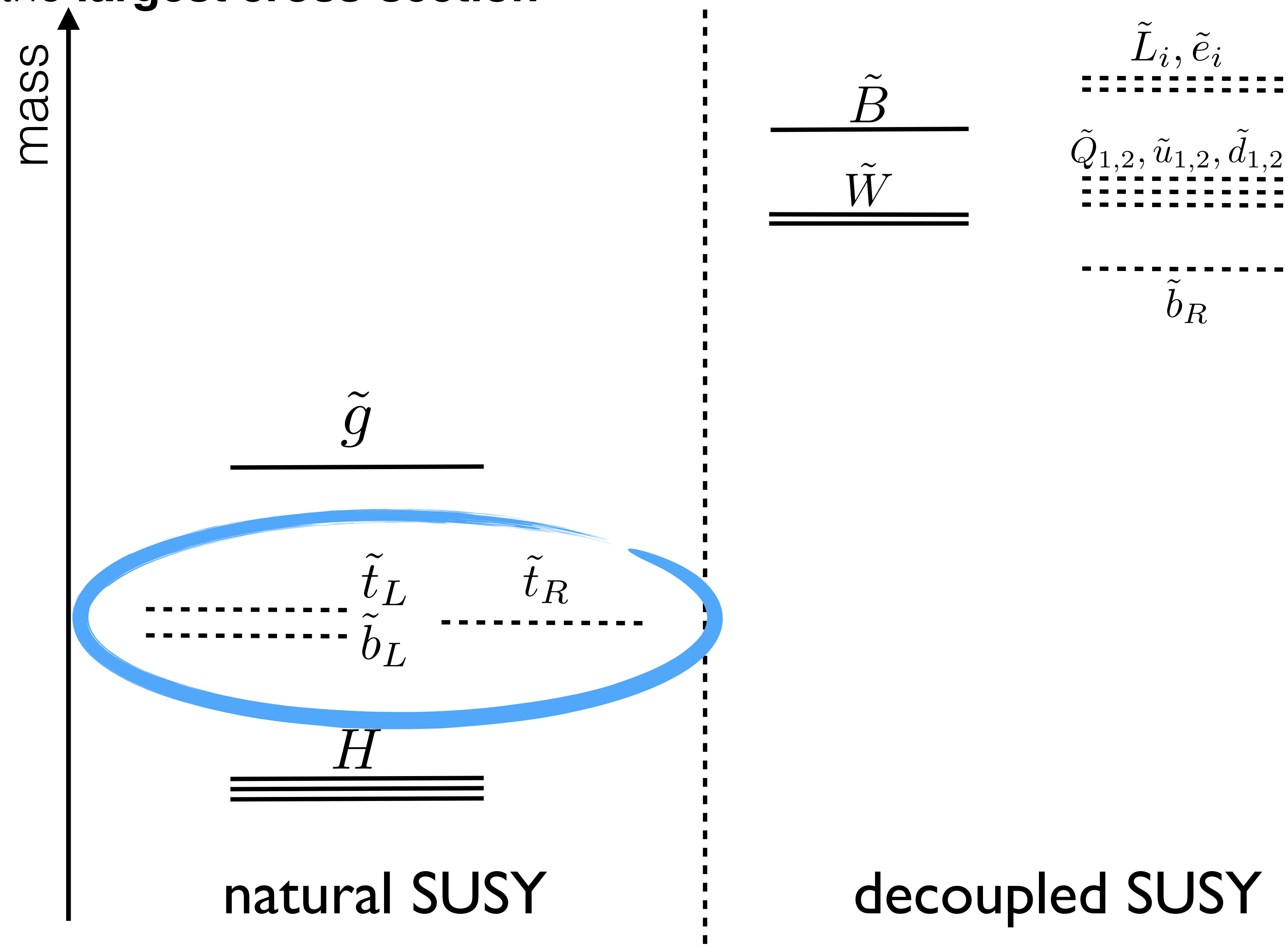
- The SUSY solution to the Higgs mass divergency
  - 2 x top squarks: **same coupling as top quark**, λ
  - Quadratic corrections cancel

- **Top Squark** is expected to be **light**:
  - 2nd order perturbative corrections to the Higgs mass
  - stopLR mixing is large, stops can be light

Top Squark mass expected in the 1 TeV range

- **Direct pair production** is the process with the **largest cross-section**





M.Papucci, J.Ruderman, A. Weiler
hep-ph:1110.6926

List of stop pair production publication

- **ATLAS** has a **broad search program** in the context of stop search
  - Final states containing **taus**
  - Final states with **h/Z** bosons

Looking at the different corners of **SUSY stop** spectrum

Short Title	Journal reference	Date	√s (TeV)	L	Links
MET + jet search 13 TeV 2016	Submitted to JHEP	09-NOV-17	13	36 fb-1	1711.03301
Stop pair; dijet pairs, RPV	Submitted to EPJC	19-OCT-17	13	37 fb-1	1710.07171
Stop pair; 2 leptons, b-jets, RPV	Submitted to PRD	16-OCT-17	13	36 fb-1	1710.05544
Stop pair; 0 lepton	Submitted to JHEP	13-SEP-17	13	36 fb-1	1709.04183
Sbottom pair, stop pair; 0-1 leptons, b-jets	Submitted to JHEP	30-AUG-17	13	36 fb-1	1708.09266
Stop pair; 2 leptons	Submitted to EPJC	10-AUG-17	13	36 fb-1	1708.03247
Stop pair; Z/h boson	**JHEP 08 (2017) 006**	**13-JUN-17**	**13**	**36 fb-1**	**1706.03986**
Two same-sign leptons or three leptons	JHEP 09 (2017) 084	12-JUN-17	13	36 fb-1	1706.03731
Gluino pair, stop pair; 1 lepton, RPV	JHEP 09 (2017) 88	27-APR-17	13	36 fb-1	1704.08493
Stop pair; Stau, gravitino	**ATLAS-CONF-2017-079**	**11-DEC-17**	**13**	**36 fb-1**	**…**

ATLAS-CONF-2017-079

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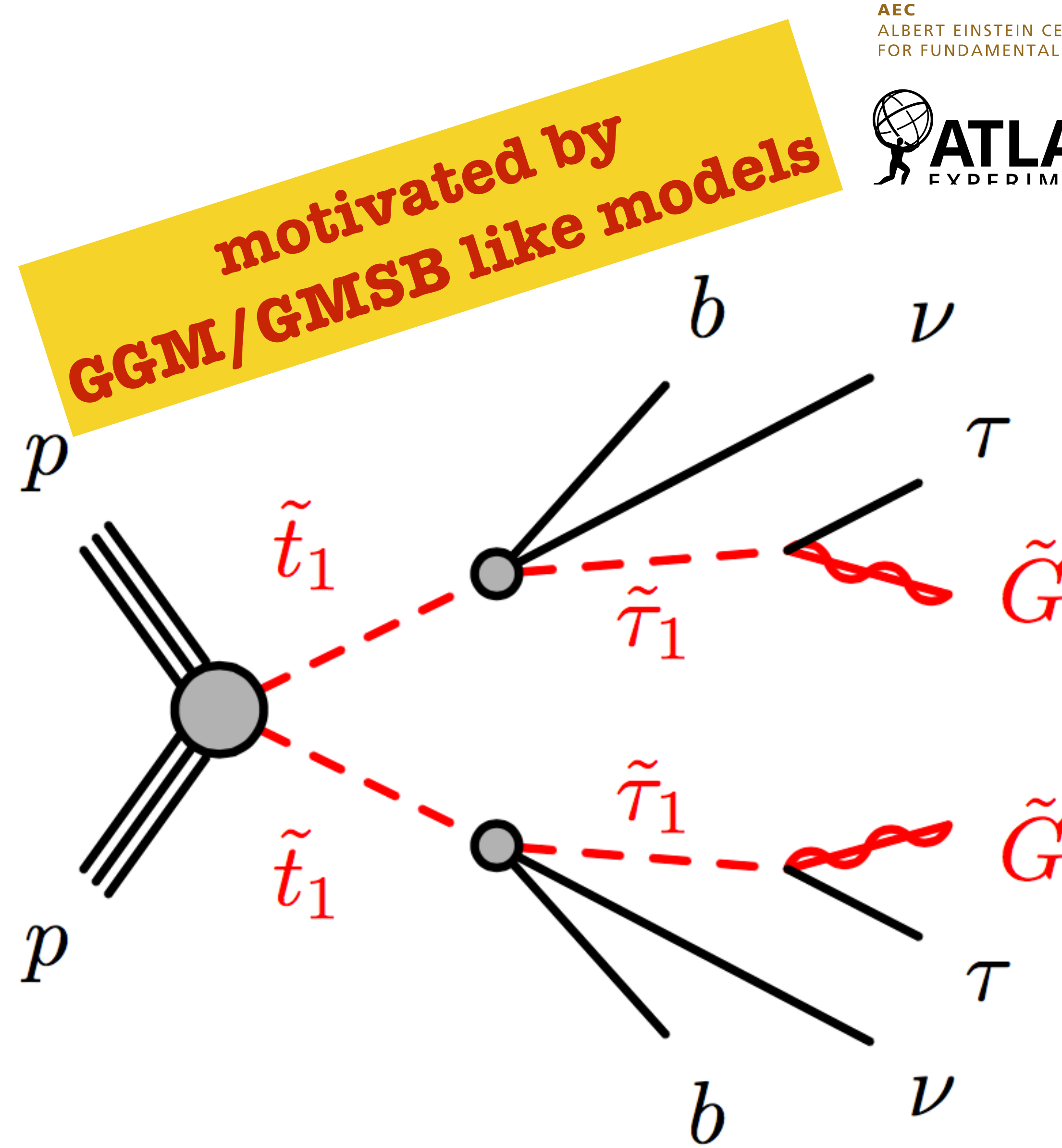
Analysis strategy

- *simplified model:* 100% branching ratio
- **2 τ in the final state ⇒ 2 dedicated selections**
  - τ_{lep}+τ_{had}:
    - 1 reconstructed τ_{had} + 1 e/μ
  - 2 τ_{had}
    - muon and electron veto
    - 2 reconstructed τ_{had}
- Common requirements
  - *2 lepton opposite charge*
  - *1 b-jet*

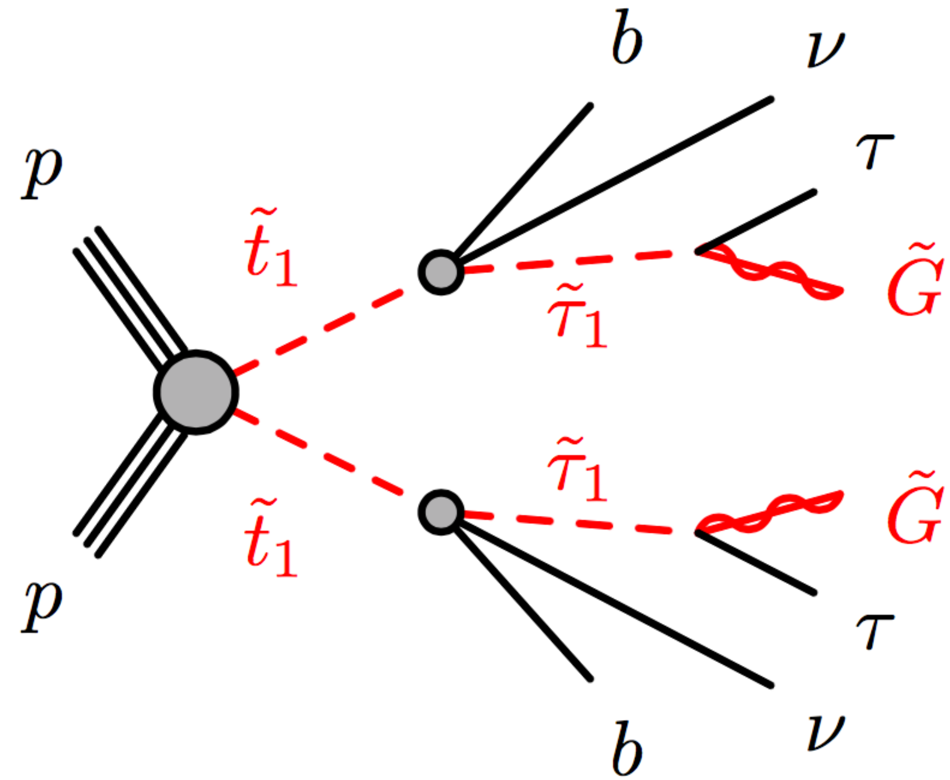


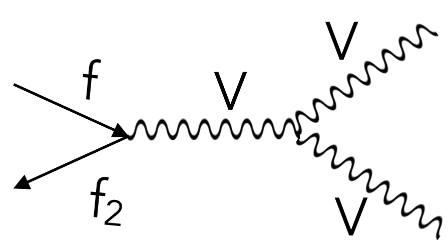
m(G) < 1GeV

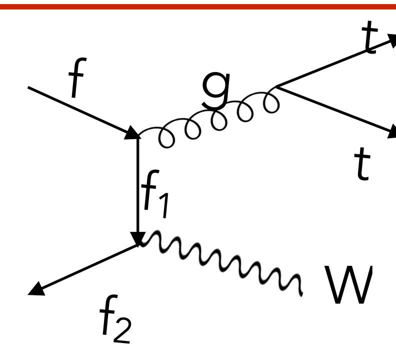
Variable	SR LH	SR HH
charge(ℓ,τ)	opposite	opposite
$m_{T2}(\ell,\tau)$	> 100 GeV	> 80 GeV
E_T^{miss}	> 230 GeV	> 200 GeV

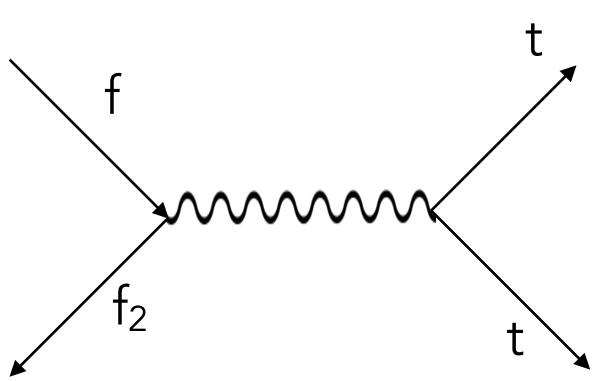
$$\mathrm{m}_{\mathrm{T2}}^2(\vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{l1}}, \vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{l2}}, \vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{miss}}) = \min_{\vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{miss1}} + \vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{miss2}} = \vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{miss}}} \{\max[\mathrm{m}_{\mathrm{T}}^2(\vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{l1}}, \vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{miss1}}), \mathrm{m}_{\mathrm{T}}^2(\vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{l2}}, \vec{\mathrm{p}}_{\mathrm{T}}^{\mathrm{miss2}})]\}$$

Main Backgrounds





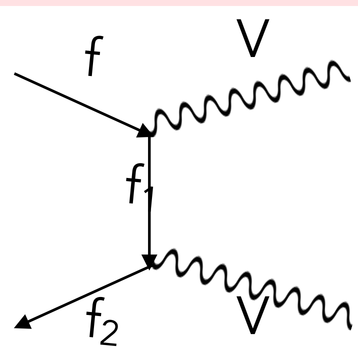


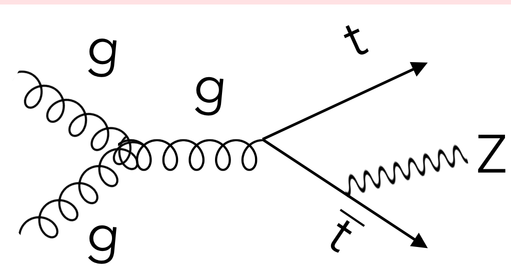


diboson Sherpa

top pair production associated with vector boson
aMC@NLO

+ **FAKES**

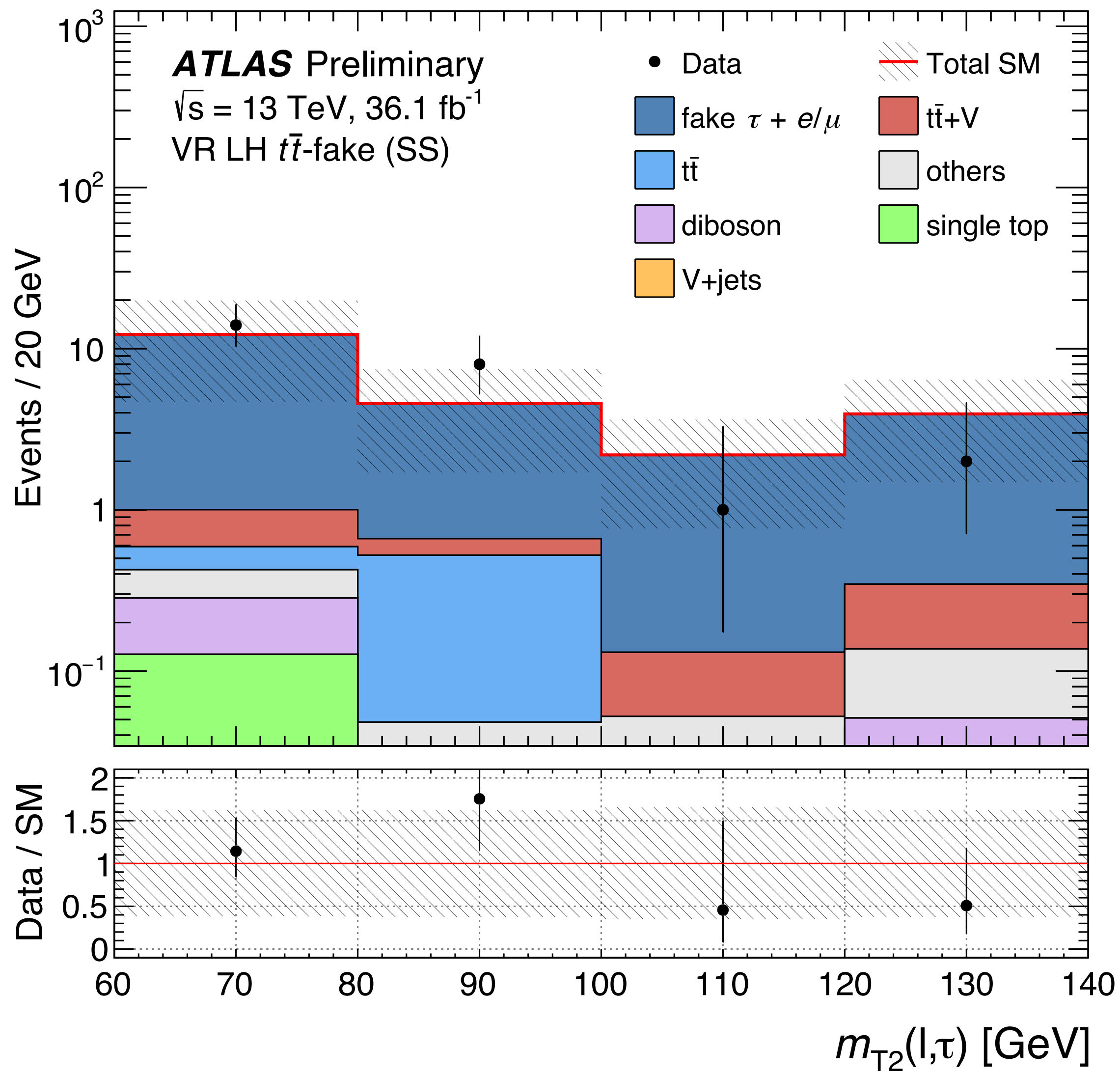




top pair production
Powheg

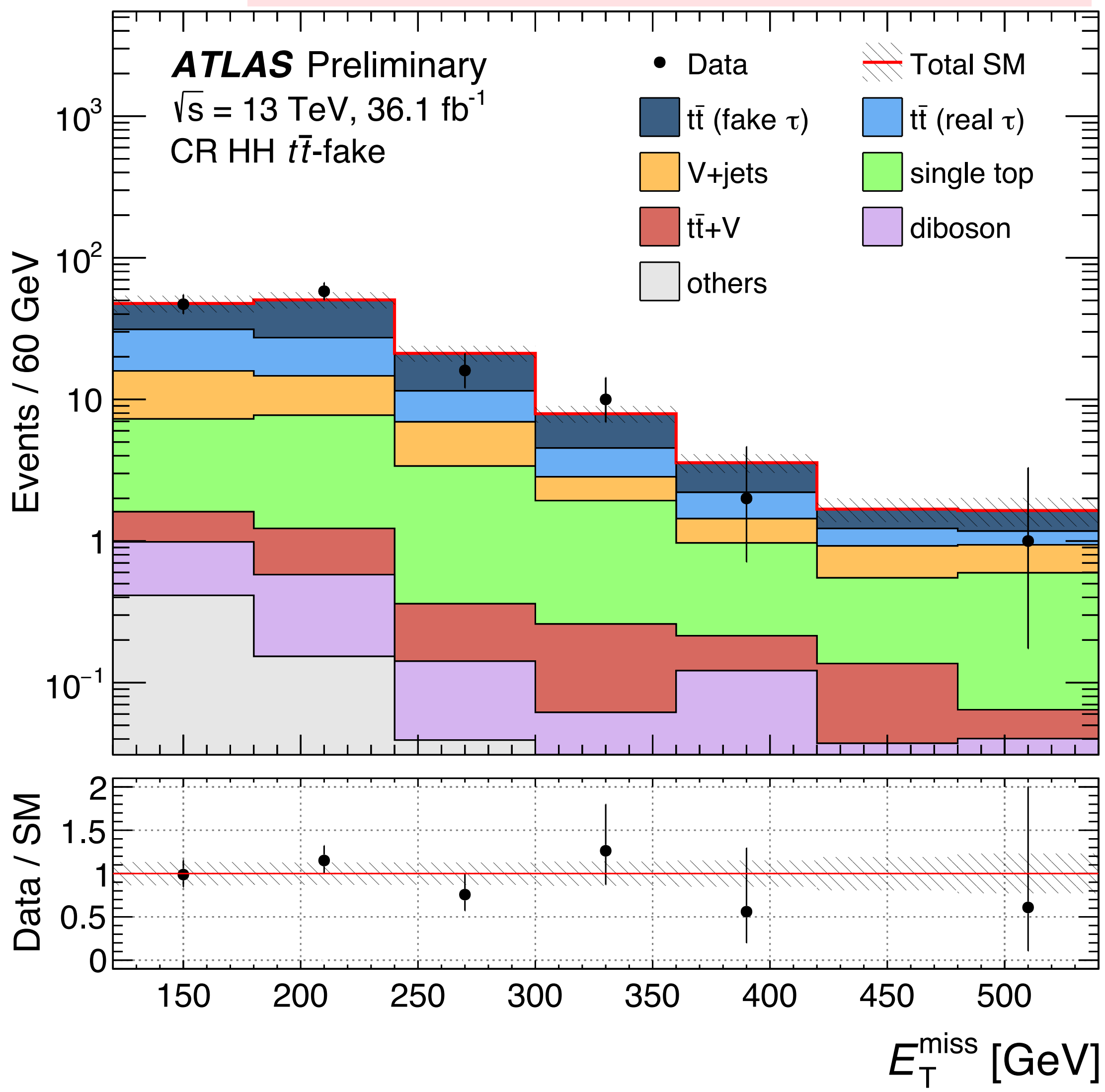
Search for top squarks in tau channel: **Backgrounds**

Leptonic-Hadronic **VR fake τ+e/μ**

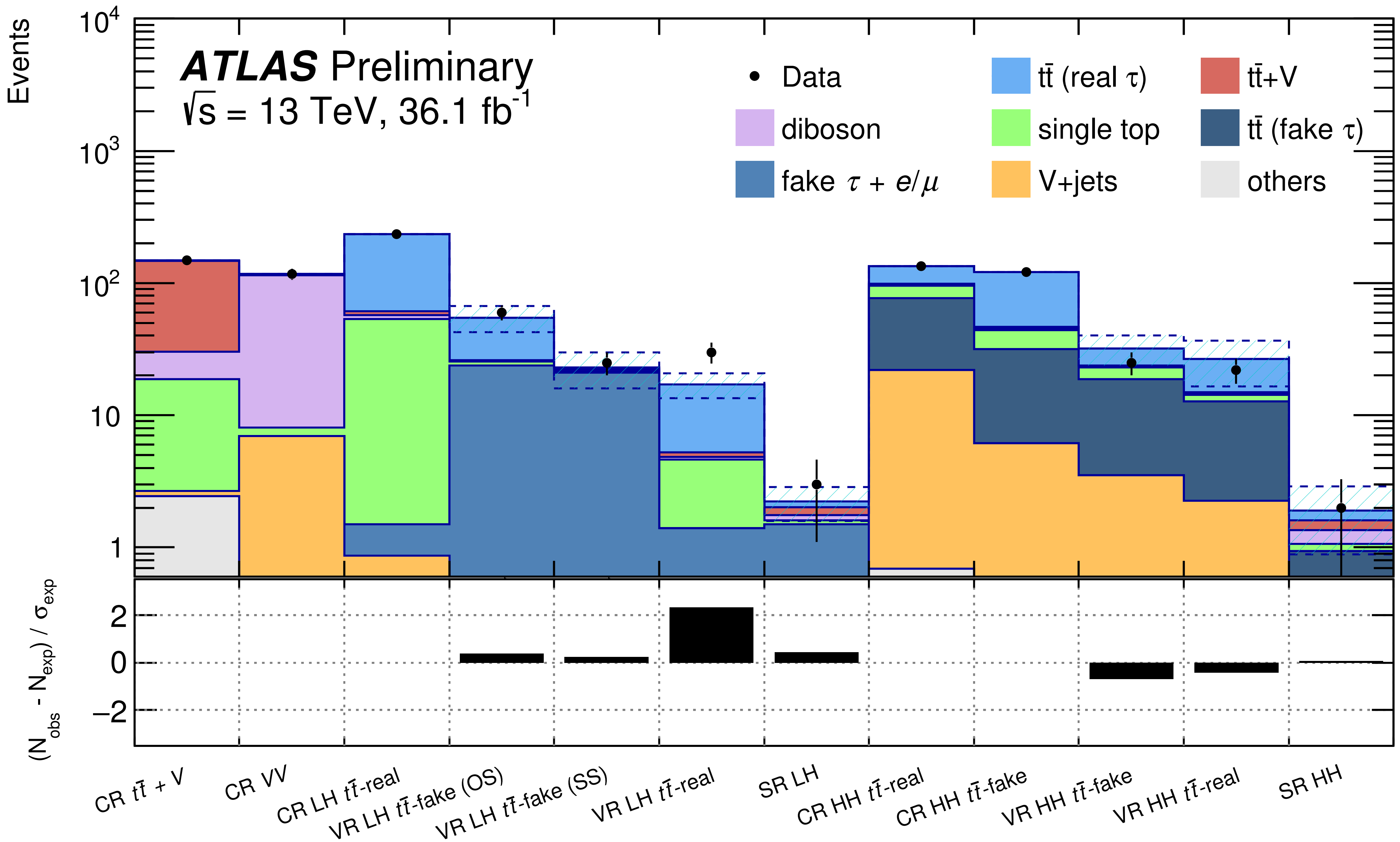


Hadronic-Hadronic

CR ttbar with fake tau reconstructed



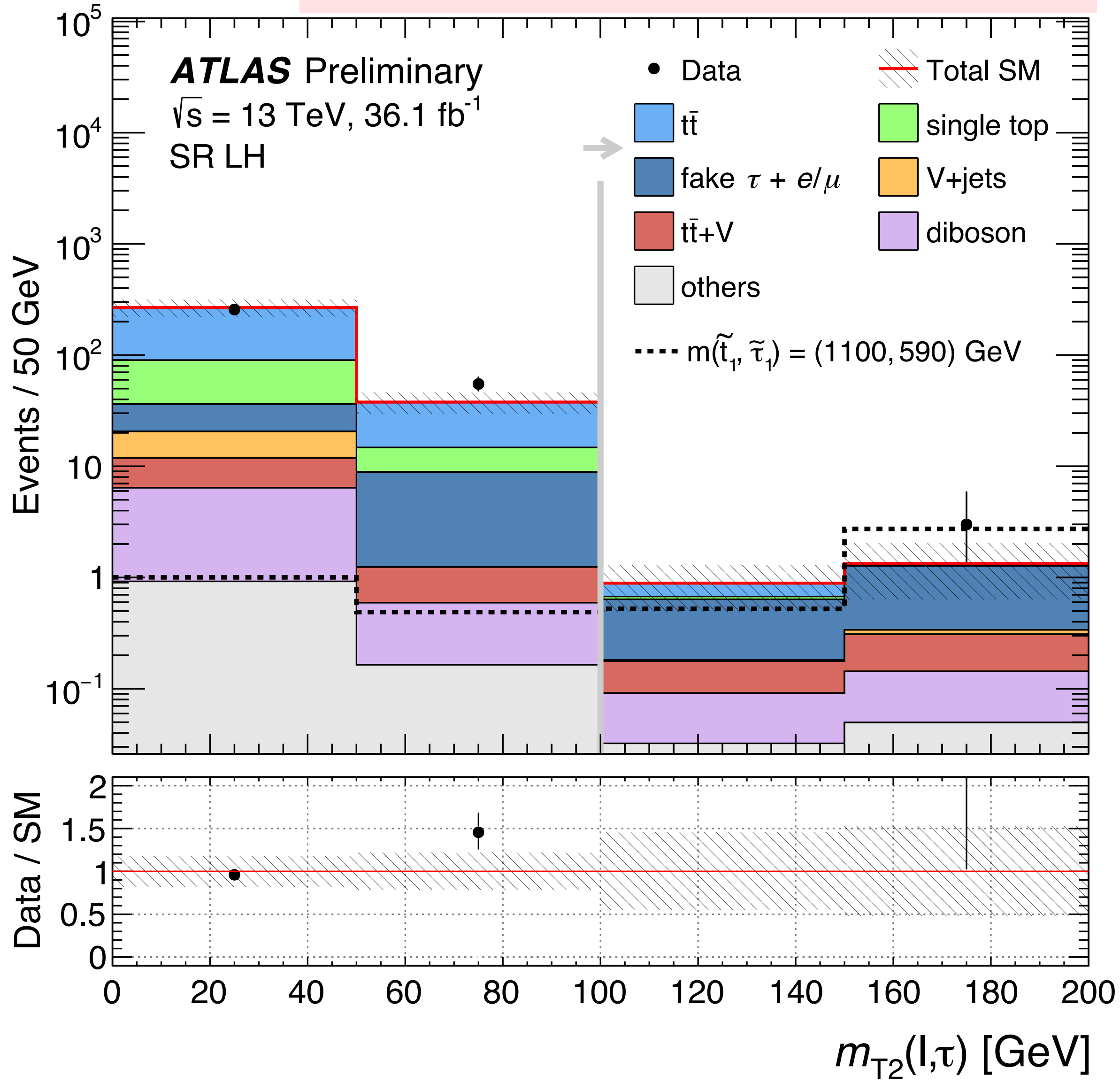
- *Leptonic-Hadronic:* Data-driven estimation for fake **τ+e/μ (Fake factor)**
  - **Anti ID:** Additional τ selection, loose working point and orthogonal to the other
  - **Fake factor:** ratio of fakes τ between the two selection estimated in dedicated **Measurement region**,
  - Number of fake τ events: **Fake factor * Anti ID** in the Target Region
- *Hadronic-Hadronic:* Additional **ttbar Control Region** for estimation of ttbar event reconstructed as **fake τ**
  - misidentified jets or electrons as tau, from the W decay of one of the ttbar leg



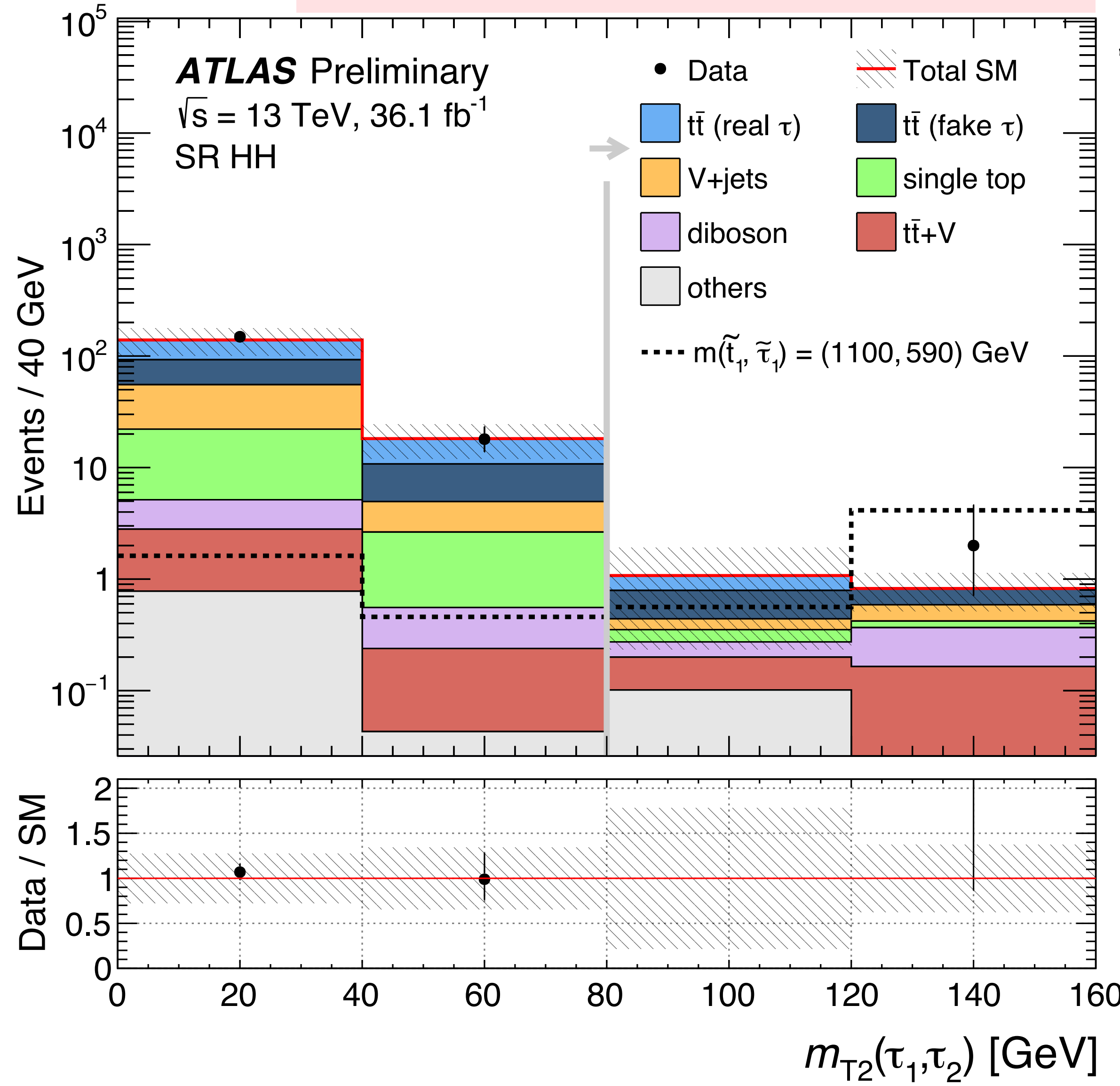
- **Control Regions** for background normalization + **Validation Regions**
  - *Maximum likelihood fit:* all the Control region at the same time
  - *Common Backgrounds:* **ttbar, diboson, ttV**

Search for top squarks in tau channel: **Signal Regions**

Leptonic-Hadronic



Hadronic-Hadronic



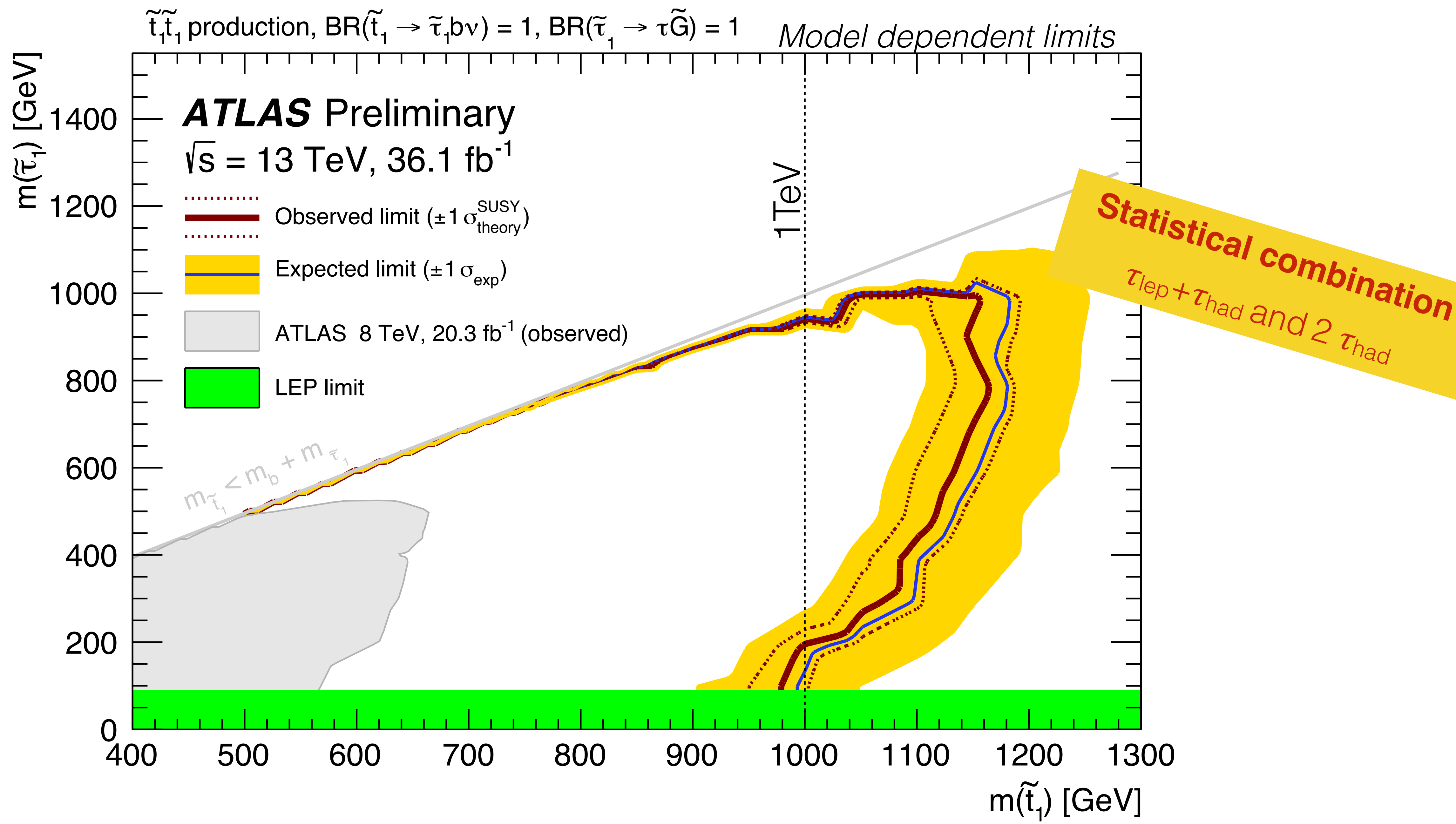
Variable	SR LH	SR HH
charge(ℓ,τ)	opposite	opposite
$m_{\mathrm{T2}}(\ell,\tau)$	> 100 GeV	> 80 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 230 GeV	> 200 GeV

Search for top squarks in tau channel: **Limits**

Model independent limits

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_b	$p(s=0)$ (Z)
SR LH	0.15	5.4	$4.5^{+2.6}_{-1.5}$	0.65	0.32 (0.47)
SR HH	0.13	4.7	$4.6^{+2.5}_{-1.5}$	0.52	0.48 (0.05)

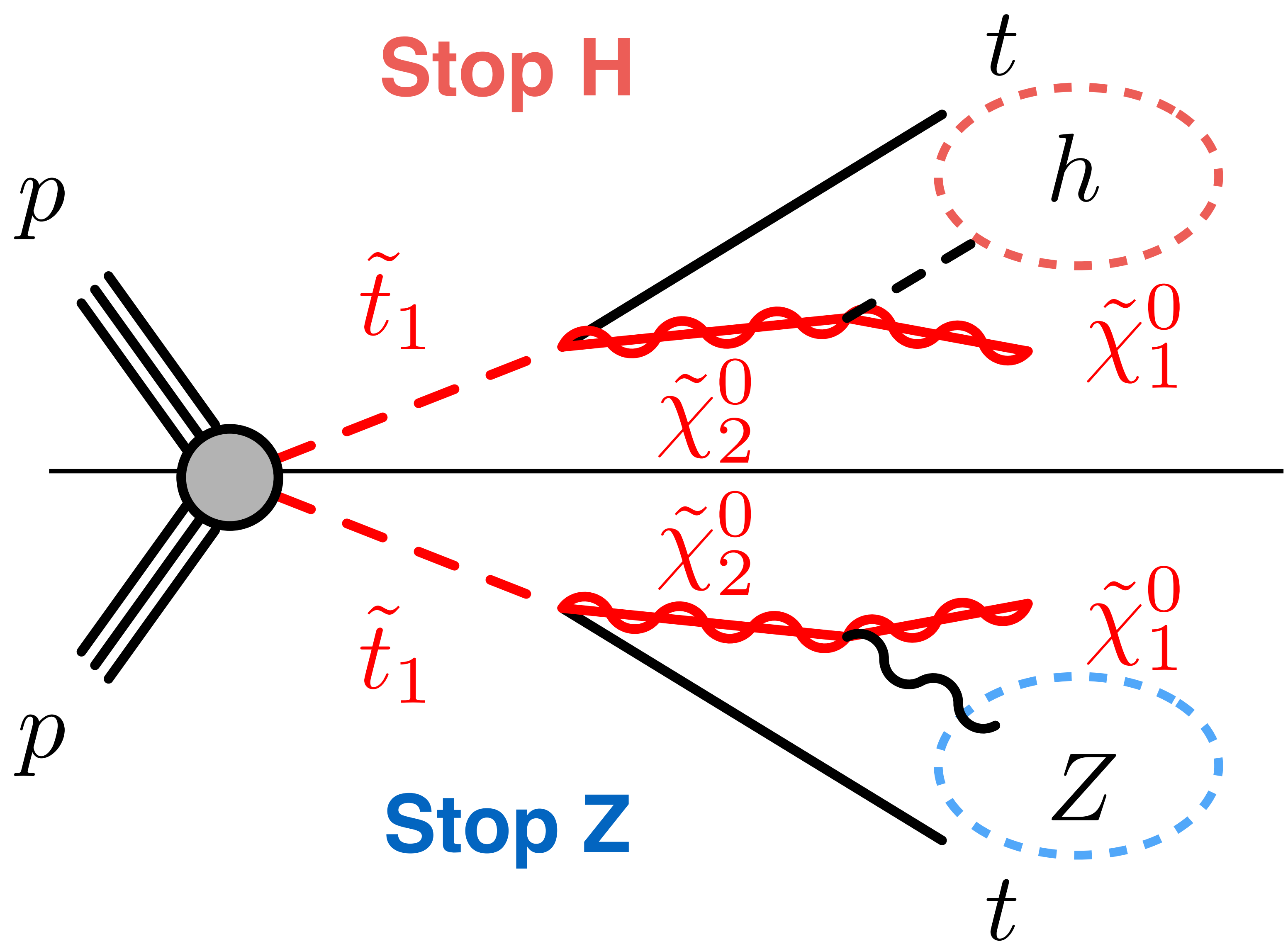
Model dependent limits



Direct top squark pair production with a Higgs or Z boson

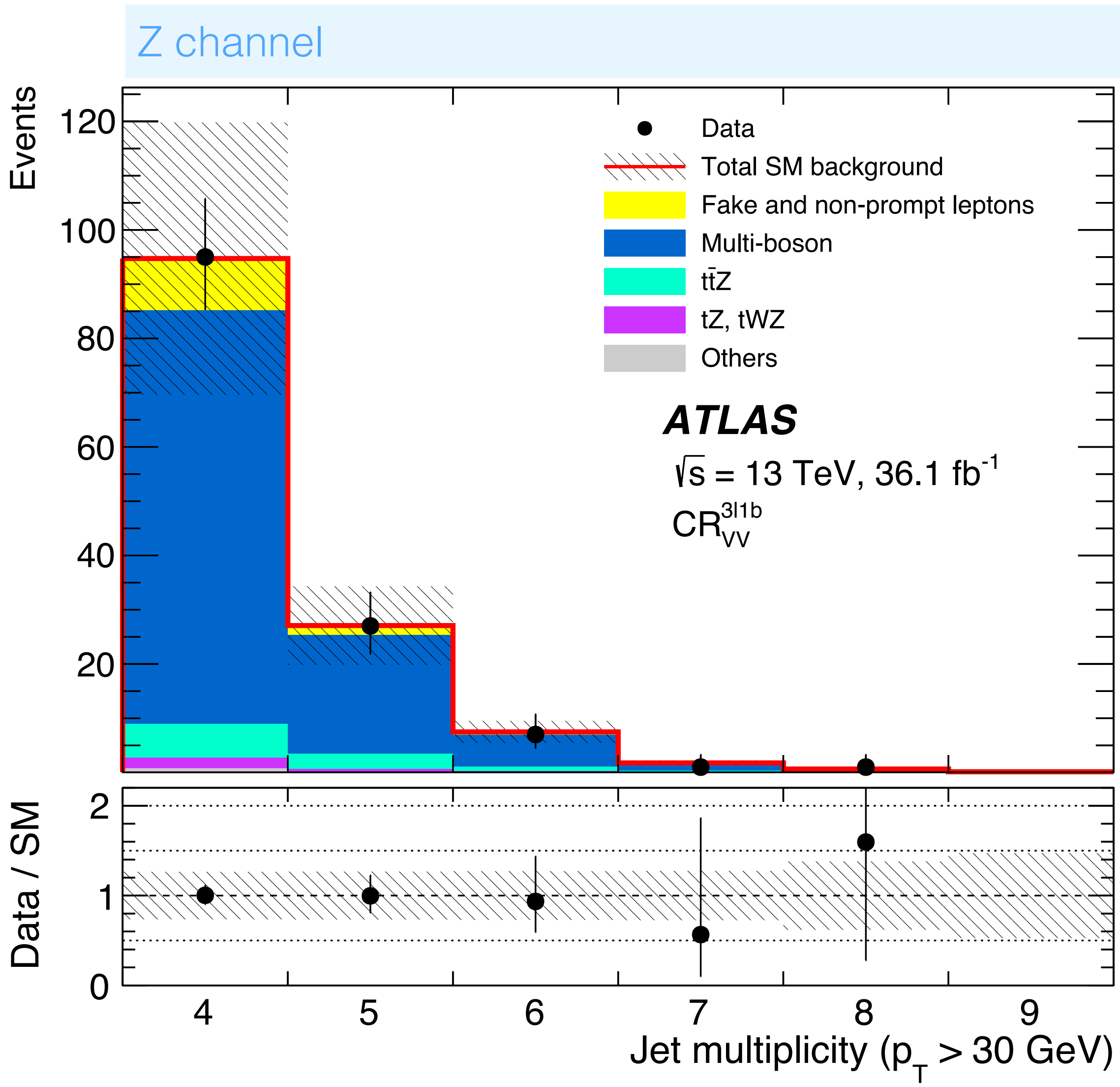
ATLAS-CONF-2016-20 || JHEP 08 (2017) 006

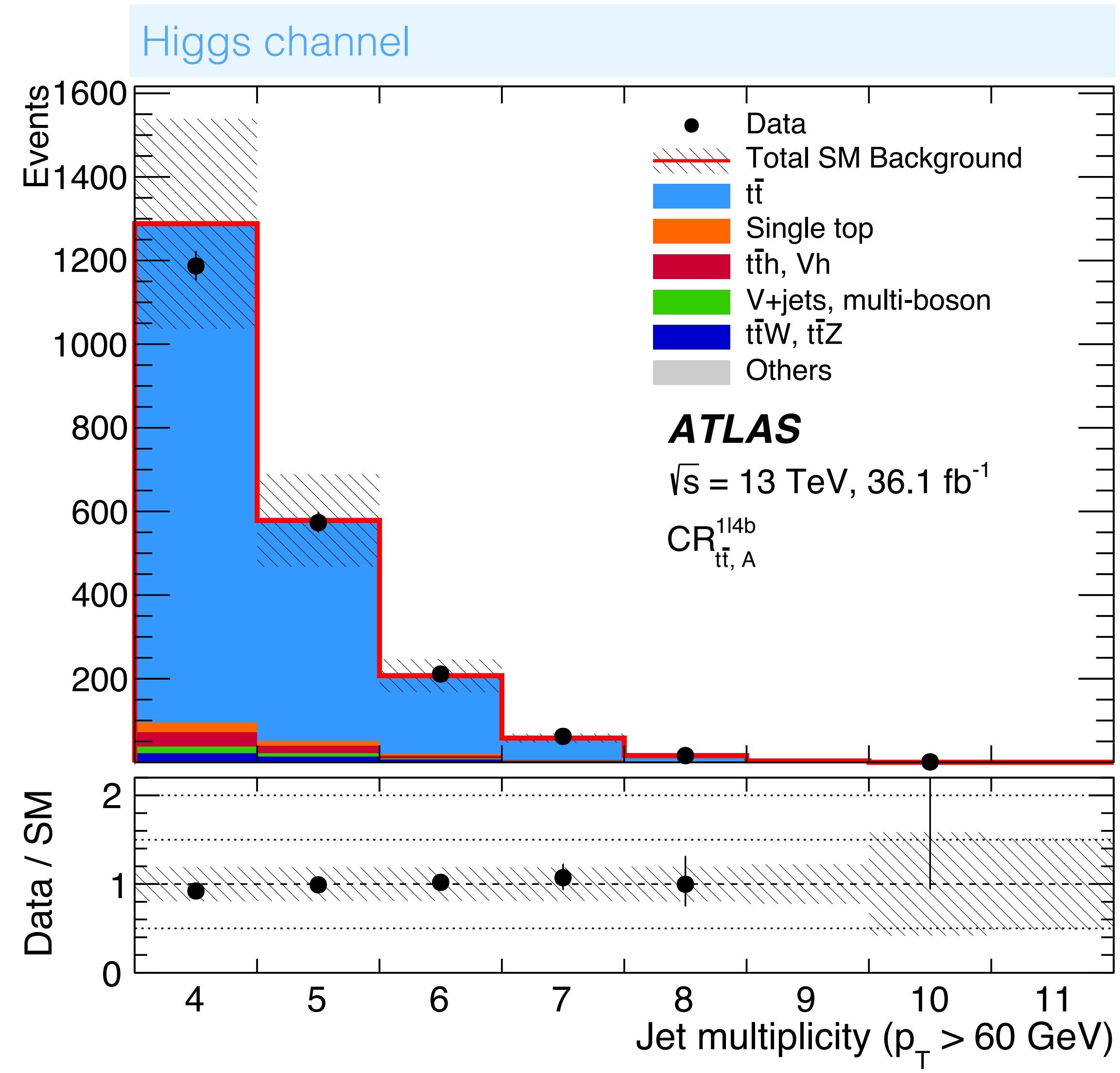
- Typical decay of stop to **wino-bino** (BinoLSP) models
  - represented by **cMSSM/mSUGRA**, generally motivated by the GUT
- Two possible branches:
  - using **simplified models:**
    - with the exception of $\tilde{t}_{1,2}$ and $\tilde{\chi}^0_{1,2}$ all the SUSY particles are decoupled
  - 100% branching ratio for each branch in two independent searches



- **Higgs boson** in the final state
  - **H decaying in b-quark pair**
  - leptonic decay of the W associated to the top
  - 1 b-jet from top decay
- **Z boson** in the final state
  - **leptonic decay of the Z**
  - leptonic decay of the W associated to the top
  - 1 b-jet from the top decay

Direct top squark with a Higgs or Z: **Backgrounds**





- **Control Regions** for background normalization + **Validation Regions**
  - Z channel: **Fake leptons** (data-driven), **Multi-bosons, ttZ**
  - Higgs Channel: **top pair production** (3 Control Regions, one per Signal Region)

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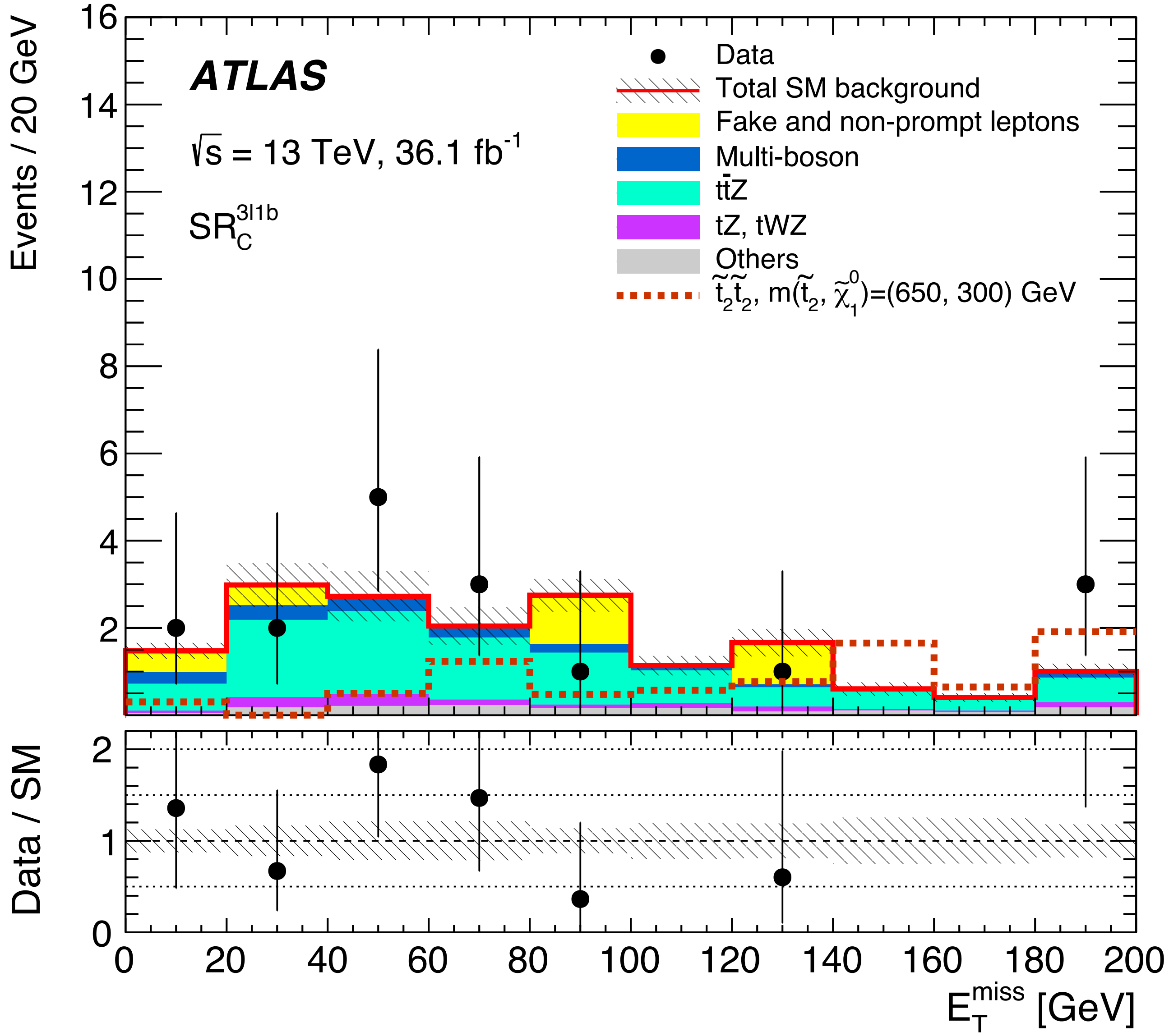
Analysis strategy

Z boson channel

- *Z decay leptonically ⇒ clean signature*
- *3 light leptons* (e or μ) in the final states
- Large E_T^{miss}
- *1 b-jet* coming from the t decay



- **3 Signal regions**:
  - optimised for different mass splitting

$$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_2^0}$$

Requirement / Region	$SR_A^{3\ell 1b}$	$SR_B^{3\ell 1b}$	$SR_C^{3\ell 1b}$
Number of leptons	≥ 3	≥ 3	≥ 3
$n_{b\text{-tagged jets}}$	≥ 1	≥ 1	≥ 1
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	< 15	< 15	< 15
Leading lepton p_T [GeV]	> 40	> 40	> 40
Leading jet p_T [GeV]	> 250	> 80	> 60
Leading b-tagged jet p_T [GeV]	> 40	> 40	> 30
n_{jets} ($p_T > 30$ GeV)	≥ 6	≥ 6	≥ 5
E_T^{miss} [GeV]	> 100	> 180	> 140
$p_T^{\ell\ell}$ [GeV]	> 150	–	< 80

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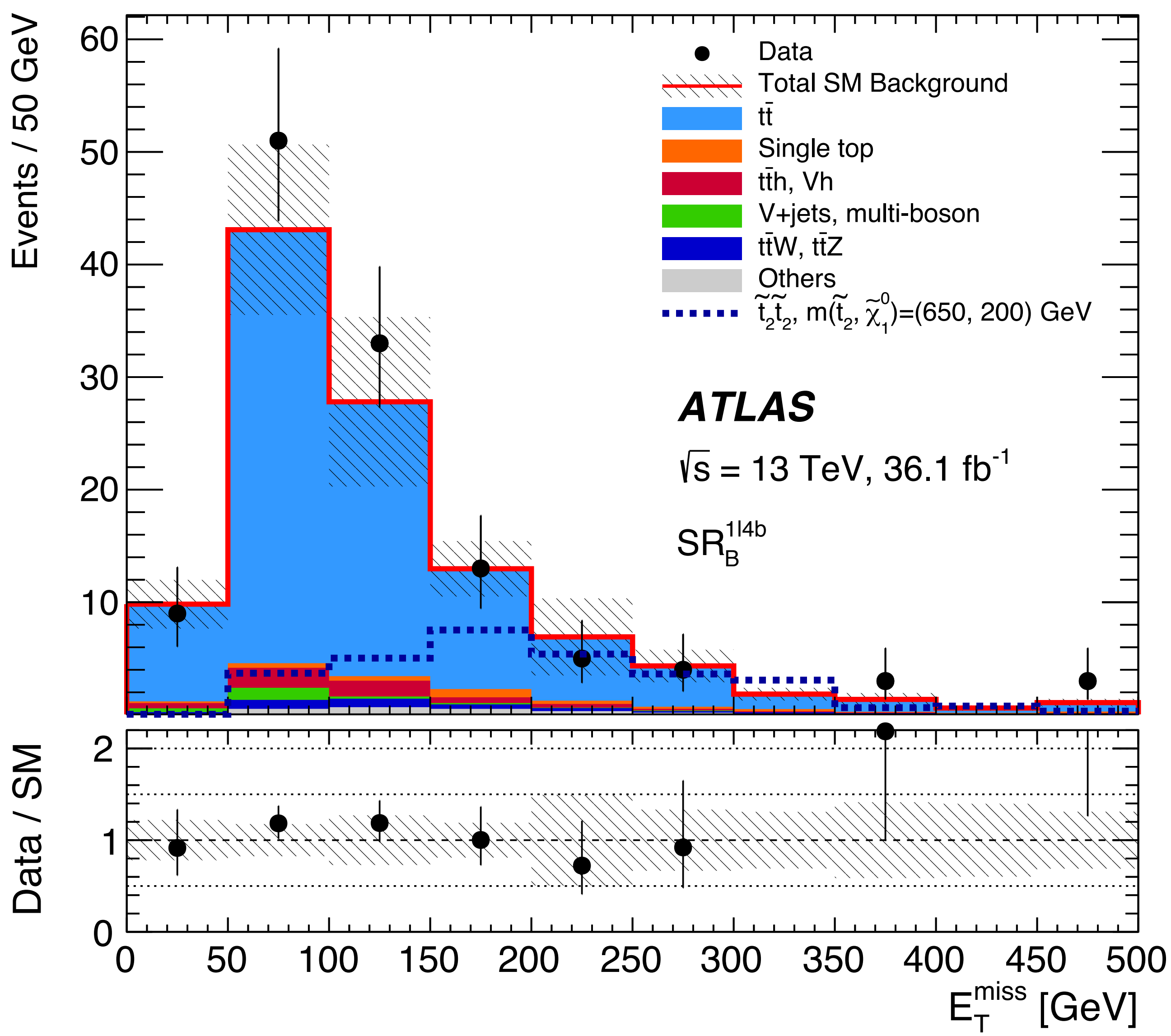
Analysis strategy

Higgs boson channel

- $H \to bb$
- *high number of b-jets* in the final state
- At least 1 lepton ⇒ reduce QCD multi-jet
- Large Hadronic activity and E_T^{miss}



- **3 Signal regions**:
  - optimised for different mass splitting

$$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_2^0}$$

Requirement / Region	$SR_A^{1\ell 4b}$	$SR_B^{1\ell 4b}$	$SR_C^{1\ell 4b}$
Number of leptons	1–2	1–2	1–2
$n_{b\text{-tagged jets}}$	≥ 4	≥ 4	≥ 4
m_T [GeV]	–	>150	>125
H_T [GeV]	> 1000	–	–
E_T^{miss} [GeV]	> 120	> 150	> 150
Leading b-tagged jet p_T [GeV]	–	–	<140
m_{bb} [GeV]	95–155	–	–
p_T^{bb} [GeV]	> 300	–	–
n_{jets} (p_T > 60 GeV)	≥ 6	≥ 5	–
n_{jets} (p_T > 30 GeV)	–	–	≥ 7

Exclusion limits for the H/Z channel

Z channel — *Model independent limits*

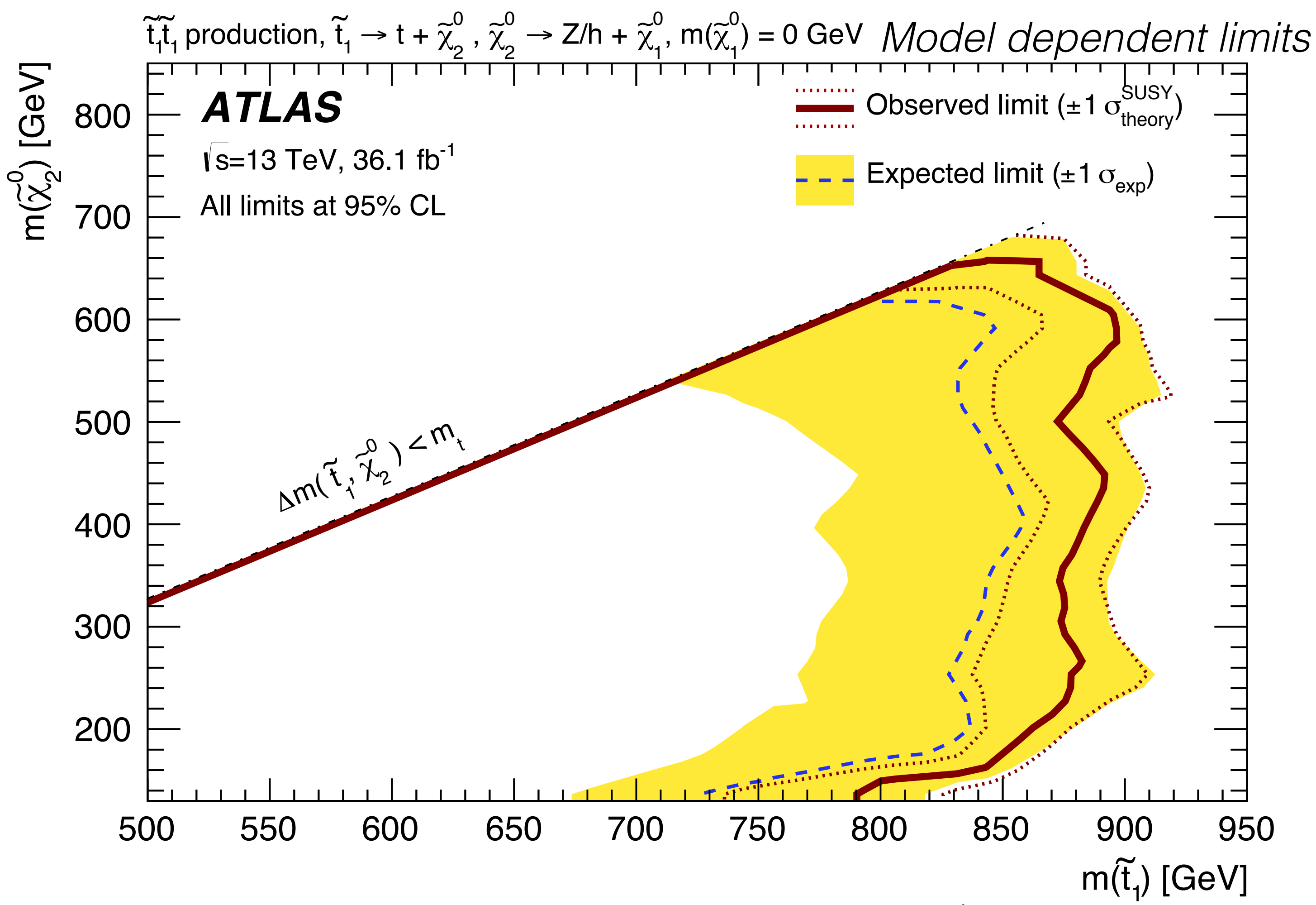
	$SR_A^{3\ell 1b}$	$SR_B^{3\ell 1b}$	$SR_C^{3\ell 1b}$
S_{obs}^{95}	4.5	3.8	5.8
S_{exp}^{95}	$4.2^{+1.9}_{-0.4}$	$4.9^{+1.5}_{-1.1}$	$4.4^{+1.8}_{-0.5}$
σ_{vis} [fb]	0.13	0.10	0.16
$p(s=0)$	0.42	0.93	0.23

Higgs channel — *Model independent limits*

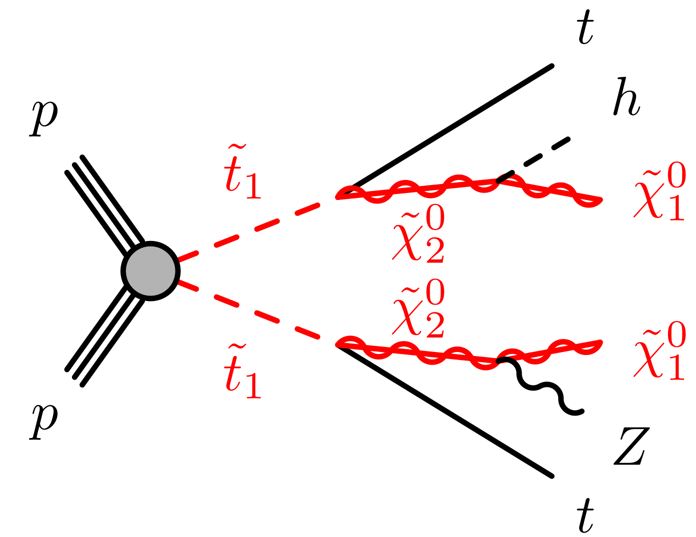
	$SR_A^{1\ell 4b}$	$SR_B^{1\ell 4b}$	$SR_C^{1\ell 4b}$
S_{obs}^{95}	7.8	14.6	15.6
S_{exp}^{95}	$9.6^{+4.1}_{-2.3}$	$15.5^{+5.6}_{-4.4}$	$10.4^{+4.2}_{-2.6}$
σ_{vis} [fb]	0.21	0.40	0.43
$p(s=0)$	0.63	0.82	0.11

Statistical combination Higgs and Z

Model dependent limits

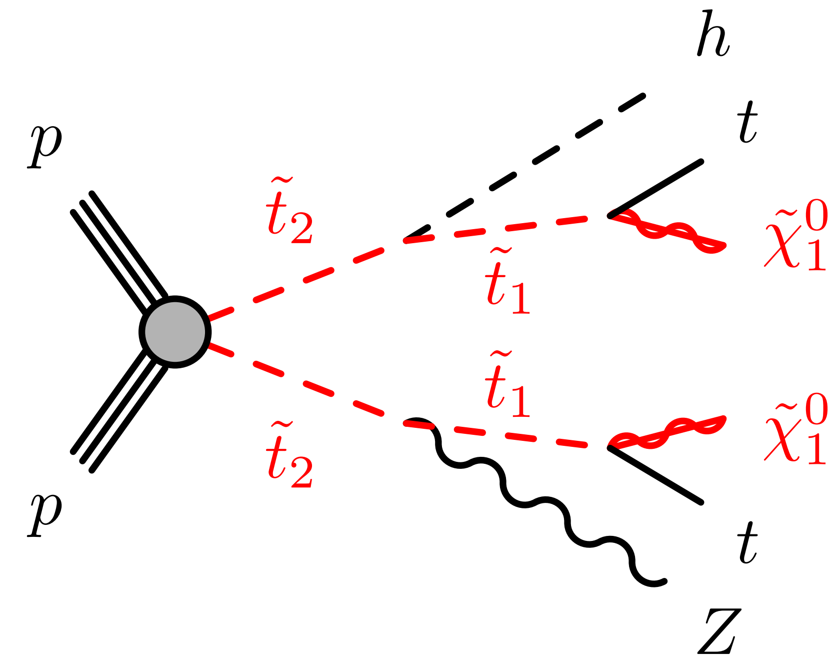


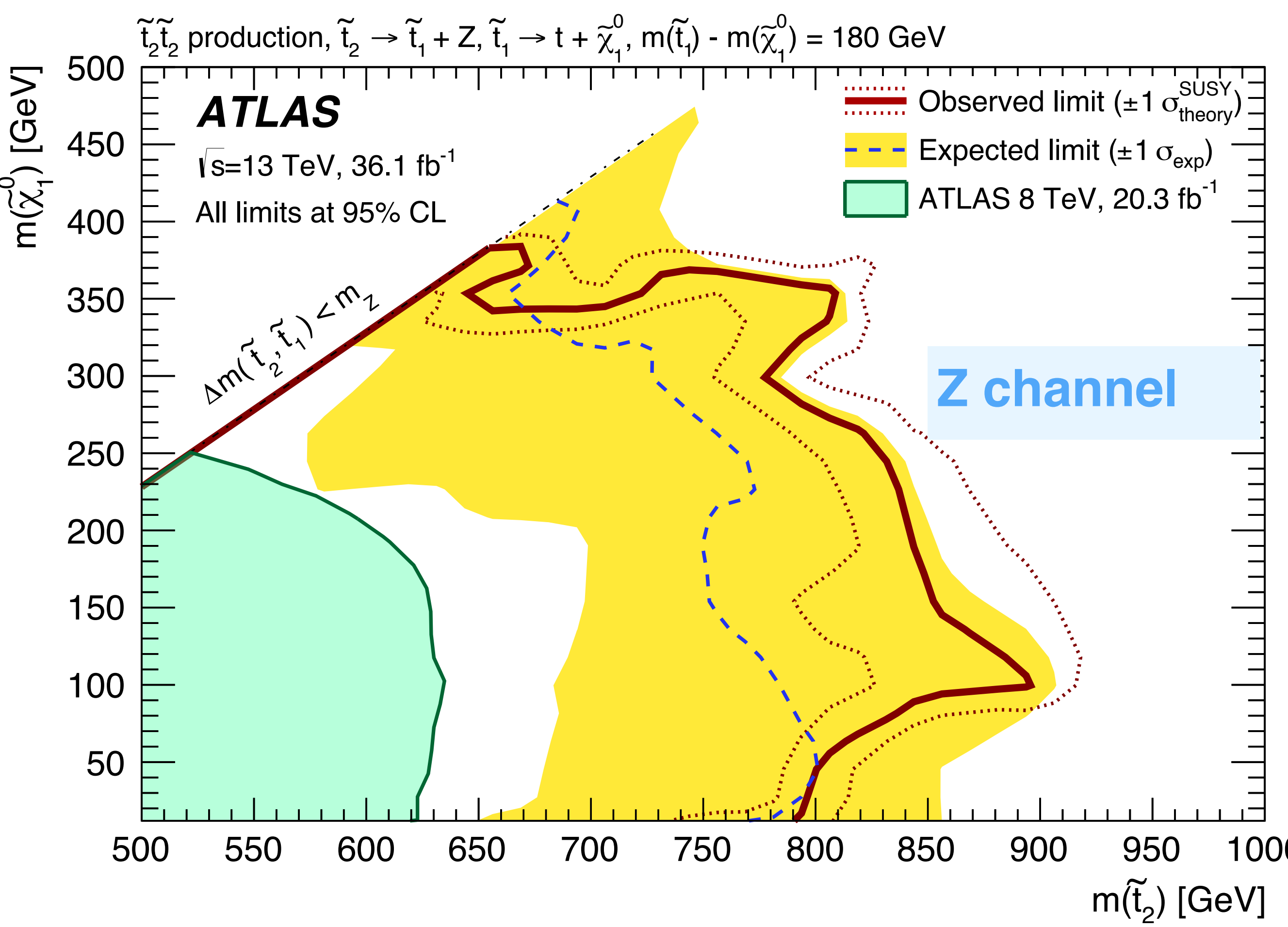
- Branching ratio: 50% Higgs + 50% Z
- **m($\tilde{\chi}_1^0$) = 0, m($\tilde{\chi}_2^0$) > 130 GeV**
  - needed for on-shell decays of Higgs and Z

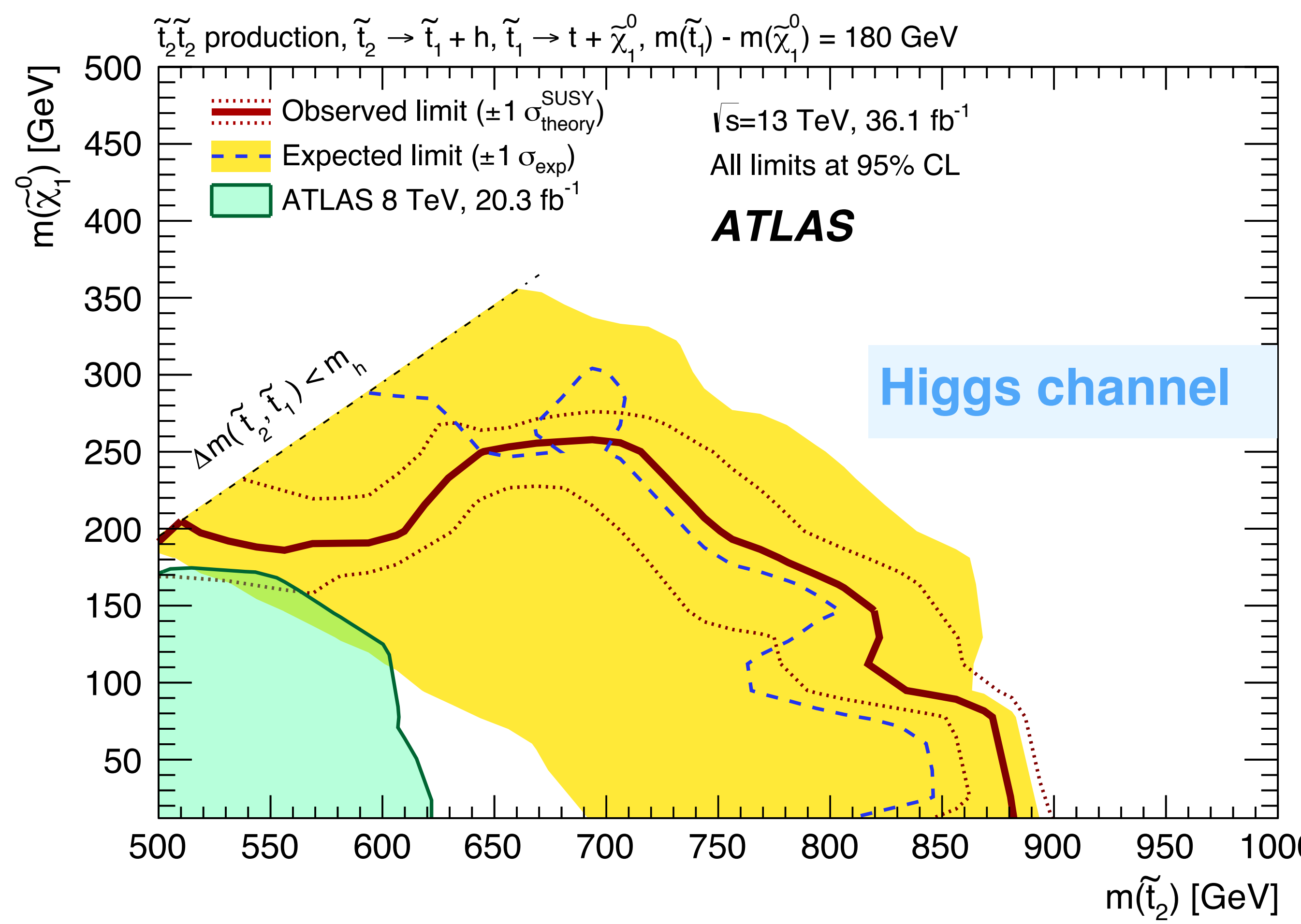


Another possible interpretation

- $\tilde{t}_2$ pair production
- **simplified model** BR =100%
  - important for compressed $\tilde{t}_1$ - $\tilde{\chi}_1^0$ scenarios







Conclusions

- Searches for top squarks based on full 2015+2016 data (36 fb-1) have given results **consistent with the SM expectations**.
- Limits on the 3rd generation squark masses close to 1 TeV for the most favorable scenarios

- The search for SUSY continues!
- Exciting results ahead with the full Run 2 dataset

Thank you for your attention

Backup

Tau Background MonteCarlo

Process	Matrix element	PDF set	Parton shower	PDF set	Tune
$t\bar{t}$	Powheg-Box v2	CT10	Pythia 6.428	CTEQ6L1	Perugia 2012
single top	Powheg-Box v1	CT10	Pythia 6.428	CTEQ6L1	Perugia 2012
$t\bar{t}H$	aMC@NLO 2.2.2	CT10	Herwig++ 2.7.1	CTEQ6L1	UE-EE-5
$t\bar{t}V$	aMC@NLO 2.3.3	NNPDF3.0 NLO	Pythia 8.210	NNPDF2.3 LO	A14
tWZ	aMC@NLO 2.3.2	NNPDF3.0 NLO	Pythia 8.210	NNPDF2.3 LO	A14
tZ	MadGraph5 2.2.1	CTEQ6L1	Pythia 6.428	CTEQ6L1	Perugia 2012
multi-top	MadGraph5 2.2.2	NNPDF2.3 LO	Pythia 8.186	NNPDF2.3 LO	A14
$V+$jets	Sherpa 2.2.1	NNPDF3.0 NNLO			
VV (1)	Sherpa 2.2.1	NNPDF3.0 NNLO			
VV (2)	Sherpa 2.1.1	CT10			
VVV	Sherpa 2.2.2	NNPDF3.0 NNLO			
SUSY	MadGraph5 2.2.3 and 2.3.3	NNPDF2.3 LO	Pythia 8.186, 8.205 or 8.210	NNPDF2.3 LO	A14