SEARCH FOR DIRECT TOP SQUARK WITH TWO LEPTONS IN THE FINAL STATE WITH THE ATLAS DETECTOR

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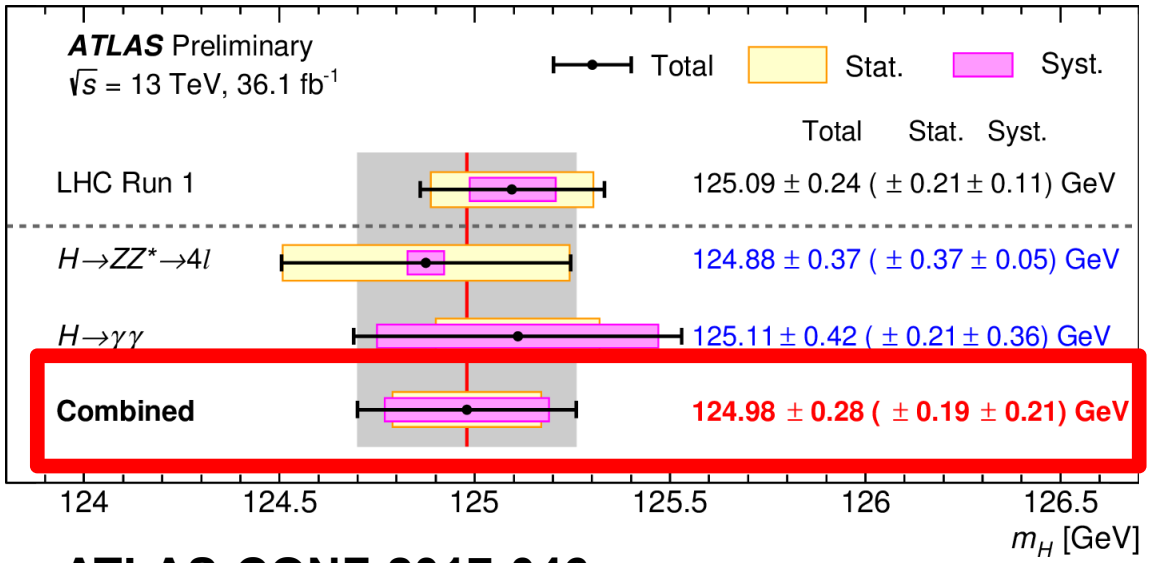
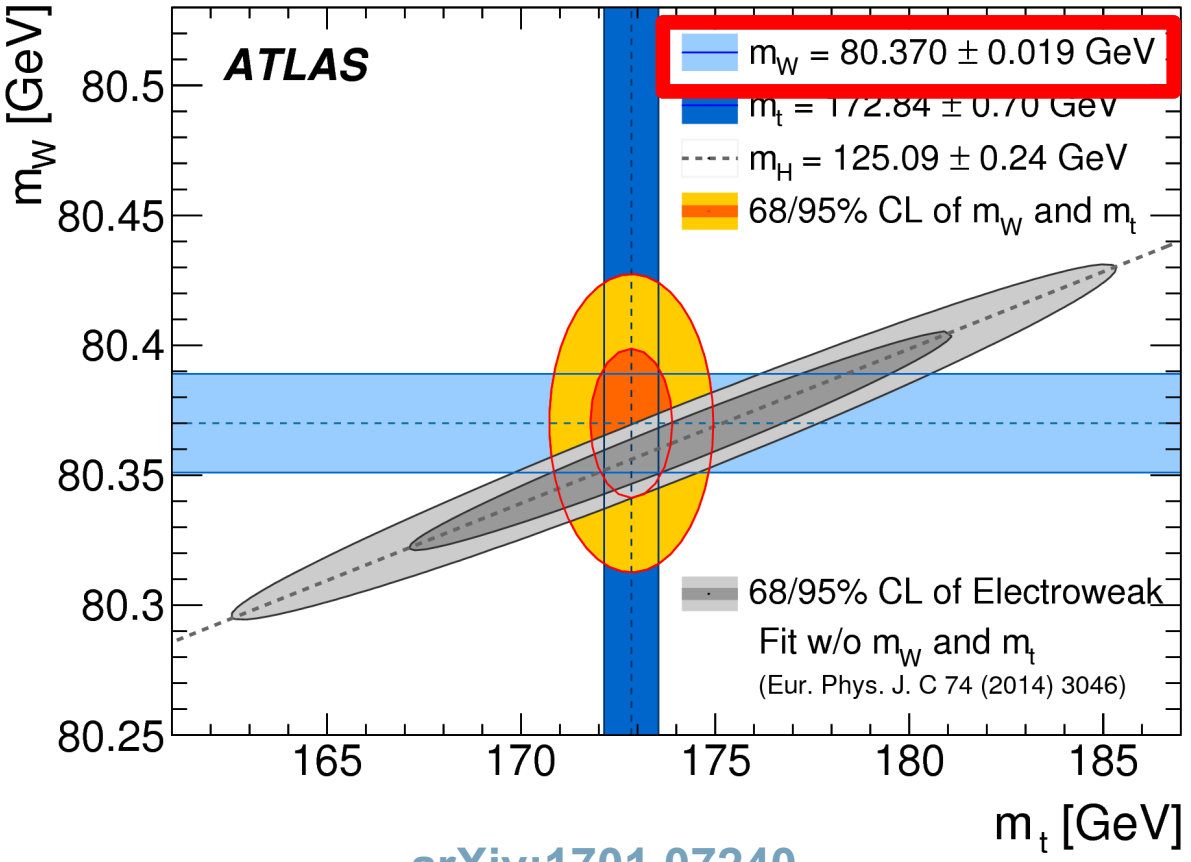
The Standard Model (SM)

The last particle of the Standard Model to be found was the Higgs Boson in 2012.



ATLAS-CONF-2017-046

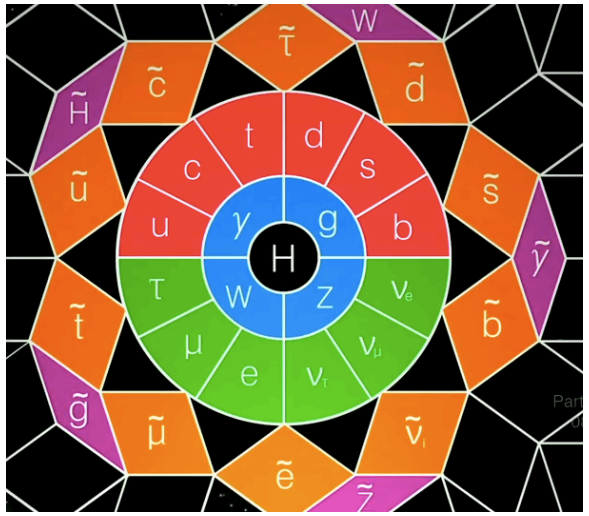


arXiv:1701.07240

No doubt about the solidity of the Standard Model.
But...

- Loop correction of the Higgs mass are divergent (major contribution coming from top quark)
- No candidate for DM
- Why matter >> anti-matter?

Supersymmetry (SUSY)

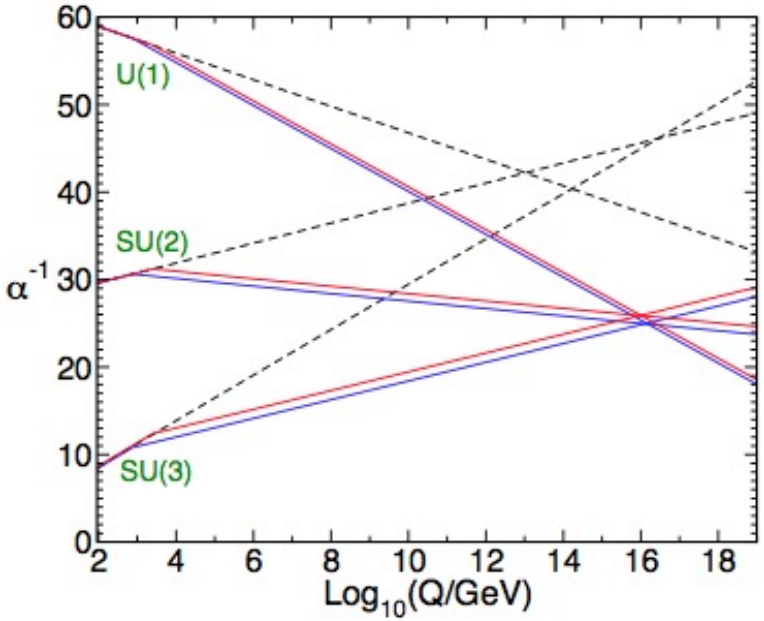


A natural way to provide solutions to the unanswered questions is

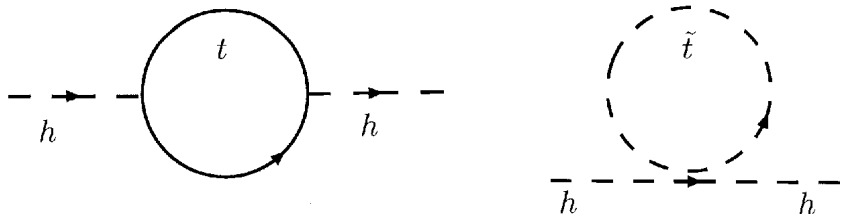
Supersymmetry.

It is a fundamental symmetry between fermions and boson introducing a partner for each SM particle with half-spin difference.

fermion (s = 1/2)	→	sfermion (s=0)
gauge bosons (s = 1)	→	gauginos (s = 1/2)
top quark	→	stop
bottom quark	→	sbottom



Top squark have opposite-sign loop correction of the Higgs mass.



If R-parity is conserved -> Lightest Supersymmetric Particle (LSP) is a Natural candidate for DM (Neutralino).

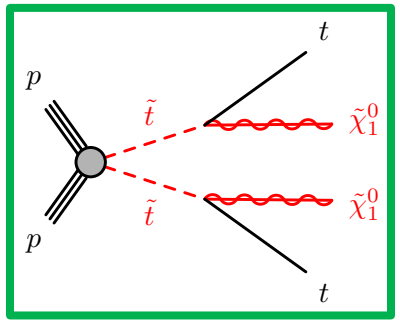
Unification of the gauge coupling at $M_{GUT} \sim 10^{16}$ GeV

Simplified Model

- Typically we are looking at the decay of the stop in a simplified model and considering only one final state ⇒ **2 Leptons Opposite Charge**
- 4 Different Scenarios

2-body decay.

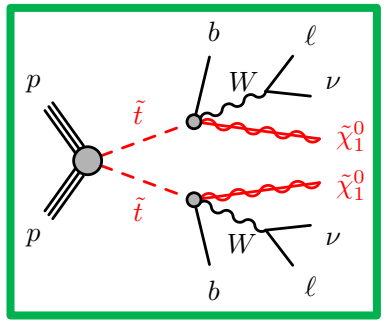
$\Delta m(t, \tilde{\chi}_1^0) > m_t$



3-body decay.

$\Delta m(t, \tilde{\chi}_1^0) > m_W + m_b$

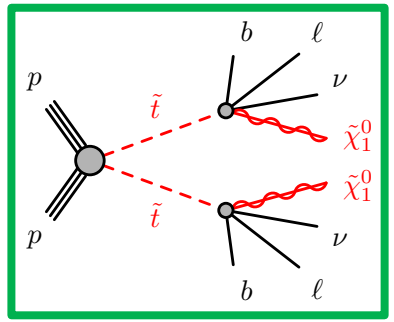
$\Delta m(t, \tilde{\chi}_1^0) < m_t$

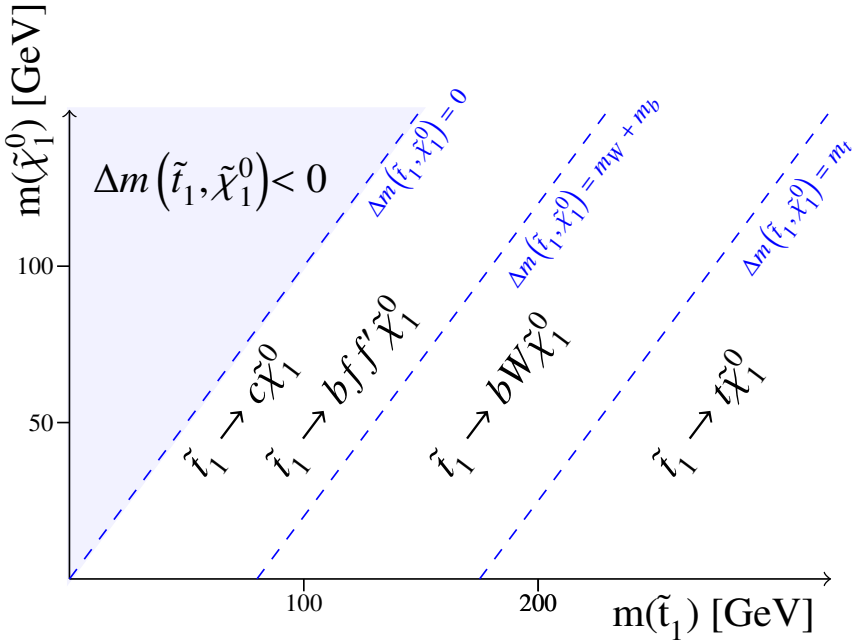


4-body decay.

$\Delta m(t, \tilde{\chi}_1^0) > 0$

$\Delta m(t, \tilde{\chi}_1^0) < m_W + m_b$

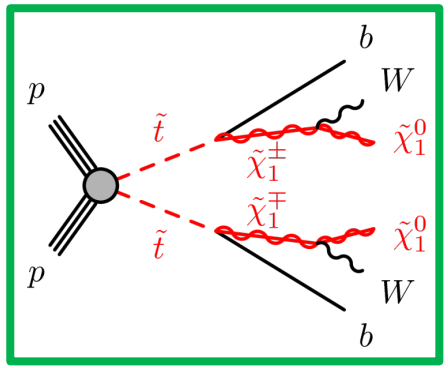




- 100% BR of decay of the stop into Neutralino

Decay chains can also be more complicated if additional particles are taken into account (e.g. charginos $\tilde{\chi}_1^{\pm}$)

- $\tilde{t}_1 \longrightarrow b + \tilde{\chi}_1^{\pm} \longrightarrow b + W^{\pm} + \tilde{\chi}_1^0$



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Signal Region Description

- After defining the signal model, Signal Regions (SR) are optimized based on the signal kinematic features by maximizing the discovery significance (Z_n)
- **11 Different SR** has been developed targeting different signal scenarios and kinematic regimes.
- Will focus on the one SR:

$$SR_{140}^{2-body}$$

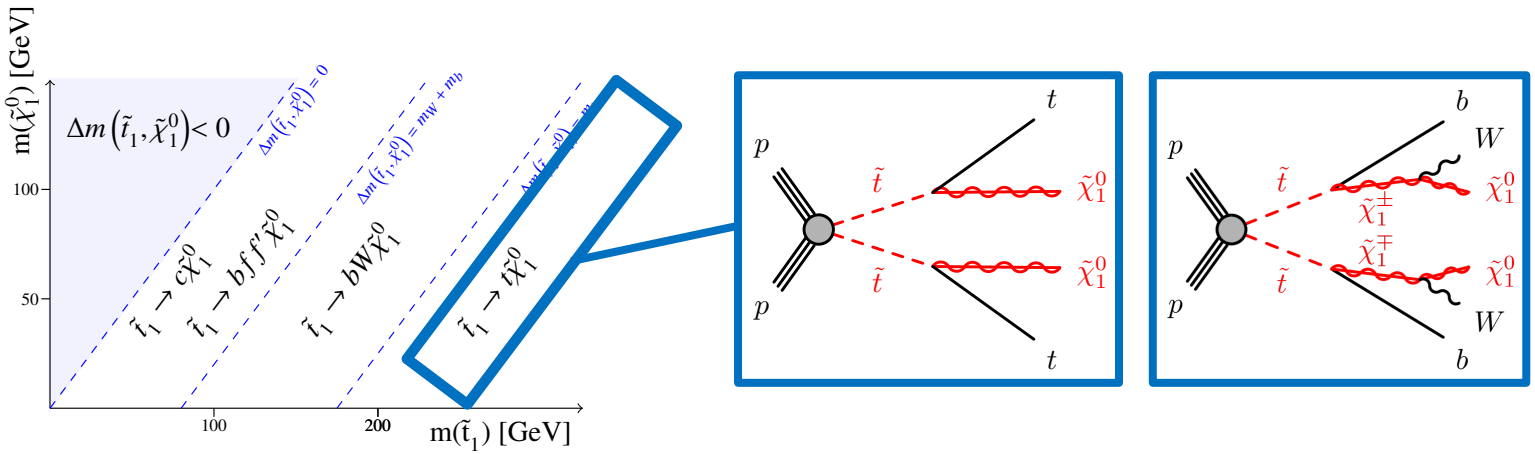
Target;

- $\tilde{t}_1 \longrightarrow t + \tilde{\chi}_1^0$ with large $\Delta m(t, \tilde{\chi}_1^0)$
- $\tilde{t}_1 \longrightarrow b + \tilde{\chi}_1^{\pm} \longrightarrow b + W + \tilde{\chi}_1^0$

$$\Delta\phi_{boost} = \Delta\phi(\boldsymbol{p}_T^{miss}, \boldsymbol{p}_{T,boost}^{ll})$$

$$\boldsymbol{p}_{T,boost}^{ll} = \boldsymbol{p}_T^{miss} + \boldsymbol{p}_T(l_1) + \boldsymbol{p}_T(l_2)$$

	$SRB_{140}^{2\text{-body}}$	
Lepton flavour	SF	DF
$p_T(\ell_1), p_T(\ell_2)$ [GeV]	$> 25, > 20$	
$m_{\ell\ell}$ [GeV]	[20, 71.2] or > 111.2	> 20
$\Delta\phi_{boost}$	< 1.5	
n_{jets}	≥ 2	
$n_{b\text{-jets}}$	≥ 1	
E_T^{miss} [GeV]	–	
$m_{T2}^{\ell\ell}$ [GeV]	> 140	



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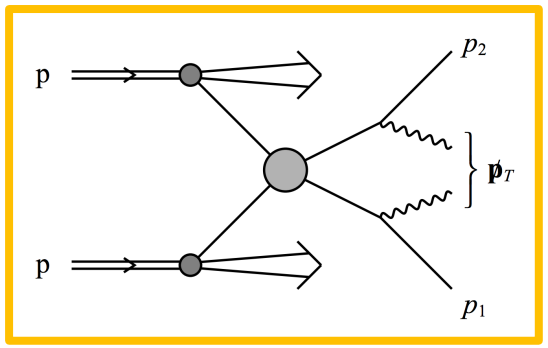
Signal Region Description

The final discriminating variables the stransverse mass (m_{T2}).

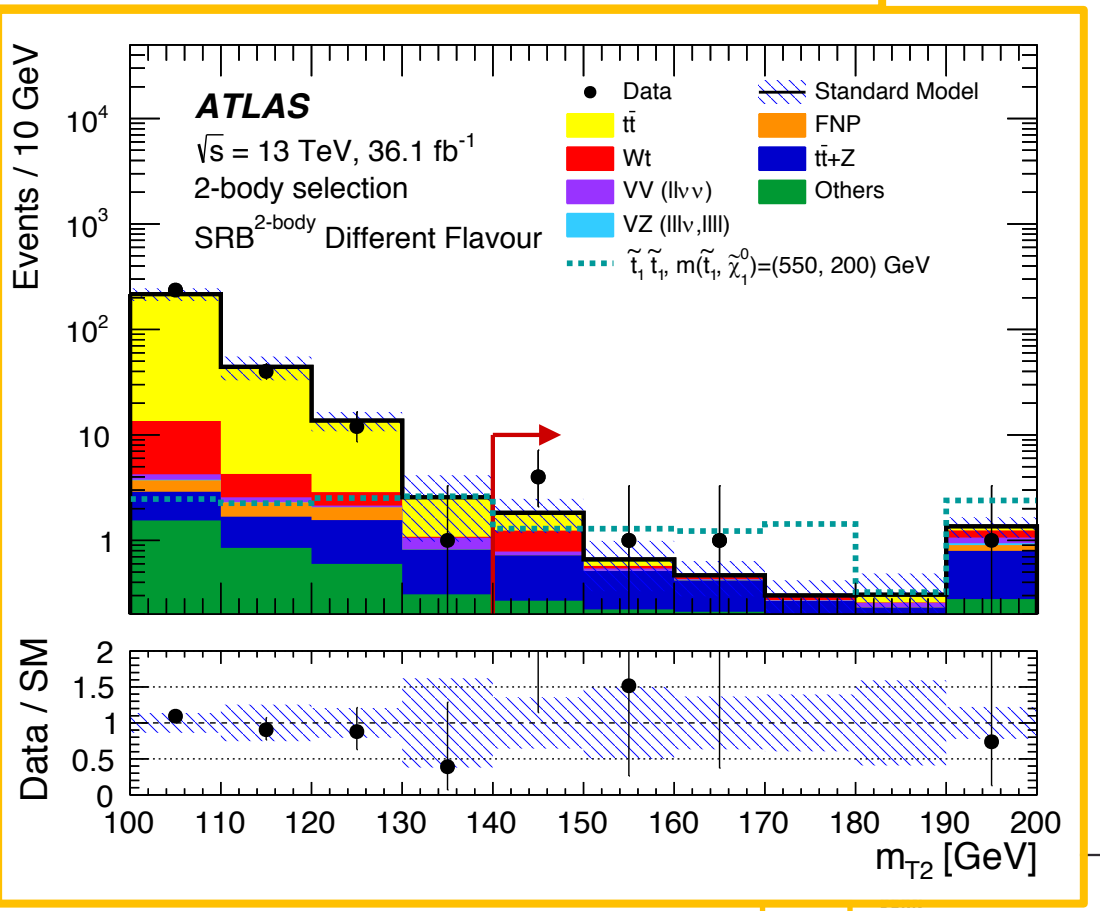
Generalization of the transverse mass in event for multi-invisible body decays.

Most of SM Backgrounds bound by the W mass, while signal extend above that

$$m_{T2}^2(\vec{p}_T^{\,l_1}, \vec{p}_T^{\,l_2}, \vec{p}_T^{\,\mathrm{miss}}) = \min_{\vec{p}_T^{\,\mathrm{miss1}} + \vec{p}_T^{\,\mathrm{miss2}} = \vec{p}_T^{\,\mathrm{miss}}} \max(m_T^2(p_T^{\,l_1}, \vec{p}_T^{\,\mathrm{miss1}}), m_T^2(p_T^{\,l_2}, \vec{p}_T^{\,\mathrm{miss2}}))$$



	$\mathrm{SRB}_{140}^{2\text{-body}}$
Lepton flavour	SF DF
$p_T(\ell_1), p_T(\ell_2)$ [GeV]	> 25, > 20
$m_{\ell\ell}$ [GeV]	[20, 71.2] or > 111.2 > 20
$\Delta\phi_{\mathrm{boost}}$	< 1.5
n_{jets}	≥ 2
$n_{b\text{-jets}}$	≥ 1
E_T^{miss} [GeV]	
$m_{T2}^{\ell\ell}$ [GeV]	> 140



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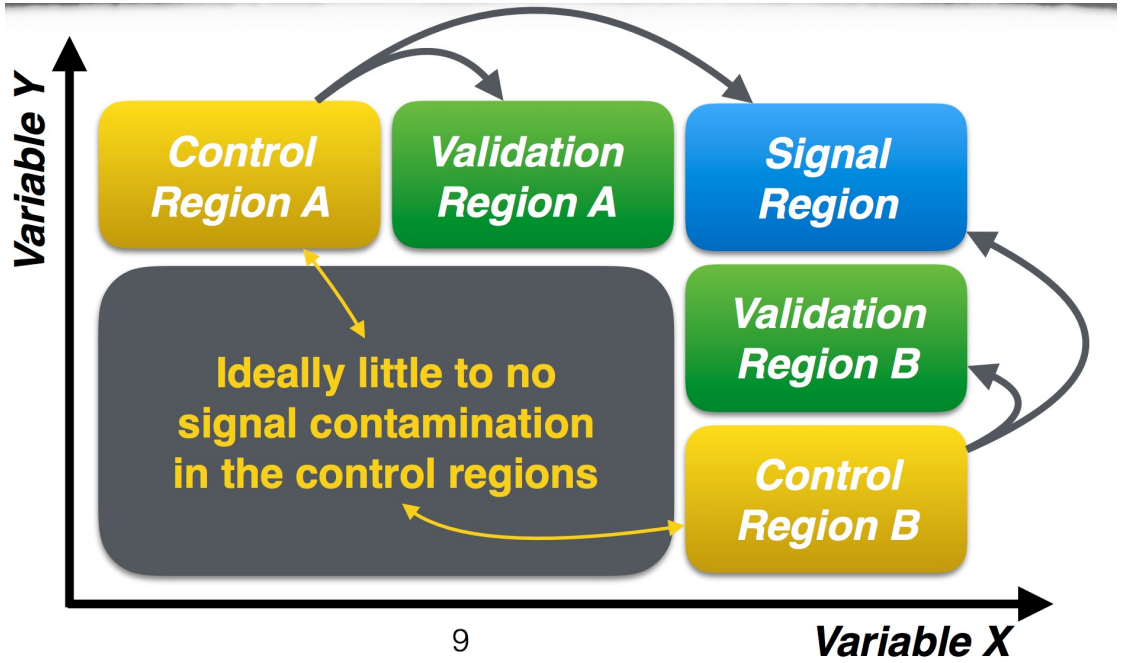
Background Measurement

- (Semi-)Data-driven approaches when possible



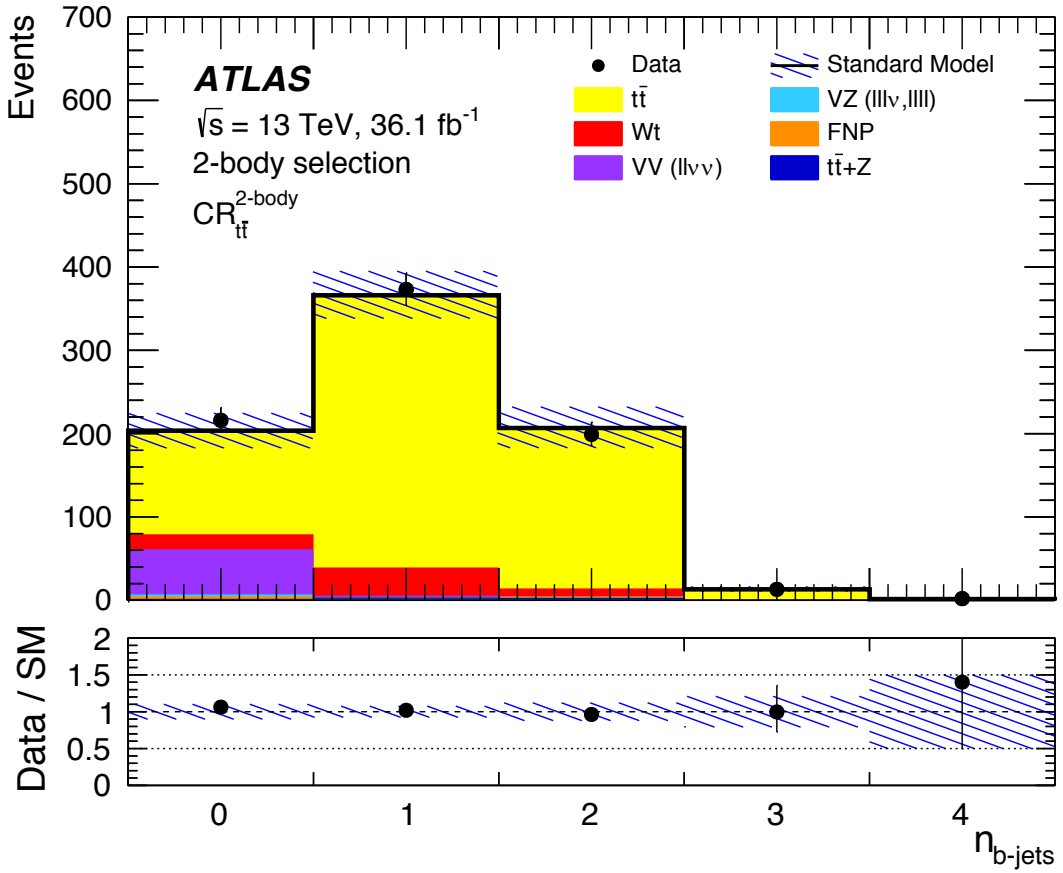
- Typical SUSY background measurement approach:
  - For each important process (e.g. $t\bar{t}$) define a representative control region (CR) rich of that process.
  - Fit the background to data simultaneously in all CRs to get the scale factors (SF) defined as

$$\mu_1 = \frac{n_{DATA}^{obs} - n_{MC}^{other}}{n_{MC}^{1}}$$

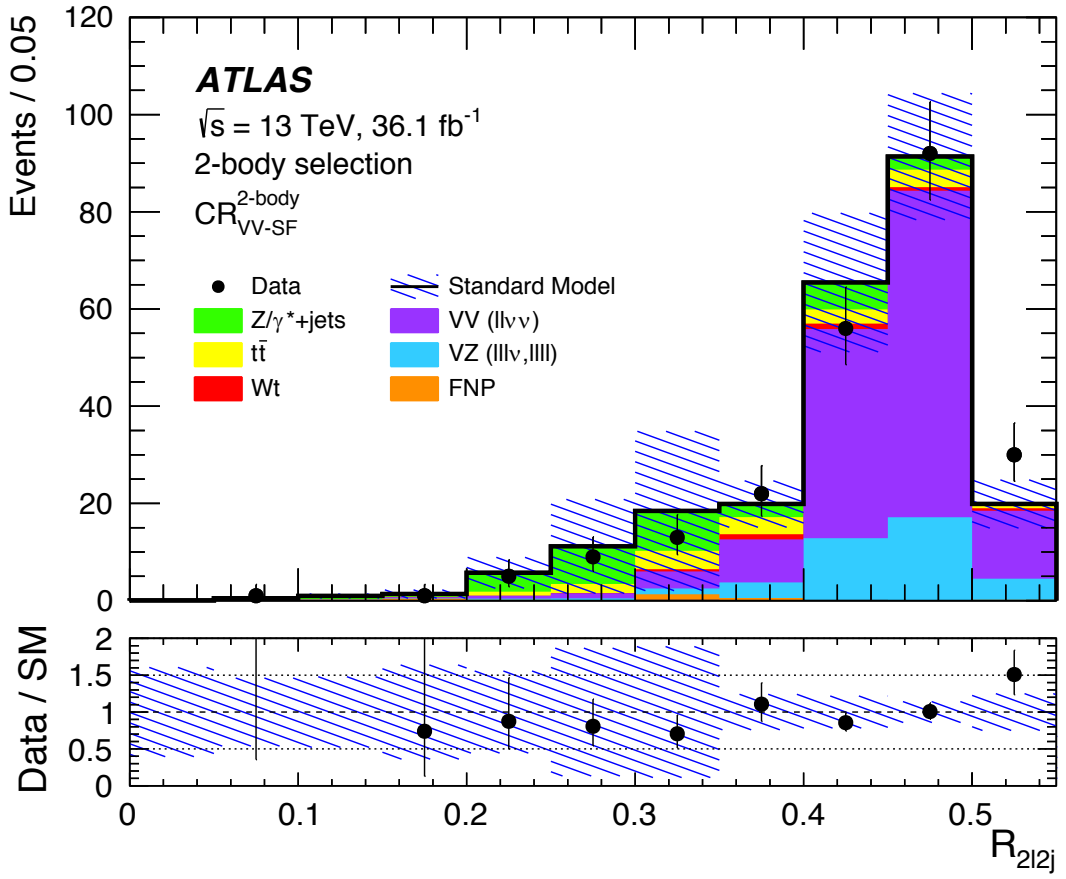
  - Validate these SFs in the validation regions (VR) then use them in the SRs
  - Discovery limits using profiled likelihood fits avoiding constraining of systematics

Background estimation

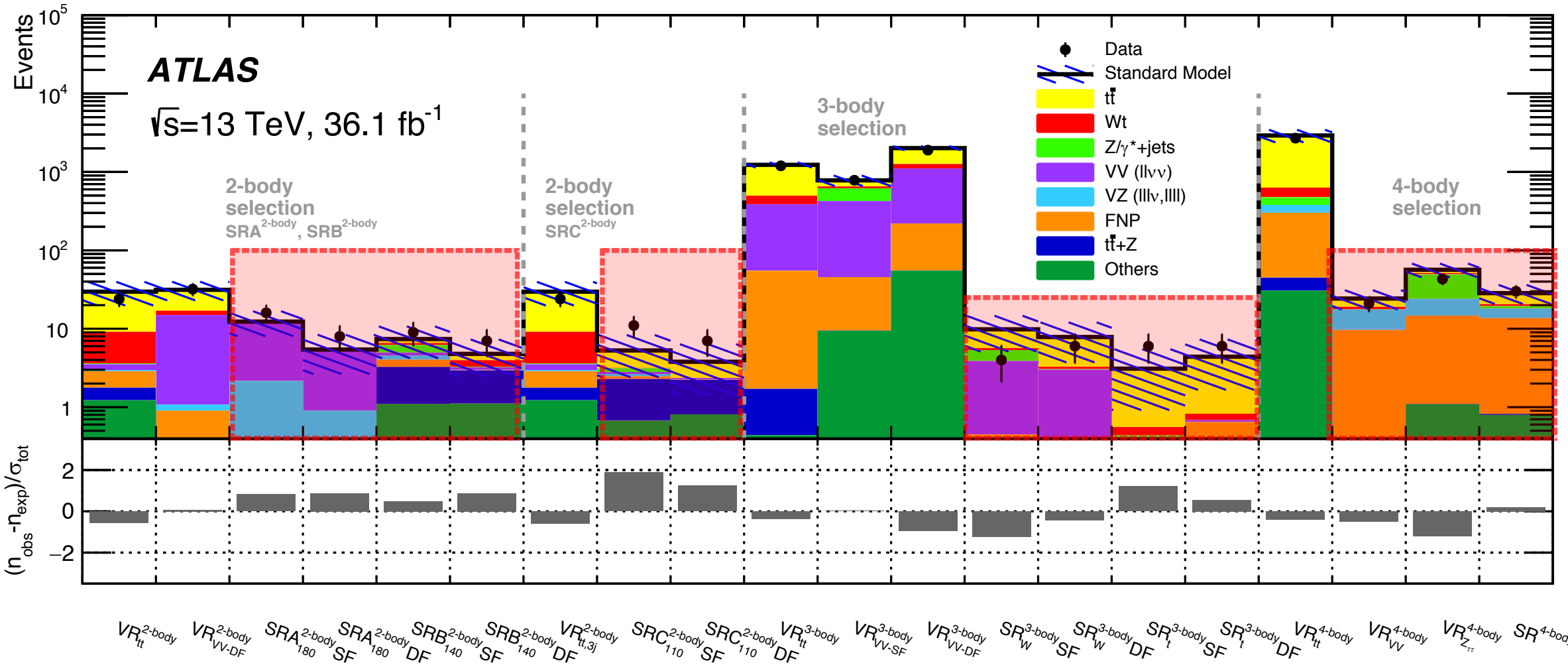
- e.g. for SR_{140}^{2-body} 4 SF are used to control $t\bar{t}$, Diboson, $t\bar{t}Z$, and VZ process
- Kinematic distributions in the $t\bar{t}$ and $Diboson$ CRs



$$R_{2l2j} = \frac{E_T^{miss}}{E_T^{miss} + \boldsymbol{p}_T(l_1) + \boldsymbol{p}_T(l_2) + \boldsymbol{p}_T(j_1) + \boldsymbol{p}_T(j_2)}$$

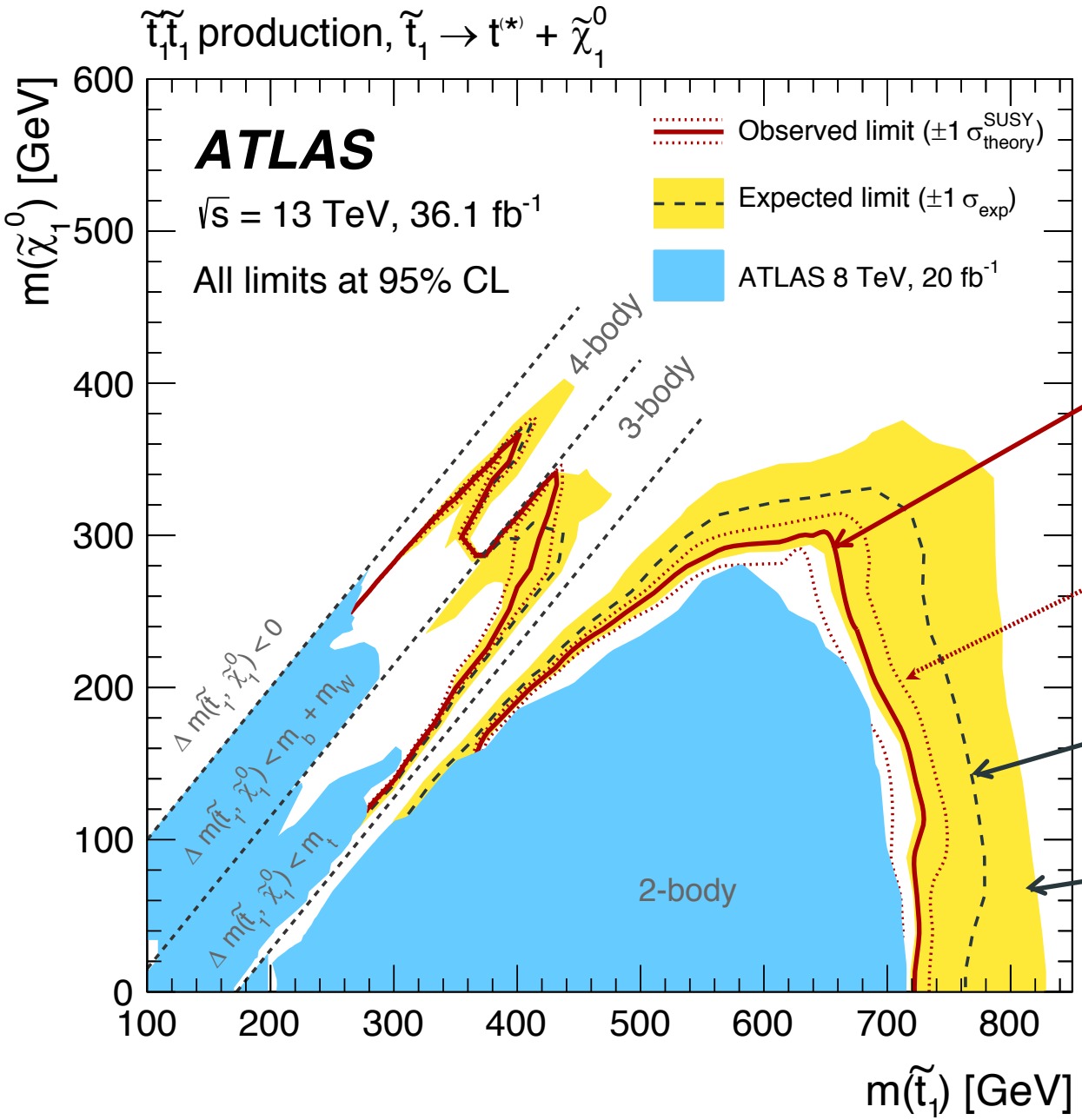


Results



No significant excess has been found.
Interpret results placing limits on signal on signal production.

Interpretation



Observed limit with nominal signal yield

Observed limit with $\pm\ 1\ \sigma_{theory}$ shifted signal yield

Expected limit with nominal signal yield

$\pm 1\ \sigma_{exp}$ uncertainty on the Expected limit

Conclusion

- ✓ The search for direct pair production of top squarks in events 2 leptons in the final state is reported.
- ✓ Several decay modes have been analyzed
- ✓ No significant excess has been found
- ✓ Limits on top squarks have been set as function of the $\tilde{t}_1$ and $\tilde{\chi}_1^0$ masses:
  - $\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0$
    - top squaks masses excluded up to 720 GeV for massless neutralino
    - neutralino masses excluded up to 300 GeV for $m_{\tilde{t}_1} = 645$ GeV
  - $\tilde{t}_1 \rightarrow b + W^{\pm} + \tilde{\chi}_1^0$
    - top squarks masses excluded up to 430 GeV for $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \sim m_W$
  - $\tilde{t}_1 \rightarrow b + f + f' + \tilde{\chi}_1^0$
    - top squarks masses excluded up to 400 GeV for $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \sim 40$ GeV

That result and more can be found in the very recently EPJC submitted paper (https://arxiv.org/abs/1708.03247).

Backup

arxiv:1607.08307

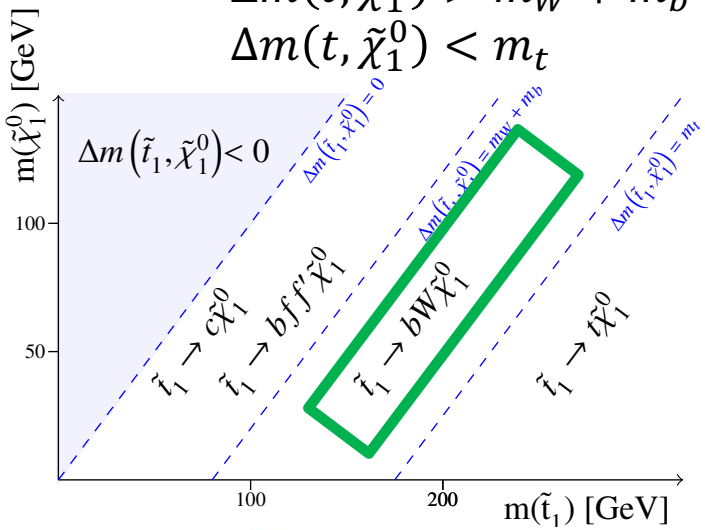
Signal Region Description

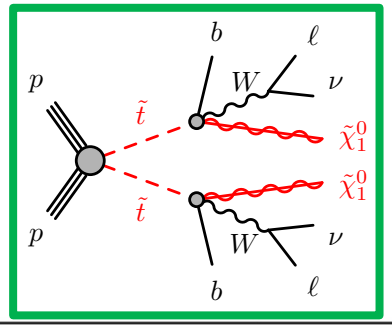
This is the SR targeting the 3 Body decay mode

SR^{3-body}

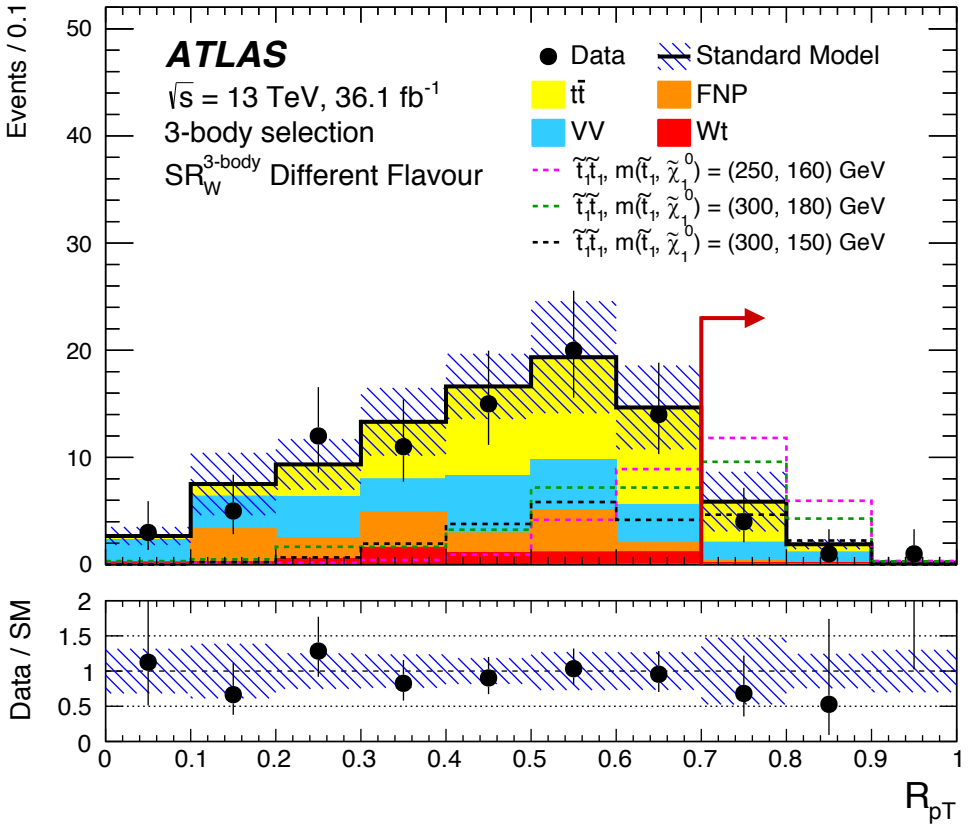
Target;

- $\tilde{t}_1 \longrightarrow b + W + \tilde{\chi}_1^0$ with
  $\Delta m(t, \tilde{\chi}_1^0) > m_W + m_b$
  $\Delta m(t, \tilde{\chi}_1^0) < m_t$





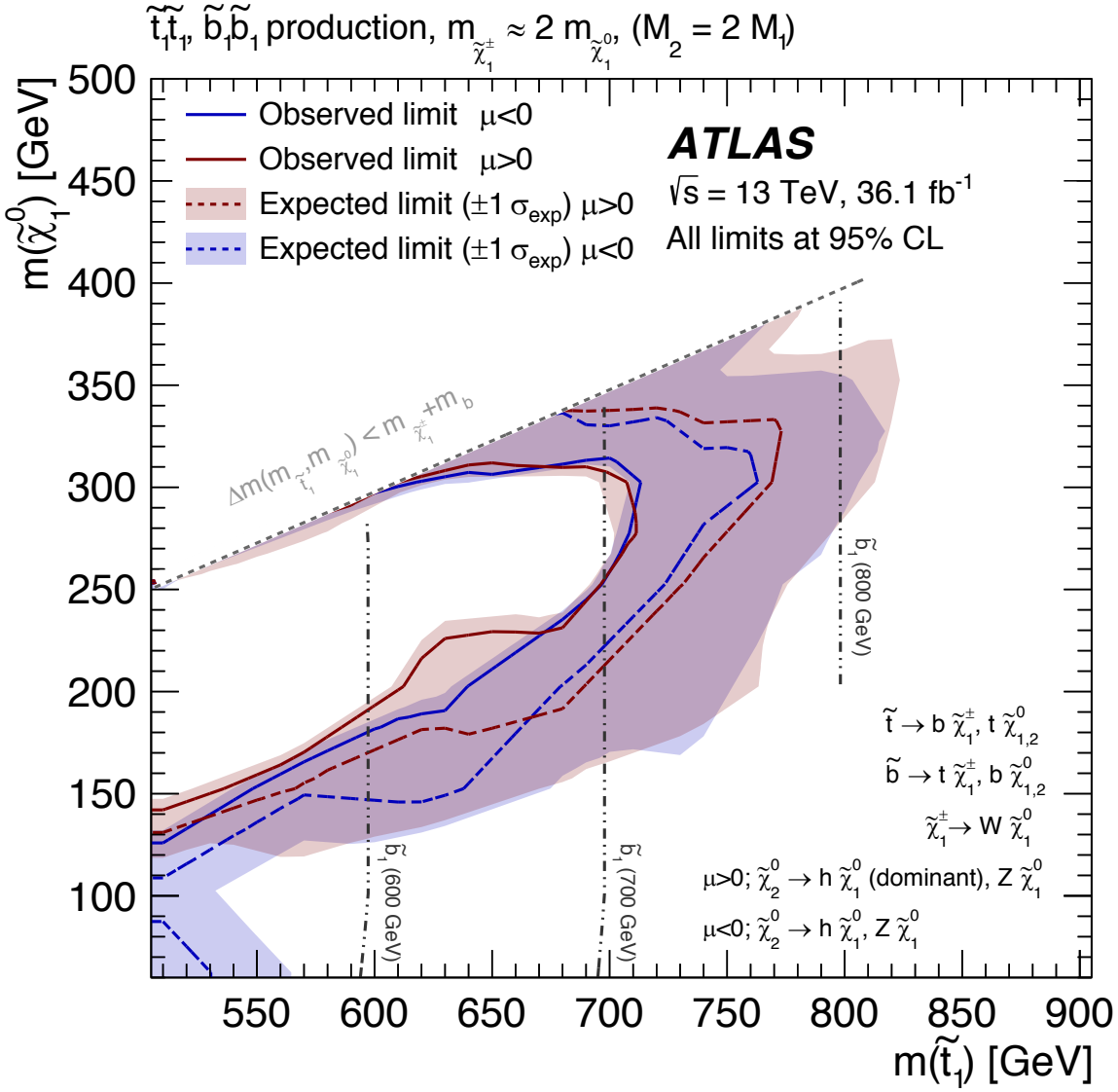
	$SR_W^{3\text{-body}}$
Lepton flavour	SF DF
$p_T(\ell_1), p_T(\ell_2)$ [GeV]	> 25, > 20
$m_{\ell\ell}$ [GeV]	[20, 71.2] or > 20 > 111.2
$n_{b\text{-jets}}$	= 0
M_Δ^R [GeV]	> 95
R_{p_T}	> 0.7
$1/\gamma_{R+1}$	> 0.7
$\Delta\phi_\beta^R$	$> 0.9\lvert\cos\theta_b\rvert + 1.6$



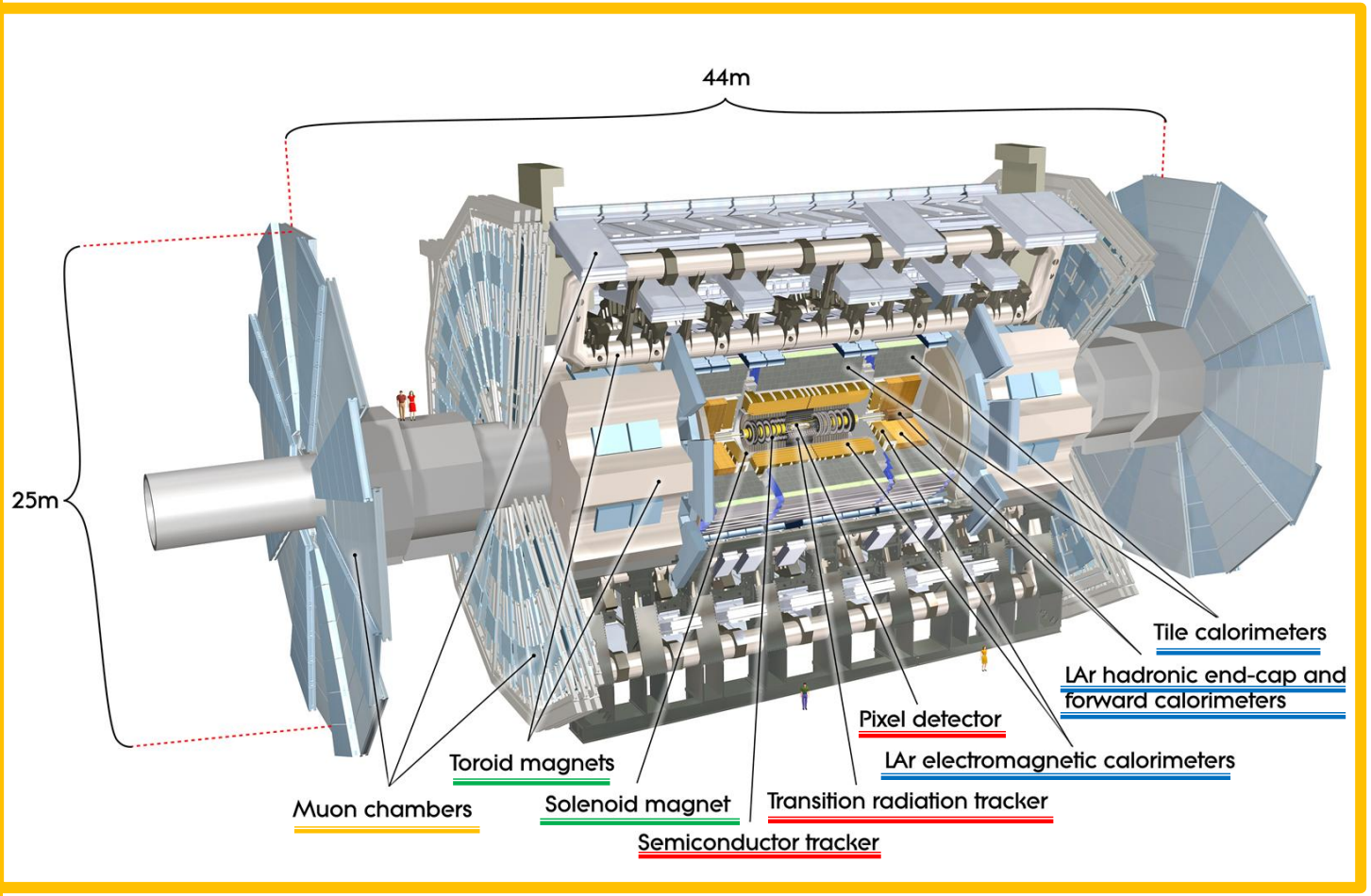
$R_{pT} = \frac{|\vec{J}_T|}{|\vec{J}_T| + \sqrt{\hat{s}_R}/4|}$ where $\vec{J}_T$ is the vector sum of the visible particles and $\mathbf{p}_T^{miss}$ and $\sqrt{\hat{s}_R}$ is a measure of the system's energy in the razor frame

$M_\Delta^R = \frac{\sqrt{\hat{s}_R}}{\gamma_{R+1}}$ has a kinematic end-point proportional to the mass-splitting between the parent particle and the invisible particle

Phenomenological MSSM



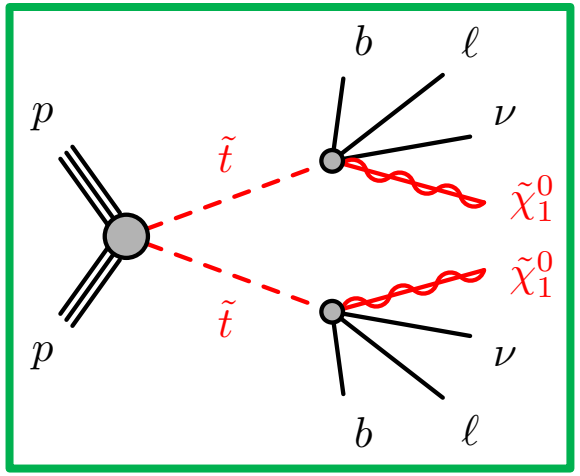
ATLAS Detector

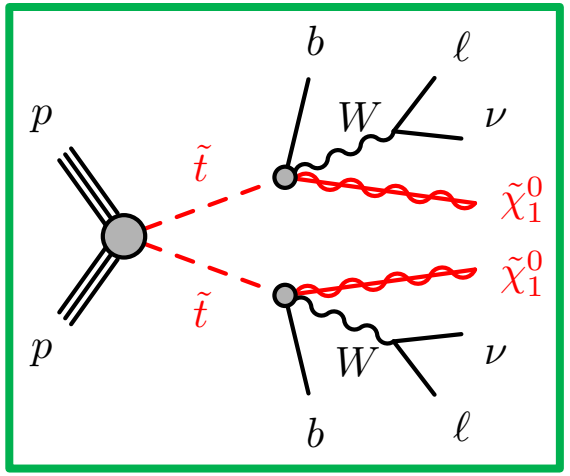


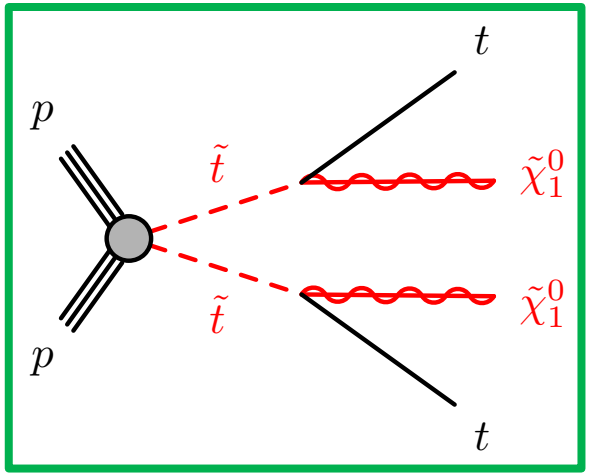
- ATLAS is a general purpose experiment:
  1. Overall efficiency for each particles (electrons, hadrons, muons).
  2. High acceptance ~ 4π
  3. Excellent identification performance.

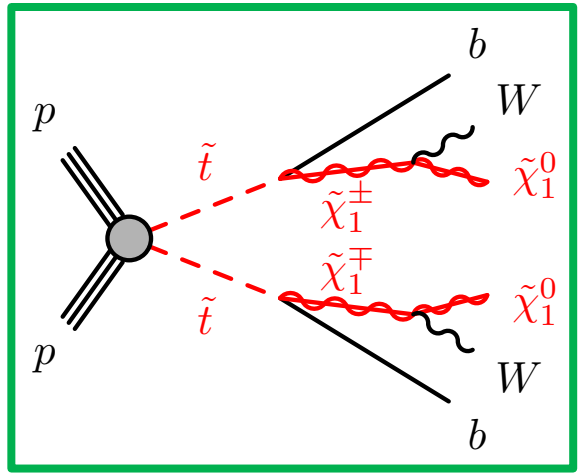
- Inner tracker
- Calorimetric System (Electromagnetic + hadronic)
- Muon System
- Magnet

Search Strategy









6 Signal Region targeting different final states with
2 LEPTONS (electron or muon) + (b-) jets + Missing transverse energy

Table 2: *Two-body selection* signal region definitions.

	$SRA^{2\text{-body}}_{180}$		$SRB^{2\text{-body}}_{140}$		$SRC^{2\text{-body}}_{110}$	
Lepton flavour	SF	DF	SF	DF	SF	DF
$p_T(\ell_1), p_T(\ell_2)$ [GeV]	$> 25, > 20$		$> 25, > 20$		$> 25, > 20$	
$m_{\ell\ell}$ [GeV]	> 111.2	> 20	[20, 71.2] or > 111.2	> 20	[20, 71.2] or > 111.2	> 20
$R_{2\ell 2j}$	> 0.3	–	–		–	
$R_{2\ell}$	–		–		> 1.2	
Δx	< 0.07		–		–	
$\Delta\phi_{\text{boost}}$	–		< 1.5		–	
n_{jets}	–		≥ 2		≥ 3	
$n_{b\text{-jets}}$	$= 0$		≥ 1		≥ 1	
E_T^{miss} [GeV]	–		–		> 200	
$m_{T2}^{\ell\ell}$ [GeV]	> 180		> 140		> 110