Search for top squarks with the ATLAS detector

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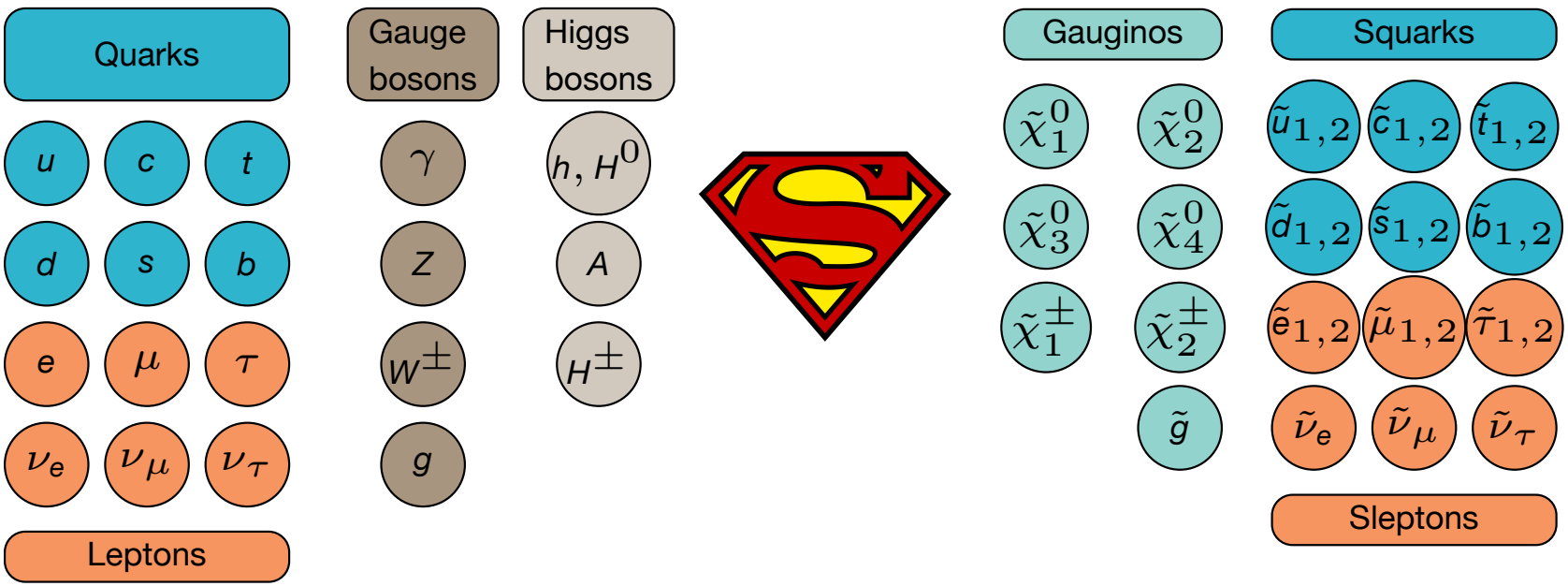
MAX-PLANCK-GESELLSCHAFT

Why searching for Supersymmetry?

Shortcomings of the Standard Model

- Dark Matter candidate
- Neutrino masses
- Unification of gauge couplings
- Hierarchy problem
- Quantum Gravity (10d string theory)



$\rightarrow$ Supersymmetry can explain all those questions

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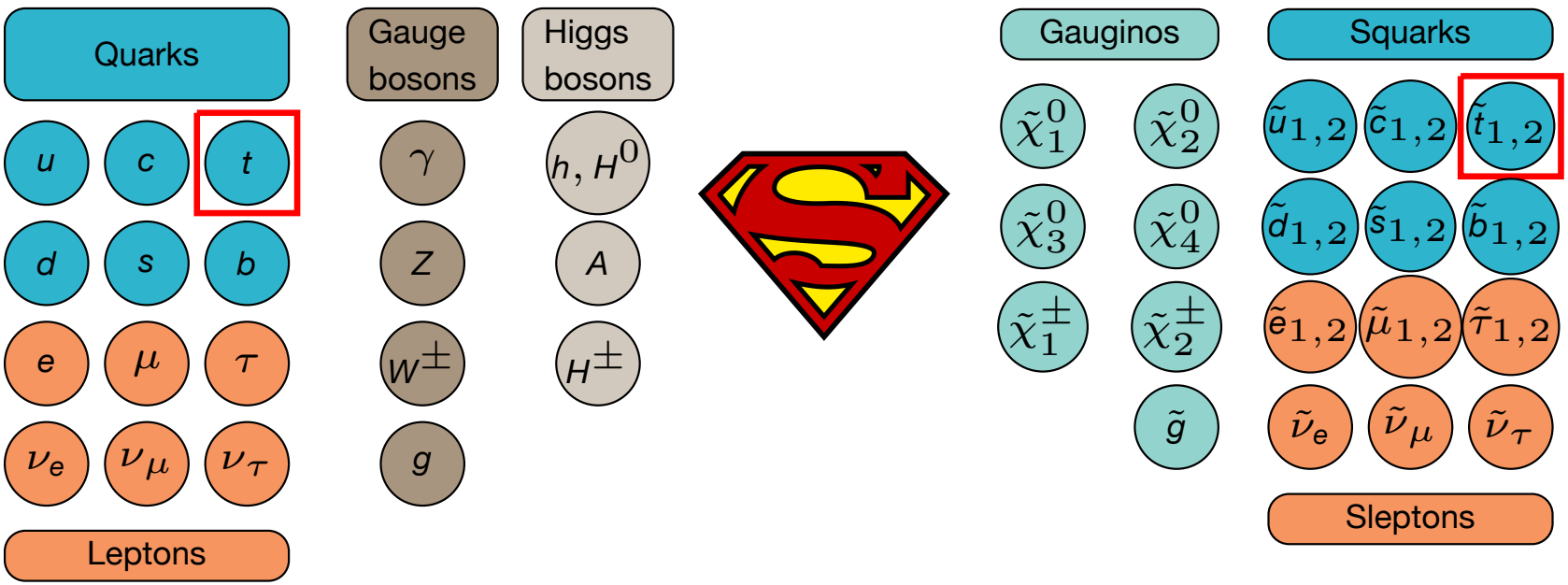


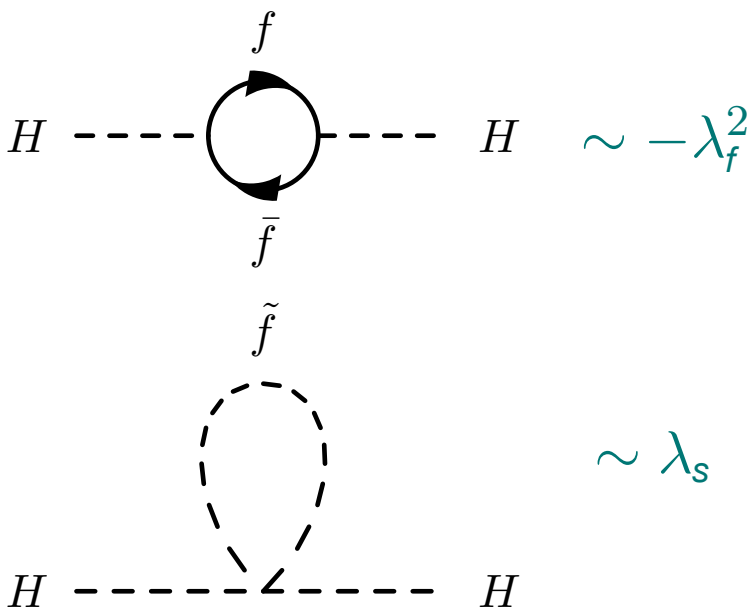
$\rightarrow$ Supersymmetry can explain all those questions

Why searching for top squarks at the LHC?

Why searching for top squarks at the LHC?

The Higgs is unnaturally light!

$m_H = 125\,\text{GeV}$
with $m_H^2 = (m_H^2)_{\text{bare}} + \delta m_H^2$



$\to$ Fermionic and scalar contributions cancel exactly if SUSY is unbroken

Remaining contribution after SUSY breaking:

$$\delta m_H^2 \sim -y_t^2 m_{stop}^2 \ln\left(\frac{\Lambda}{m_{stop}}\right)$$
(one-loop-level)

where Λ is the energy scale up to which the theory is renormalizable

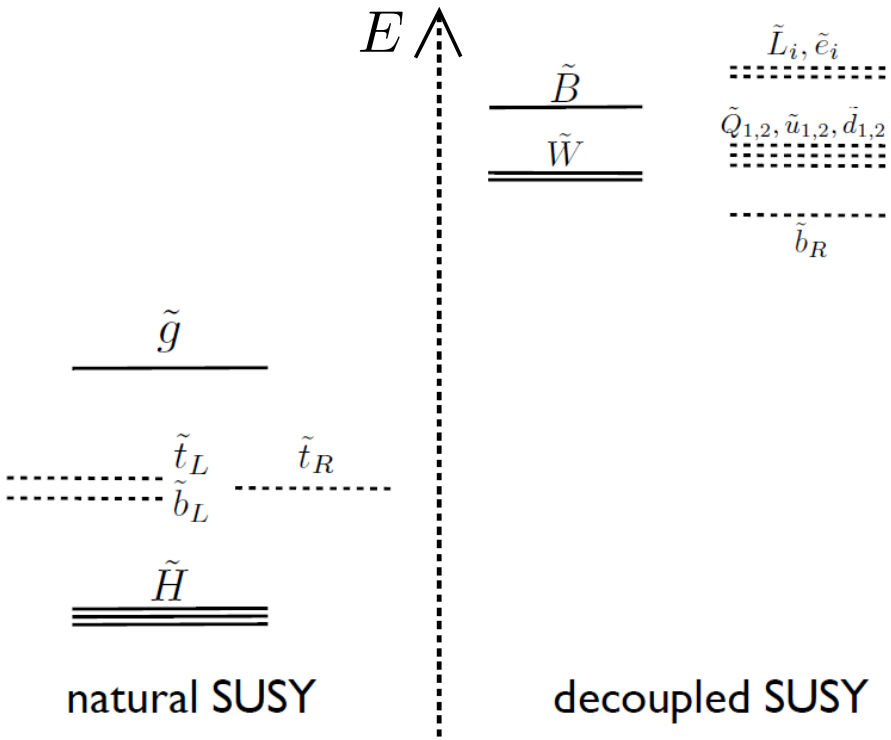
$\to$ m_{stop} should be in the TeV range

Simulated SUSY processes

- The MSSM has 105 free parameters

→ Use simplified models where $m_{\tilde{t}}$, $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_1^\pm}$ are in the TeV range, but the other sparticles are decoupled with higher masses

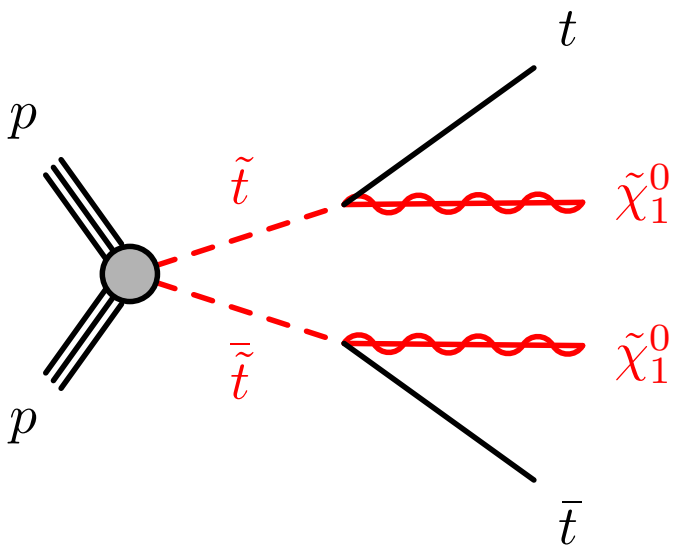
- Stops described by these models are accessible to searches at the LHC
- Assume R-parity conservation
- Assume $m_{\tilde{t}_2} \gg m_{\tilde{t}_1}$

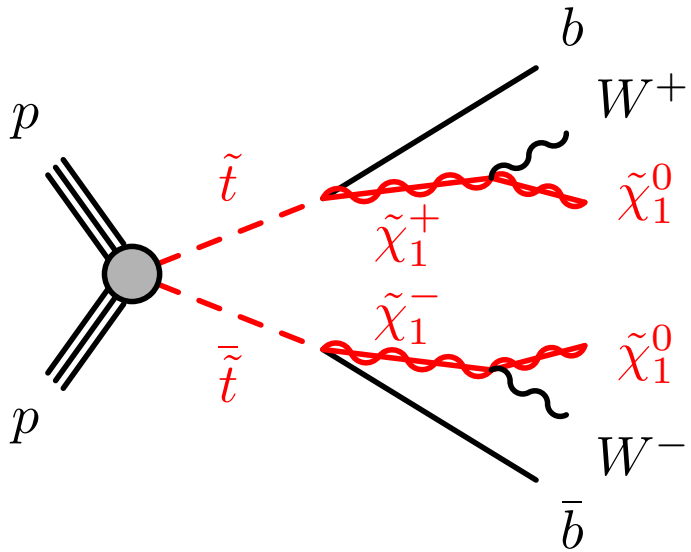


JHEP 1209 (2012) 035

Top squark ($\tilde{t}_1$) decays

Assume only 2 decays are possible:

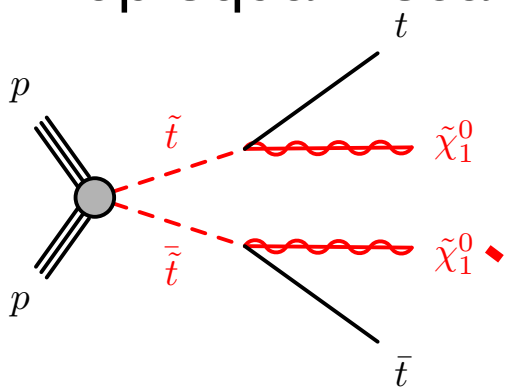


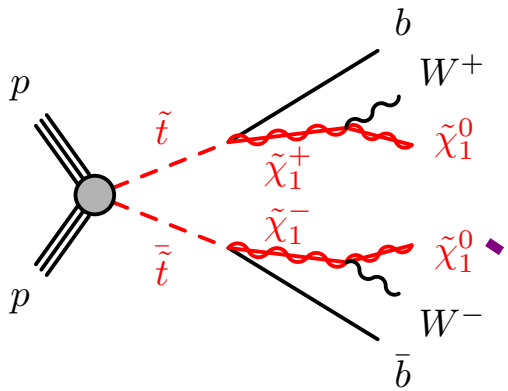


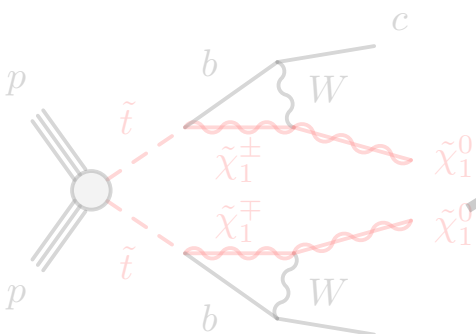
$$\mathcal{BR}(\tilde{t} \to t + \tilde{\chi}_1^0) = 1 - \mathcal{BR}(\tilde{t} \to b + \tilde{\chi}_1^{\pm})$$

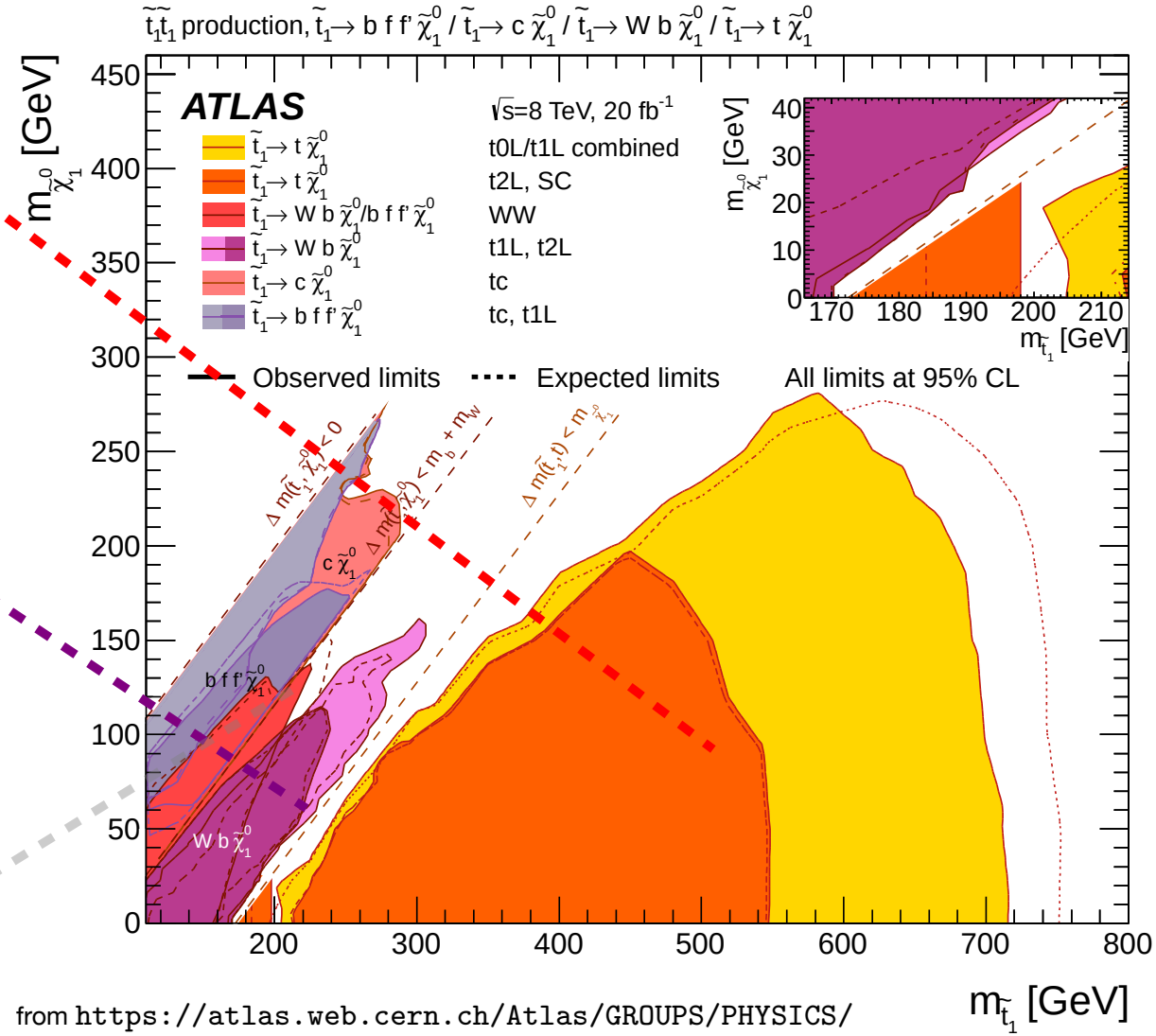
$\to$ Search for signatures with either 0, 1 or 2 Leptons

Top squark searches in ATLAS during LHC Run 1



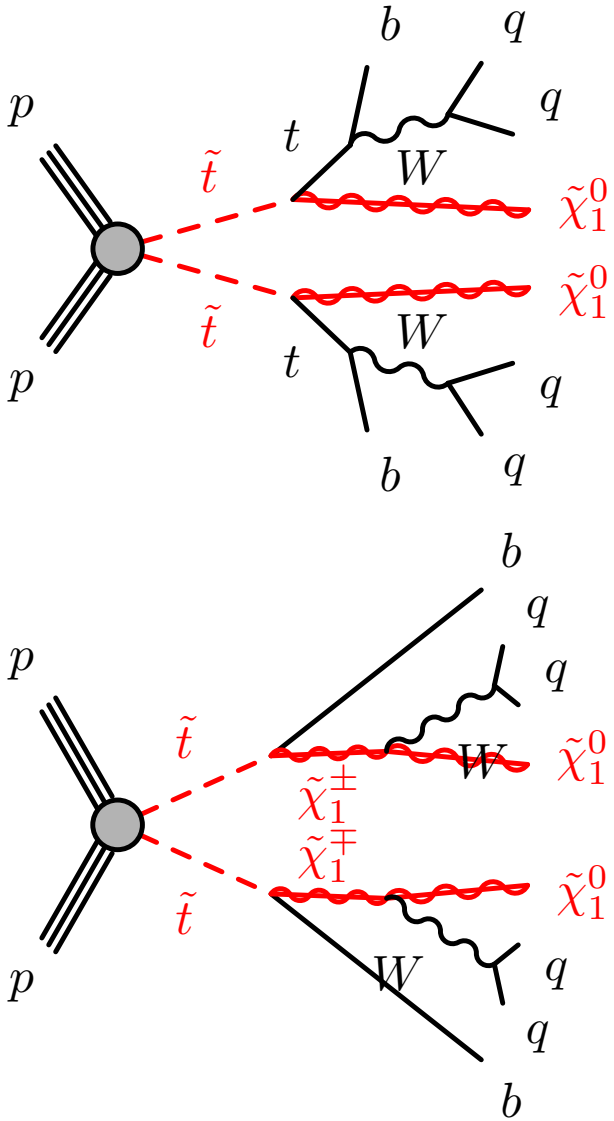






from `https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/index.html`

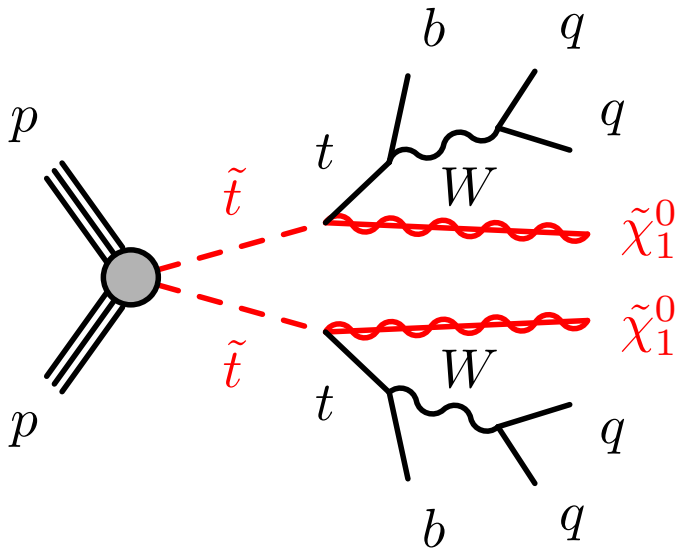
The full-hadronic decay channel ($\tilde{t} \to bqq\tilde{\chi}_1^0$)



- Lepton veto leads to good background suppression
- Remaining backgrounds:
  - -- $t\bar{t}$+Z ($Z \to \nu\nu$)
  - -- Z+jets ($Z \to \nu\nu$)
  - -- $t\bar{t} \to bbqq\ell\nu$ (missing the ℓ)
- Full reconstruction of top quark due to full-hadronic W-decay

$\to$ Both $\tilde{t} \to t + \tilde{\chi}_1^0$ and $\tilde{t} \to b + \tilde{\chi}_1^{\pm}$ are accessible

Select events of interest



- Veto against leptons
- Large missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$)
- At least 4 jets ($R = 0.4$) with $p_{\mathrm{T}} > (80, 80, 40, 40)\,\mathrm{GeV}$
- At least 2 b-jets

$\to$ Reconstruct top quark

$+$ More discriminating variables

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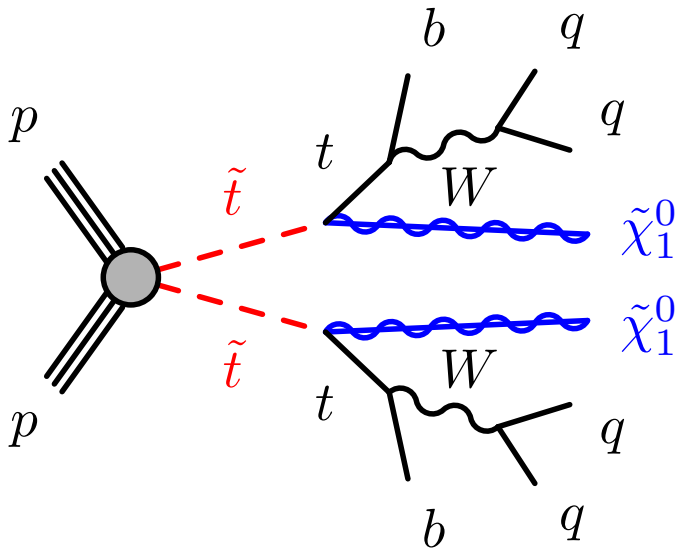

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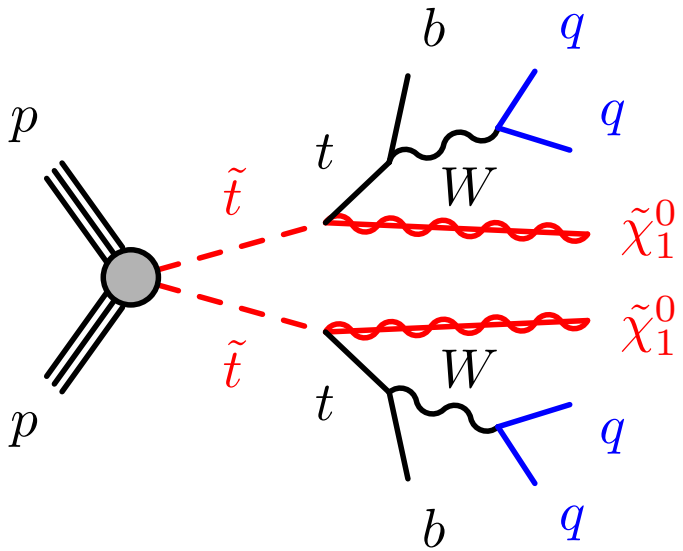

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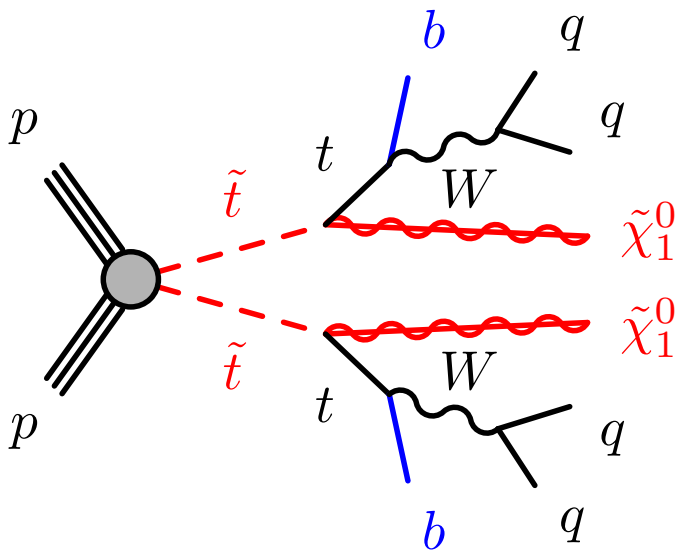

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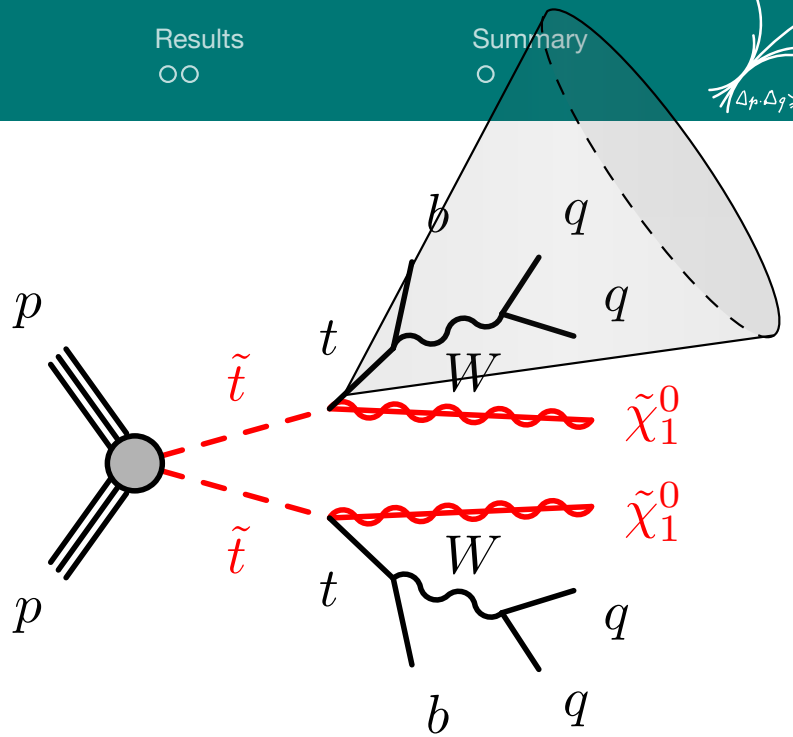

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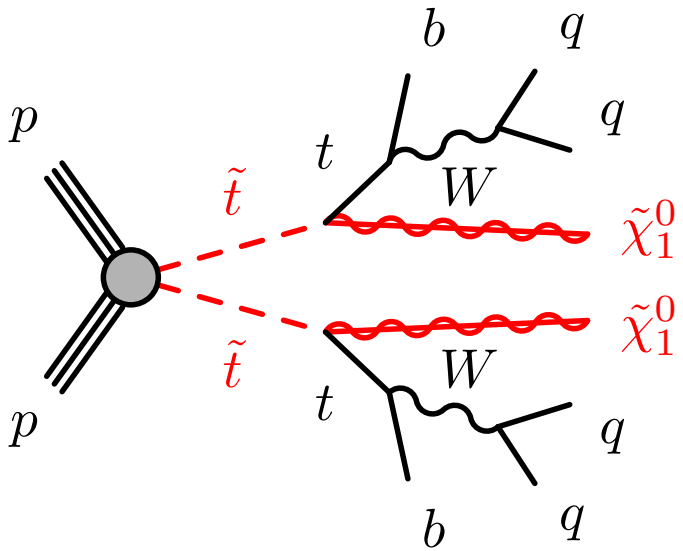

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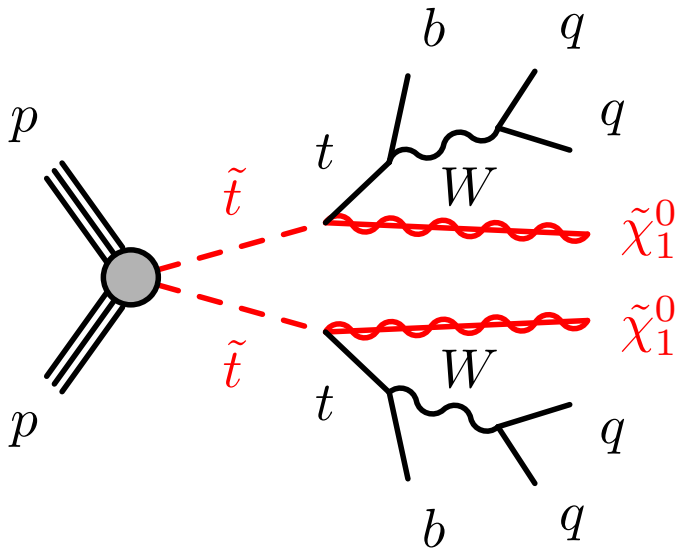

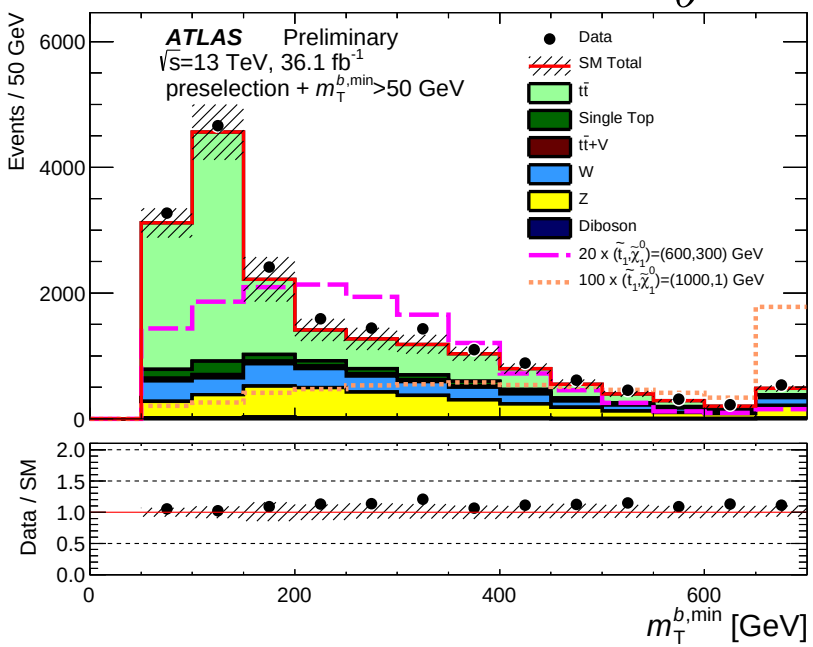

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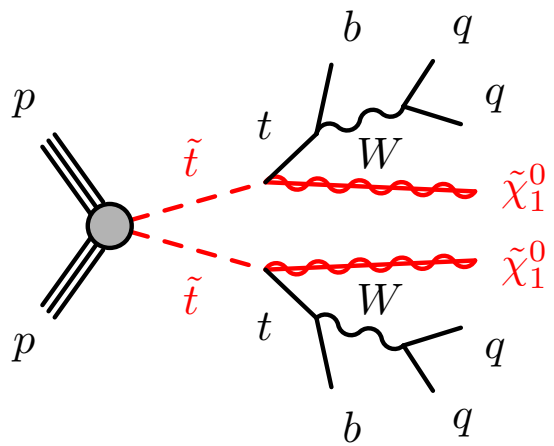
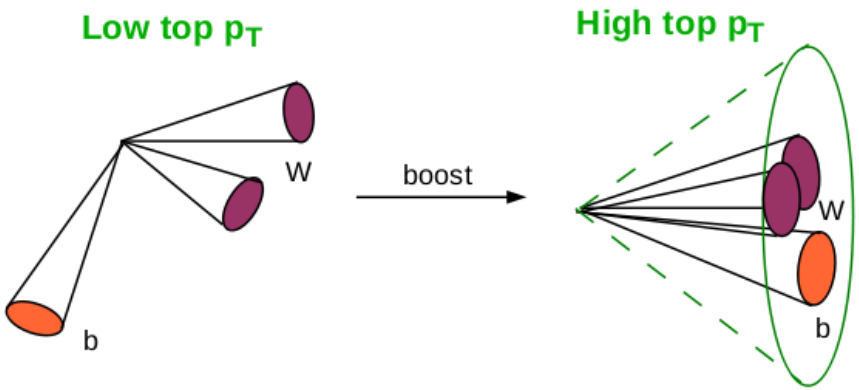
Reconstruct top quarks: Jet reclustering

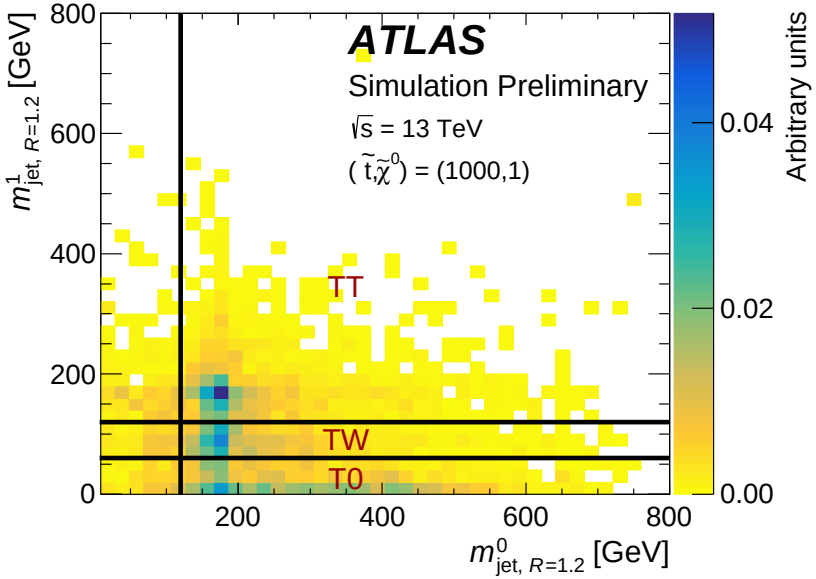


- Higher centre-of-mass energy can lead to strongly boosted final state objects
- Full-hadronic top quark decay products can be collimated

→ Use **large-R**(adius) **jets** ($R = 1.2$)



http://www.quantumdiaries.org/author/emily-thompson/



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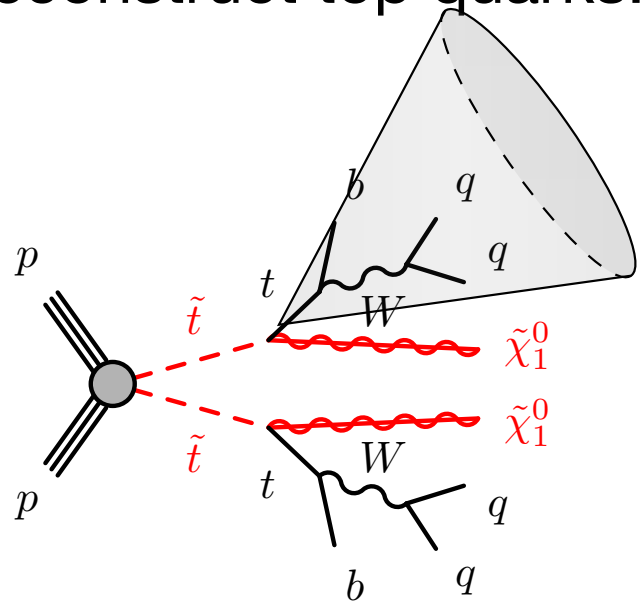

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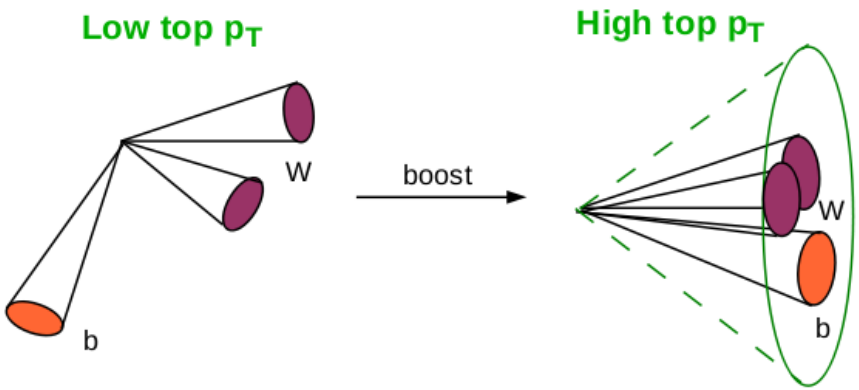

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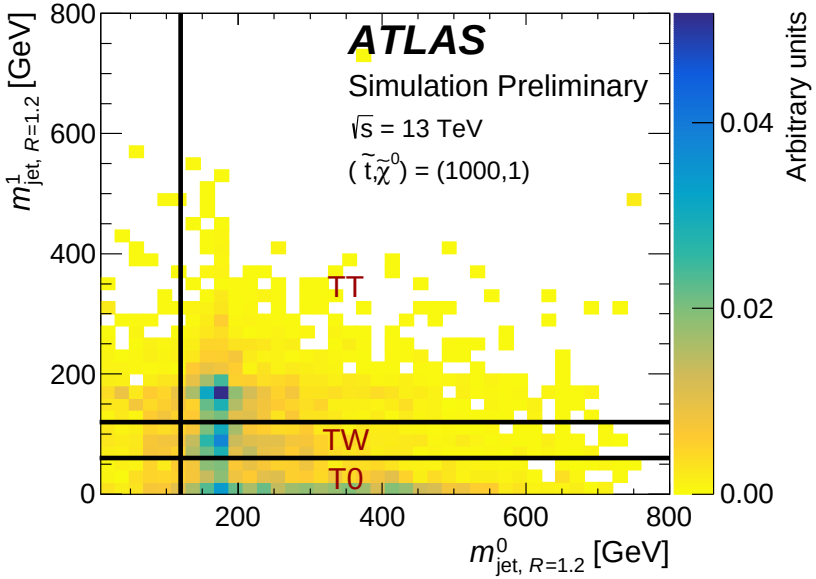

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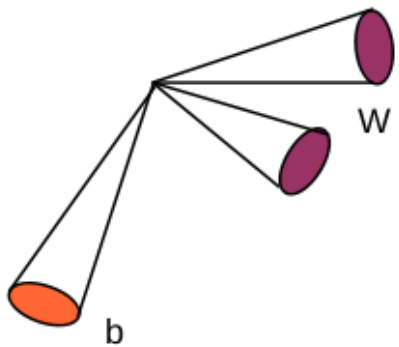
Reconstruct top quarks: χ^2-method

- Minimize $\left|\frac{m_{jj} - m_{W^\pm}}{m_{W^\pm}}\right|$ for all jet pairs jj

$\rightarrow$ Define $W^\pm$ candidates

- Minimize $\left|\frac{m_{bW^\pm} - m_t}{m_t}\right|$ for all b-jet $W^\pm$ pairs

$\rightarrow$ Define top quark candidates



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- Minimize $\left|\frac{m_{jj}-m_{W^\pm}}{m_{W^\pm}}\right|$ for all jet pairs *jj*

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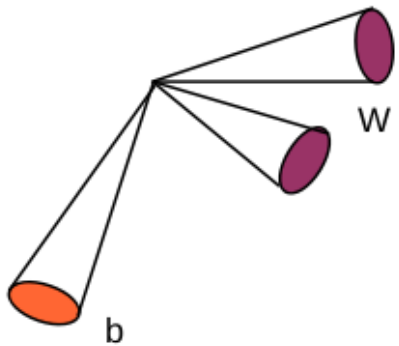
- Minimize $\left|\frac{m_{bW^\pm}-m_t}{m_t}\right|$ for all *b*-jet $W^\pm$ pairs

$\to$ Define top quark candidates

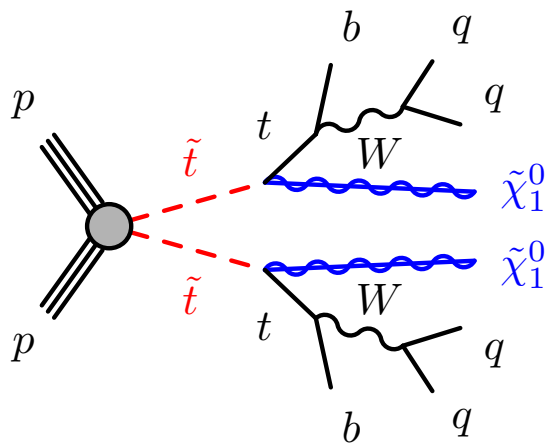


Reconstruct top **s**quarks:

- Both $\tilde{\chi}_1^0$ of $\tilde{t} \to t + \tilde{\chi}_1^0$ decays contribute to $E_{\mathrm{T}}^{\mathrm{miss}}$
- $m_{\mathrm{T2}}^2 = \min_{q_1+q_2=E_{\mathrm{T}}^{\mathrm{miss}}} \left\{\max\left\{m_{\mathrm{T}}^2(q_1,t), m_{\mathrm{T}}^2(q_2,\bar{t})\right\}\right\}$

  splits $E_{\mathrm{T}}^{\mathrm{miss}}$ into 2 $\tilde{\chi}_1^0$

$\to$ Top squark candidates are build



After applying all cuts to supress SM backgrounds

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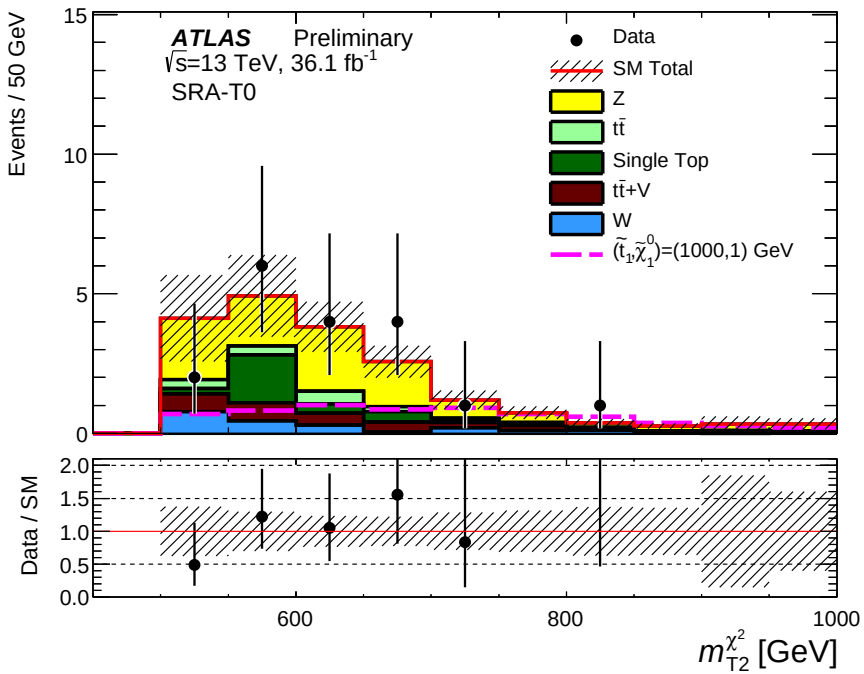
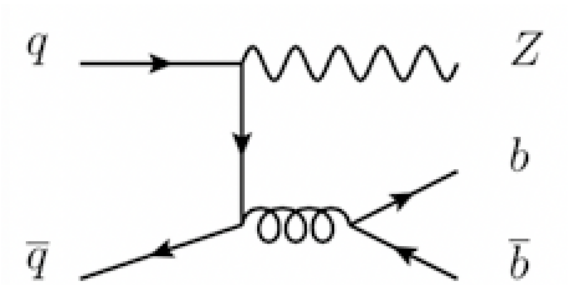
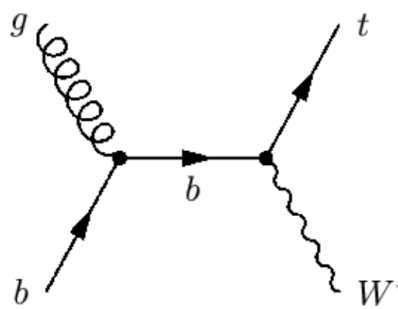


Out of >6 billion recorded events:

Observed data events	18
Total SM	18.7± 5.40
Z+jets	9.8± 3.90
Single top	2.9± 3.10
$t\bar{t}+W/Z$	2.61± 0.64
W+jets	2.0± 0.96
$t\bar{t}$	1.31± 0.71
Multijets	0.12± 0.07

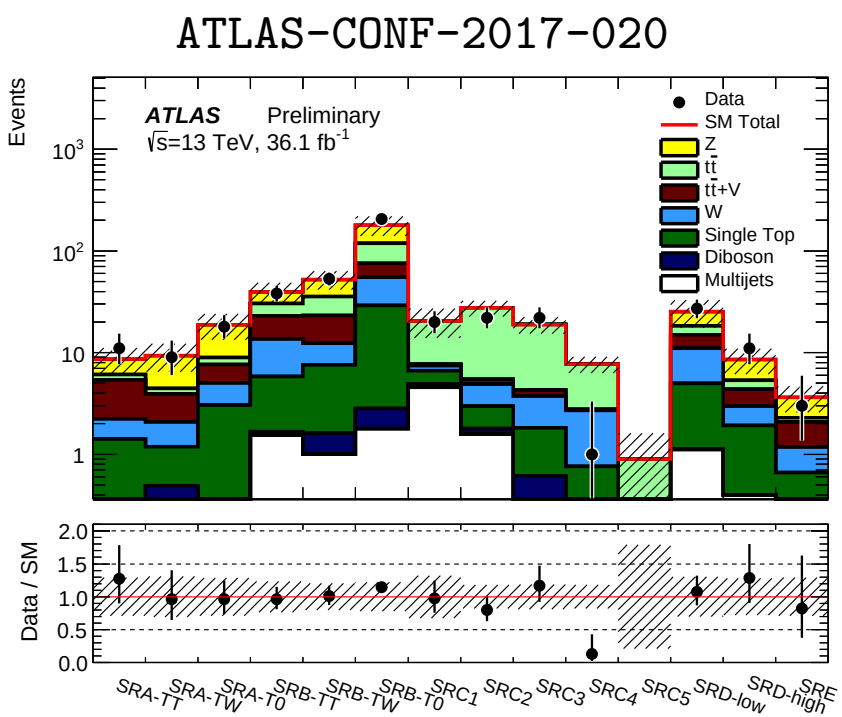
→ No excess over SM expectation found





→ Use data-driven methods to estimate SM backgrounds

Set exclusion limits



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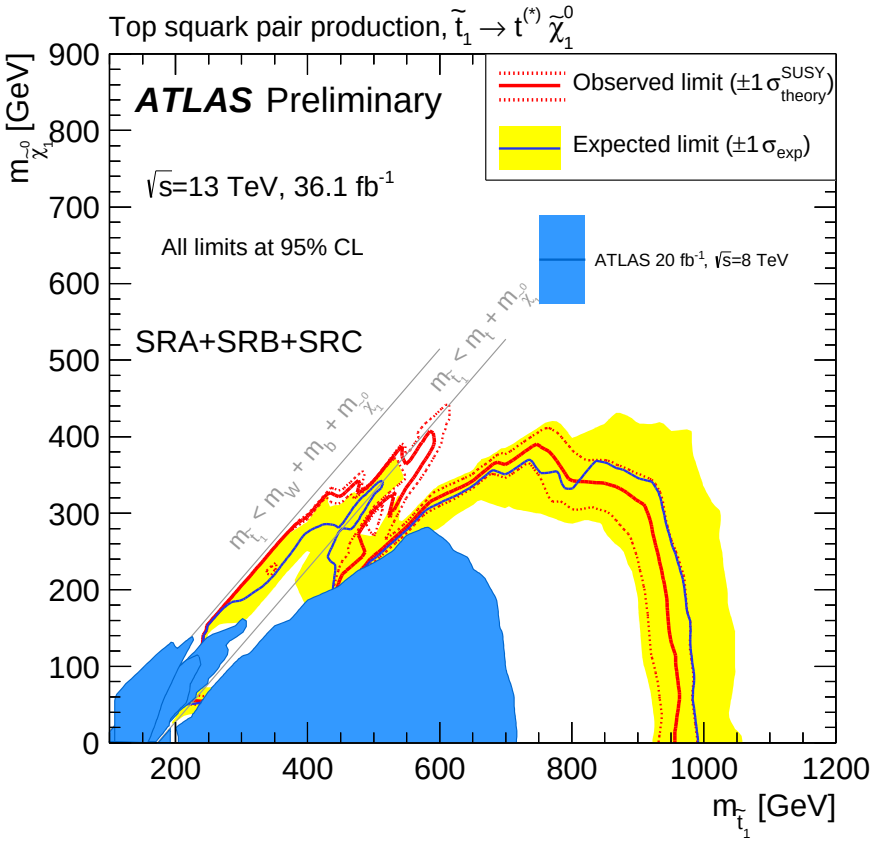

→ Exclude top squark masses up to 950 GeV (for $m_{\tilde{\chi}_1^0} < 300$ GeV)

Conclusions

Presented search for top squarks

- 0ℓ channel allows top reconstruction
- Results published with 36.1fb^{-1} of LHC Run 2 data

  0 Lepton: `ATLAS-CONF-2017-020`

  1 Lepton: `ATLAS-CONF-2017-037`

  2 Lepton: `ATLAS-CONF-2017-034`

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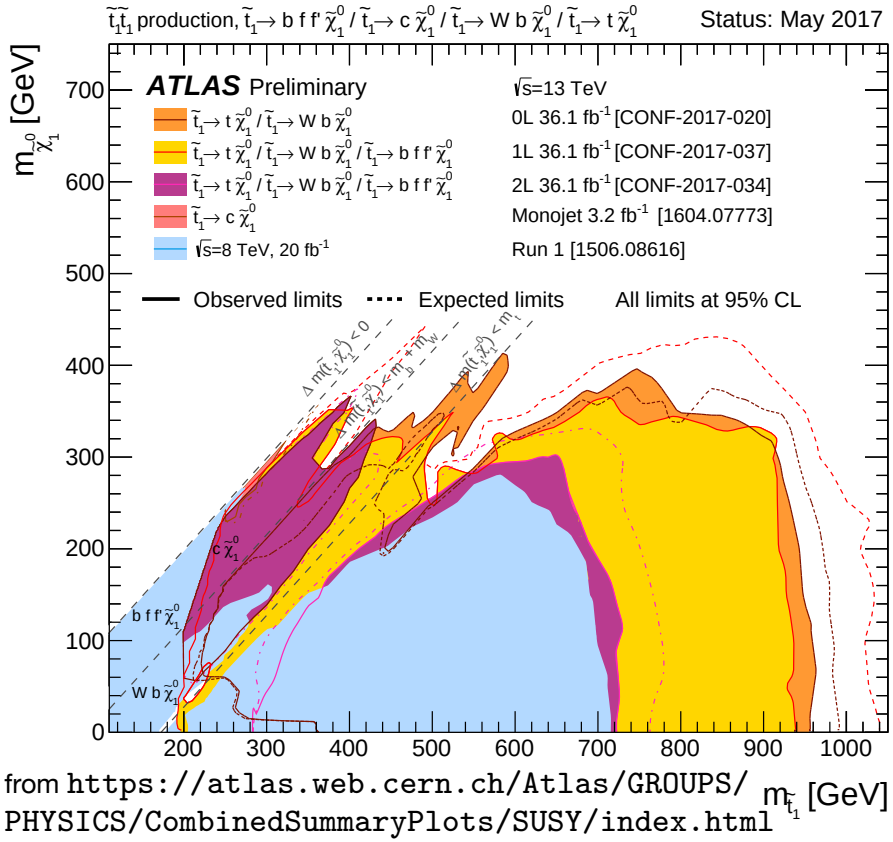

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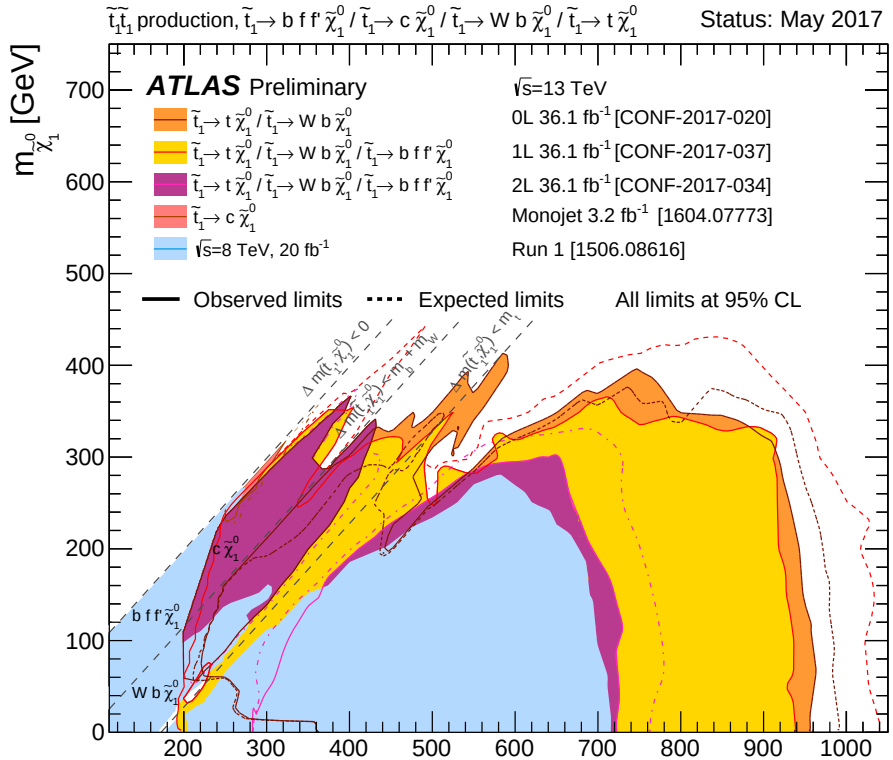

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Thanks for your attention!

BACKUP

Backup

Signal Region		TT	TW	T0
	$m^{0}_{\mathrm{jet},R=1.2}$	$> 120\,\mathrm{GeV}$		
	$m^{1}_{\mathrm{jet},R=1.2}$	$> 120\,\mathrm{GeV}$	$[60, 120]\,\mathrm{GeV}$	$< 60\,\mathrm{GeV}$
	$m_{\mathrm{T}}^{b,\mathrm{min}}$	$> 200\,\mathrm{GeV}$		
	$N_{b-\mathrm{jet}}$	≥ 2		
	τ-veto	yes		
	$\left\|\Delta\phi\left(\mathrm{jet}^{0,1,2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\right)\right\|$	> 0.4		
A	$m^{0}_{\mathrm{jet},R=0.8}$	$> 60\,\mathrm{GeV}$		
	$\Delta R\,(b, b)$	> 1	-	
	$m_{\mathrm{T2}}^{\chi^2}$	> 400 GeV	> 400 GeV	> 500 GeV
	$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 400\,\mathrm{GeV}$	$> 500\,\mathrm{GeV}$	$> 550\,\mathrm{GeV}$
B	$m_{\mathrm{T}}^{b,\mathrm{max}}$	$> 200\,\mathrm{GeV}$		
	$\Delta R\,(b, b)$	> 1.2		

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Backup

Variable	SRD-low	SRD-high
$\left\|\Delta\phi\left(\mathrm{jet}^{0,1,2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\right)\right\|$	> 0.4	
$N_{b-\mathrm{jet}}$	≥ 2	
$\Delta R\,(b, b)$	> 0.8	
$p_{\mathrm{T}}^{0,b}+p_{\mathrm{T}}^{1,b}$	> 300 GeV	> 400 GeV
τ-veto	yes	
p_{T}^{1}	> 150 GeV	
p_{T}^{3}	> 100 GeV	> 80 GeV
p_{T}^{4}	> 60 GeV	
$m_{\mathrm{T}}^{b,\mathrm{min}}$	> 250 GeV	> 350 GeV
$m_{\mathrm{T}}^{b,\mathrm{max}}$	> 300 GeV	> 450 GeV

Variable	SRE
$\left\|\Delta\phi\left(\mathrm{jet}^{0,1,2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\right)\right\|$	> 0.4
$N_{b-\mathrm{jet}}$	≥ 2
$m_{\mathrm{jet},R=0.8}^{0}$	> 120 GeV
$m_{\mathrm{jet},R=0.8}^{1}$	> 80 GeV
$m_{\mathrm{T}}^{b,\mathrm{min}}$	> 200 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 550 GeV
H_{T}	> 800 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$	$> 18\sqrt{\mathrm{GeV}}$

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