Search for top squark pair production in a final state with two leptons at LHC Run 2 with the ATLAS detector

Sonia Carrà
Supervisor: Tommaso Lari

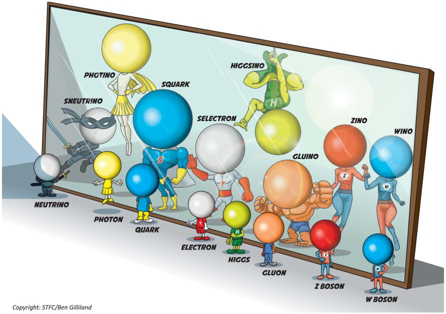
First Year PhD Students Workshop

October 20th, 2016 - Milano

Outline

Analysis based on data collected by the ATLAS detector at the LHC.
Goal: observation of supersymmetric particles and top squark production.

- LHC and ATLAS detector
- Motivation: beyond the Standard Model
- Supersymmetry and top squark
- Analysis strategy
- Results and conclusions

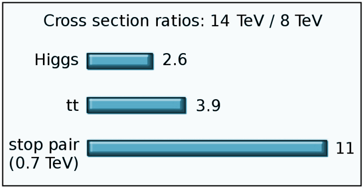


LHC - Large Hadron Collider

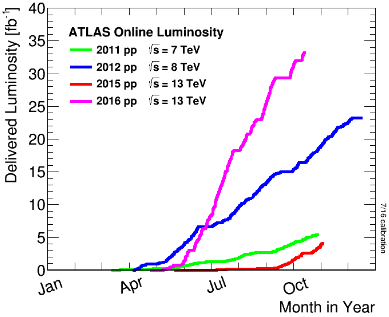
Proton-proton collisions, number of events produced: $N_{events} = \sigma_{process} \times L$

2010-2012: Run 1 with $\sqrt{s} = 7 - 8$ TeV

2015-2017: Run 2 with $\sqrt{s} = 13 - 14$ TeV



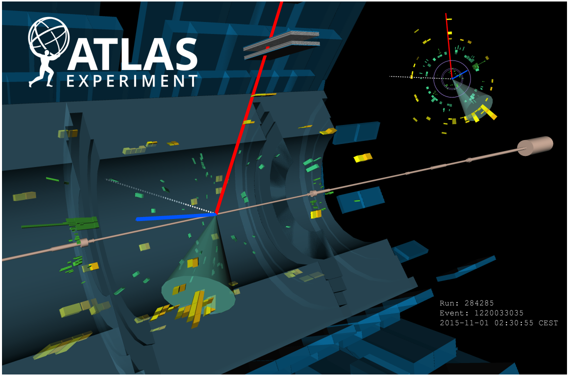
Integrated luminosity increased:



The analysis uses the 2015 and 2016 data collected by ATLAS until July 2016.

Integrated luminosity: 13.3 fb^{-1}

ATLAS detector



General purpose experiment.
Sub-detectors:

- inner tracker
- electromagnetic calorimeter
- hadronic calorimeter
- muon spectrometer

Objects reconstruction and identification using a sub-detectors combination.

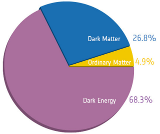
Weakly interacting particles escaping the detector. Momentum conservation in the plane transverse to the beam $\rightarrow$ missing transverse momentum due to the invisible particles.
$p_{\mathrm{T}}^{\mathrm{miss}}$ defined as the negative vectorial sum of visible momenta.

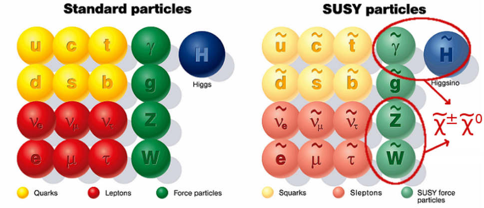
Beyond the Standard Model

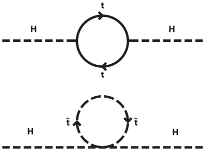
Standard Model: not a complete theory, many open questions:

- dark matter nature
- Higgs Boson mass divergency

Supersymmetry can solve these problems.



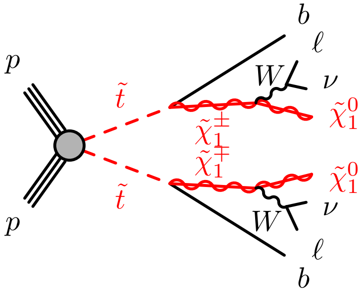




Largest contribution to the Higgs mass: top quark. In order to avoid the divergency: greatest correction from the top super-partner (top squark or stop).

Top squark

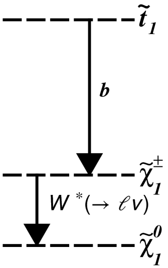
Stop associated production:



$$\tilde{t} \rightarrow \tilde{\chi}^{\pm} + b \rightarrow W^{\pm} + \tilde{\chi}^0 + b$$
$$\rightarrow l + \nu_l + \tilde{\chi}^0 + b$$

Final state:

- 2 leptons (e or μ)
- 2 b-jets
- $E_{\mathrm{T}}^{\mathrm{miss}}$ from ν and $\tilde{\chi}^0$



$\tilde{\chi}^0$ is massive, neutral and weakly interacting → dark matter candidate
Analysis designed to target a scenario with large $\tilde{t}$ - $\tilde{\chi}^{\pm}$ mass difference

Standard Model Background

Many Standard Model processes with the same final state:

- $t\bar{t}$
- Wt
- minor contribution from:
  - dibosons
  - Z + jets
  - fake leptons
  - $t\bar{t}$ + V and $t\bar{t}$ + H

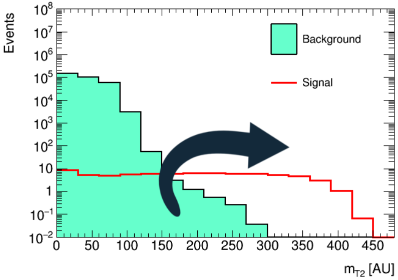
Kinematic cut providing a region with good signal/background ratio and performing a counting experiment

→ "Cut and count" strategy

SUSY cross sections are very small compared to the SM ones.
13 TeV cross sections:

$$\sigma_{t\bar{t}} = 831.8 \text{ pb}$$

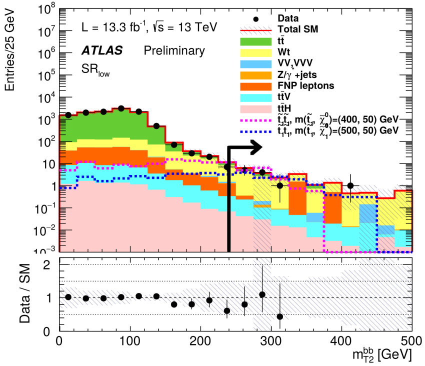
$$\sigma_{\tilde{t}\tilde{\bar{t}},m(\tilde{t})=400\text{GeV}} = 18.5 \text{ pb}$$



Hadronic m_{T2} variable

Key discriminanting variable is *stransverse* mass:

$$m_{T2}(\chi) = \min_{(q_T^{(1)}+q_T^{(2)}=E_T^{miss})}\left[\max\left\{m_T^2(p_T^{jet1}, q_T^{(1)};\chi), m_T^2(p_T^{jet2}, q_T^{(2)};\chi)\right\}\right]$$



Computed using the b-jets as visible momenta:

$$m_{T2}^{bb} = m_{T2}(\text{b-jet1, b-jet2, } E_T^{miss})$$

$t\bar{t}$: m_{T2}^{bb} end-point limited by $\sqrt{m^2(t) - m^2(W)}$

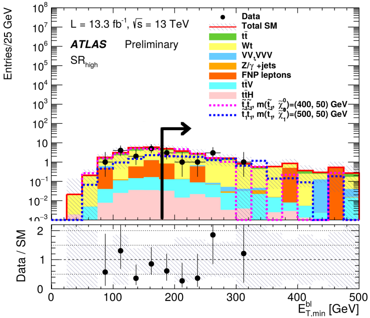
signals : m_{T2}^{bb} end-point limited by $\sqrt{m^2(\tilde{t}) - m^2(\tilde{\chi}^{\pm})}$

Signal Regions

Signal region (SR): a kinematic region with a good signal/background ratio.
Two SR designed for different stop masses:

- $\mathrm{SR_{low}}$ optimized for $m(\tilde{t}) = 400$ GeV
- $\mathrm{SR_{high}}$ targetting $m(\tilde{t}) \geq 500$ GeV

Variable	SRlow	SRhigh
b-jet multiplicity	2	2
$m_{\mathrm{T2}}^{\mathrm{bb}}$ [GeV]	>220	>220
$p_{\mathrm{T}}^{\mathrm{lep1}}$ [GeV]	<120	<120
$E_{\mathrm{T}}^{\mathrm{min,bl}}$ [GeV]	-	>180

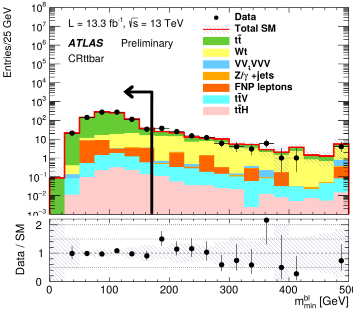


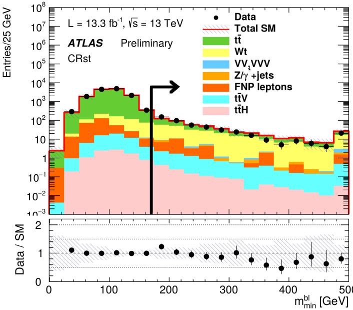
$$E_{\mathrm{T}}^{\mathrm{min,bl}} = \min(E_{\mathrm{T}}(\mathrm{lep}, \mathrm{b\text{-}jets}))$$

Background Fit

Monte Carlo simulations of the main backgrounds are simultaneously normalized to data in dedicated kinematic regions: control regions for $t\bar{t}$ and Wt Monte Carlo. Normalization extrapolated to the signal regions.

Variable	CRttbar	CRst
b-jet multiplicity	2	2
$m_{\mathrm{T2}}^{\mathrm{bb}}$ [GeV]	>120 & <160	<160
$m_{\mathrm{bl}}^{\mathrm{min}}$ [GeV]	<170	>170





$$m_{\mathrm{bl}}^{\mathrm{min}} = \min(\max(m_{\mathrm{b_1 l_1}}, m_{\mathrm{b_2 l_2}}), \max(m_{\mathrm{b_1 l_2}}, m_{\mathrm{b_2 l_1}}))$$

Background Systematic Uncertainties

Two kind of systematic uncertainties affect the Monte Carlo simulation:

	SR_{low}	SR_{high}
Total background expectation	34.9	17.3
Total background systematic	50%	58%
Jet energy scale	–	–
Jet energy resolution	–	–
E_T^{miss} modelling	1%	1%
Flavor tagging	–	–
MC statistical uncertainties	3%	5%
$t\bar{t}$ and Wt theoretical uncertainties	30%	29%
$t\bar{t}$ - Wt interference	22%	27%
$t\bar{t}$ fitted normalization	1%	1%
Wt fitted normalization	26%	26%
Fake leptons	4%	6%
Luminosity	1%	1%

Main uncertainties: theoretical systematics

- theoretical systematics for $t\bar{t}$ and Wt, comparison between different Monte Carlo:
  - generator
  - parton shower
  - additional radiation
  - $t\bar{t}$-Wt interference
- experimental systematic uncertainties:
  - jet energy scale and resolution
  - E_T^{miss} modelling
  - flavor tagging

Results

The table reports the observed data and the SM background. As example, the expected signal for two stop masses is also reported.

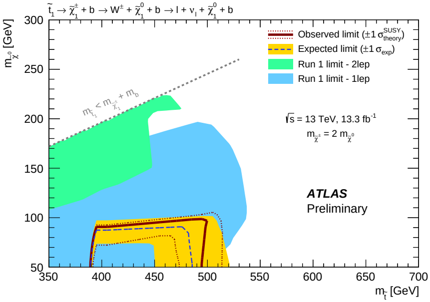
	SR_{low}	SR_{high}
Observed data	21	8
Total Standard Model	34.9 ± 14.3	17.3 ± 7.5
$m(\tilde{t}, \tilde{\chi}^{\pm}, \tilde{\chi}^{0}) = (400, 106, 50)$ GeV	27.4 ± 3.4	12.4 ± 2.5
$m(\tilde{t}, \tilde{\chi}^{\pm}, \tilde{\chi}^{0}) = (500, 106, 50)$ GeV	16.2 ± 1.6	10.8 ± 1.1

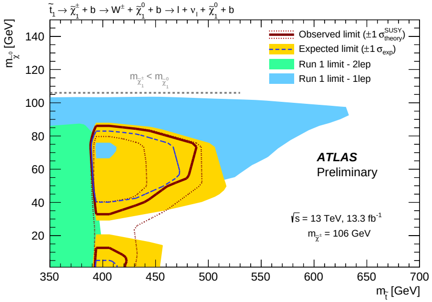
No excess observed: data compatible with background estimation
$\rightarrow$ Limits have been placed on the supersymmetric particles masses

Results

Considering the $\tilde{t} - \tilde{\chi}^0$ mass plane with:

- $m(\tilde{\chi}^{\pm}) = 2m(\tilde{\chi}^0)$
- $m(\tilde{\chi}^{\pm}) = 106$ GeV



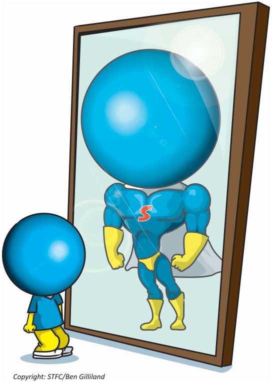


Exclusion limits at 95% confidence level

Run 1 limits for the top squark search with 1 or 2 leptons in the final state are also reported.

Conclusions

- An analysis for the search for the top squark with two leptons in the final state has been presented
- A scenario with large mass difference between $\tilde{t}$ and $\tilde{\chi}_1^{\pm}$ has been addressed
- The main discriminanting variable is the hadronic stransverse mass
- No excess has been observed
- The analysis provides an extension of the Run 1 limits on the $\tilde{t}$-$\tilde{\chi}^0$ masses



Result presented at ICHEP: **ATLAS-CONF-2016-076** on CDS

Backup

Preselection

- Trigger:
  [dileptonic-trigger and $p_T^{lep1} > 25$ GeV & $p_T^{lep2} > 20$ GeV]
  or
  [MET-trigger and $E_T^{miss} > 200$ GeV & $p_T^{lep1} > 10$ GeV & $p_T^{lep2} > 10$ GeV]
- $m_{\ell\ell} > 20$ GeV
- Z-veto $|m_{\ell\ell} - m_Z| > 20$ GeV for SF events only
- $E_T^{miss} > 100$ GeV

b-tagging working point: 77 %

m_{T2}^{bb} variable

$$m_{T2}^{bb} = m_{T2}(\text{b-jet1, b-jet2, } E_T^{miss})$$

$$m_{T2}(\chi) = \min_{(q_T^{(1)}+q_T^{(2)}=p_T^{miss})}\left[\max\left\{m_T^2(p_T^{jet1}, q_T^{(1)}; \chi), m_T^2(p_T^{jet2}, q_T^{(2)}; \chi)\right\}\right]$$

See also:

C.G.Lester, D.J.Summers, *Measuring masses of semi-invisibly decaying particles pair produced at hadron colliders*, arXiv: **hep-ph/9906349 [hep-ph]**

A. Barr, C. Lester and P. Stephens, *m(T2): The Truth behind the glamour*, arXiv: **hep-ph/0304226 [hep-ph]**

Regions definition

Variable	CRttbar	CRst	VRttbar	VRst
m_{T2}^{bb} [GeV]	>120 & <160	<160	>160 & <220	>160 & <220
b-jet multiplicity	2	2	1	2
m_{bl}^{min} [GeV]	<170	>170	-	-
E_T^{miss} [GeV]	-	-	-	< 200

Variable	SRlow	SRhigh
b-jet multiplicity	2	2
m_{T2}^{bb} [GeV]	>220	>220
p_T^{lep1} [GeV]	<120	<120
$E_T^{min,bl}$ [GeV]	-	>180

Background estimation

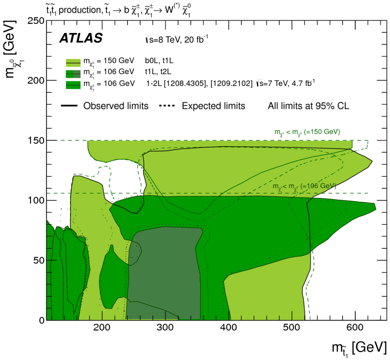
	CRttbar	CRst	VRttbar	VRst
Observed	849	512	545	48
Total Standard Model	849 ± 29	512 ± 22	530 ± 152	65.3 ± 18
Fitted $t\bar{t}$	767 ± 43	236 ± 94	390 ± 180	23 ± 17
Fitted Wt	54 ± 28	240 ± 97	100 ± 51	38 ± 21
Diboson	0.43 ± 0.13	3.76 ± 0.67	9.9 ± 1.3	0.20 ± 0.16
Z/γ^*+jets	0.73 ± 0.72	5.0 ± 3.0	5.0 ± 3.6	0.75 ± 0.59
Fake leptons	21.1 ± 5.6	17.7 ± 5.1	20.2 ± 5.1	2.0 ± 1.6
$t\bar{t}$ V	4.71 ± 0.31	8.3 ± 1.1	4.72 ± 0.49	0.98 ± 0.11
$t\bar{t}$ H	1.00 ± 0.15	1.41 ± 0.18	0.44 ± 0.10	0.30 ± 0.04
MC exp. Standard Model	848	460	520	57
MC exp. $t\bar{t}$	777	239	400	23
MC exp. Wt	42	185	77	30

Scale factors	
$\mu_{t\bar{t}}$	0.986 ± 0.056
μ_{Wt}	1.293 ± 0.526

Signal regions

	SRlow	SRhigh
Observed	21	8
Total Standard Model	35 ± 14	17.3 ± 7.5
Fitted $t\bar{t}$	7.6 ± 3.4	3.3 ± 2.3
Fitted Wt	22 ± 15	11.7 ± 8.3
Diboson	0.44 ± 0.17	0.29 ± 0.15
$Z/\gamma*$+jet	0.15 ± 0.12	0.07 ± 0.05
Fakes and non-prompt	3.7 ± 1.5	1.5 ± 1.0
$t\bar{t}$ V	0.81 ± 0.10	0.42 ± 0.05
$t\bar{t}$ H	0.21 ± 0.03	0.09 ± 0.02
MC exp. Standard Model	30	14.7
MC exp. $t\bar{t}$	7.6	3.4
MC exp. Wt	17	9.0
$m(\tilde{t}, \tilde{\chi}^{\pm}, \tilde{\chi}^{0}) = (400, 106, 50)$ GeV	27.4 ± 3.4	12.4 ± 2.5
$m(\tilde{t}, \tilde{\chi}^{\pm}, \tilde{\chi}^{0}) = (500, 106, 50)$ GeV	16.2 ± 1.6	10.8 ± 1.1

Run 1 Results



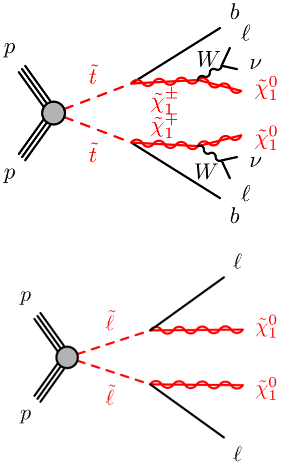
ATLAS Collaboration, *Search for direct top-squark pair production in final states with two leptons in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, arXiv: **1403.4853 [hep-ex]**

Model Indipendent Limits

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B
SRlow	1.18	15.7	$19.2^{+5.8}_{-4.2}$	0.23
SRhigh	0.60	8.0	$10.5^{+4.1}_{-2.8}$	0.18

Left to right: 95% CL upper limits on the visible cross section ($\langle\epsilon\sigma\rangle^{95}_{\rm obs}$) and on the number of signal events ($S^{95}_{\rm obs}$). The third column ($S^{95}_{\rm exp}$) shows the 95% CL upper limit on the number of signal events, given the expected number (and $\pm 1\sigma$ excursions on the expectation) of background events. The last column contains the CL_B value, i.e. the confidence level observed for the background-only hypothesis.

Future Plans



- The objetc of my PhD thesys is the search for sleptons direct production with 2 leptons in the final state.
- The sleptons ans stop into 2 letpons channels have a very similar final state, so they share various point of the analysis stategy.
- The analysis for the search of sleptons is now under development.