SEARCH FOR A HEAVY TOP PARTNER IN FINAL STATES WITH TWO LEPTONS

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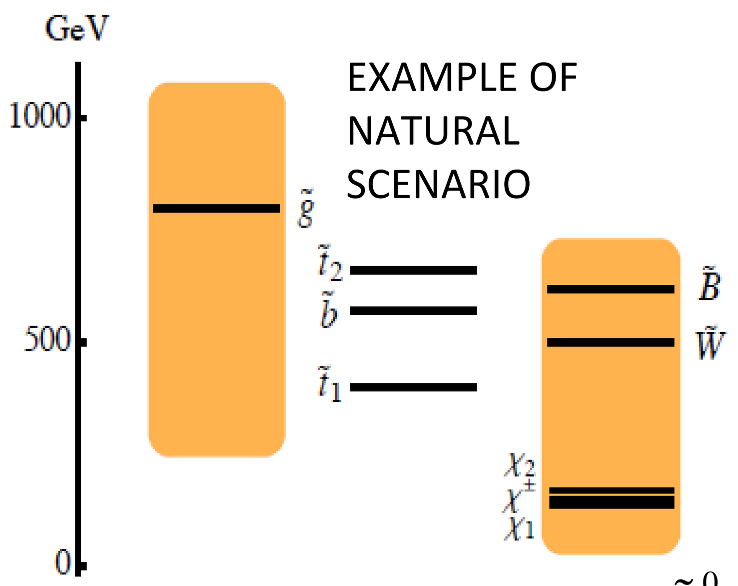
ATLAS EXPERIMENT

Many BSM models introduce an heavy partner T of the top quark and a new weakly interacting particle A

- Scalar top partner - Supersymmetry
- Spin ½ T - Little Higgs, UED, …

The new particles have a conserved quantum number: **T is produced in pairs, and A is stable** (Dark Matter candidate)



In this analysis we are looking for
$TT \rightarrow AtAt \rightarrow Abl\nu\, Abl\nu$ (with $l = e,\mu$)

- In SUSY, T is the lightest **scalar top** $\tilde{t}_1$ and A is the **lightest neutralino** $\tilde{\chi}_1^0$

In SUSY the scalar top cancels the Higgs radiative corrections from the top quark loop: **SUSY is a natural solution to the hierarchy problem if, and only if, there is a light scalar top**.

- More generally, in BSM models addressing the naturalness feature a top partner T is expected to be close to the EWSB scale.

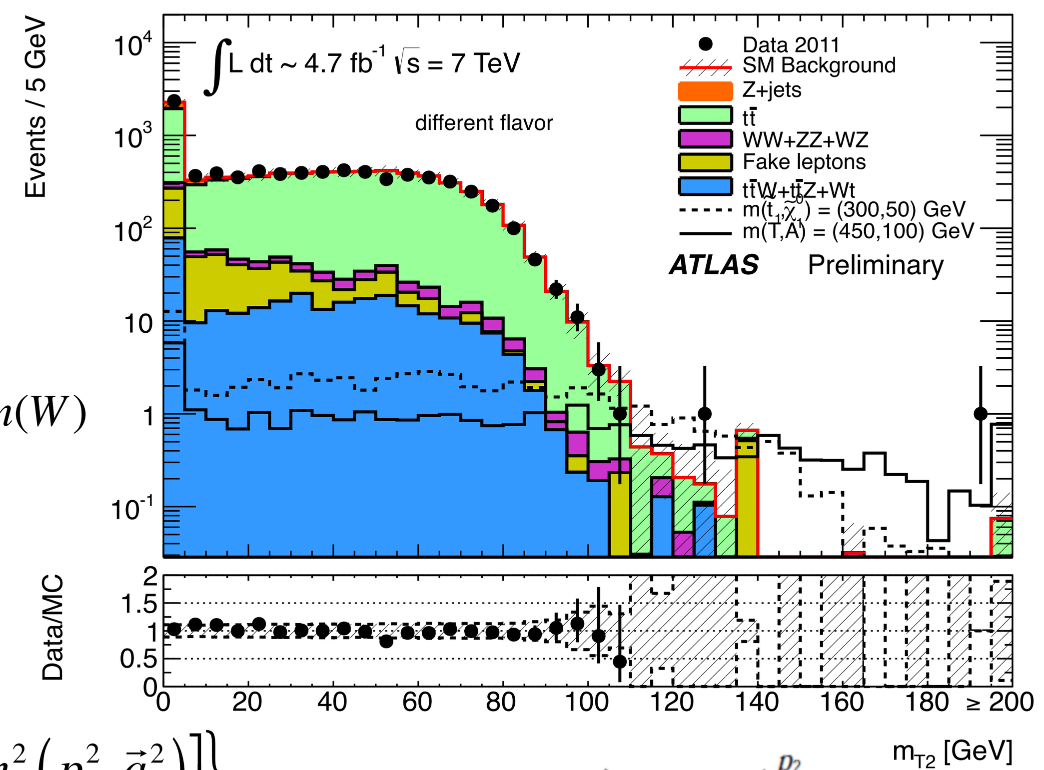
Stransverse mass: the lepton-neutrino transverse mass obeys $m_T(l,\nu) = \sqrt{2 p_T(l) p_T(\nu)\left[1-\cos(\varphi_l - \varphi_\nu)\right]} < m(W)$ on both sides: $\max\left[m_T\left(p_T^1, \vec{q}_T^1\right), m_T\left(p_T^2, \vec{q}_T^2\right)\right] < m(W)$

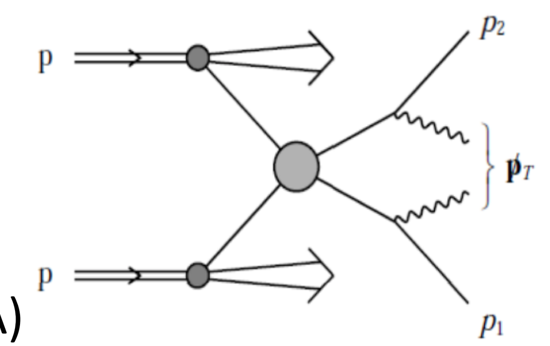
The direction of the two neutrinos is unknown, but it's possible to **try all possibilities and take the minimum.**

$$M_{T2}\left(\vec{p}_T^1, \vec{p}_T^2, \vec{p}_T\right) = \min_{\vec{q}_T^1 + \vec{q}_T^2 = \vec{p}_T} \left\{ \max\left[m_T^2\left(p_T^1, \vec{q}_T^1\right), m_T^2\left(p_T^2, \vec{q}_T^2\right)\right] \right\}$$

$M_{T2} < m(W)$ for *top pairs*, and also for *Wt* and *WW*.
Signal has two additional (A or χ) particles contribute to missing energy (E_T^{miss}) leading to events with $M_{T2} > m(W)$

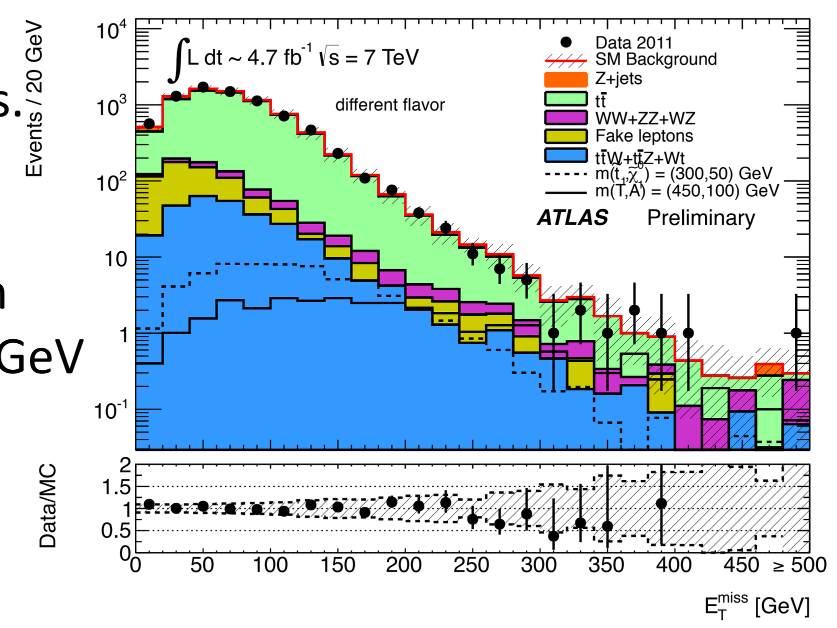
- Better if m(T)-m(A) is large (more momentum transferred to A)



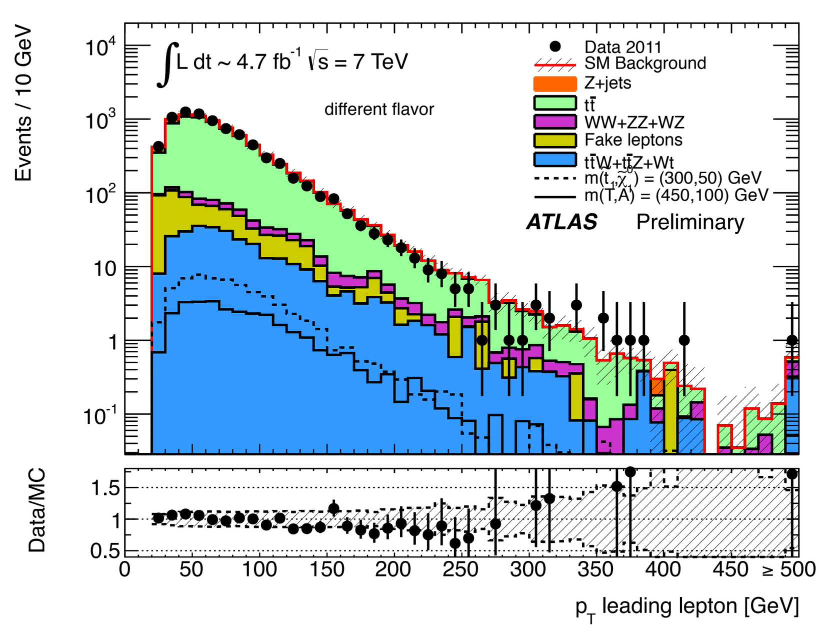


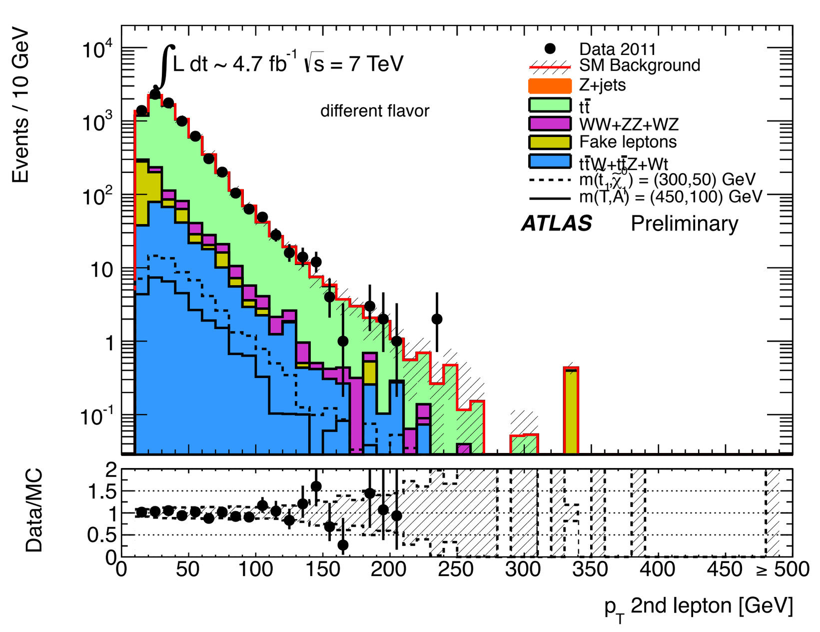
Main backgrounds before the M_{T2} selection is by far top pairs. **Only 0.007% of top pair** events *passing all other selections* **survives** the M_{T2} cut

- Surviving events are due to finite E_T^{miss} detector resolution
- Good signal *efficiency* (**20-40%**) for m(T)-m(A) > m(t)+200 GeV



Top quark partner mass [GeV]	200	300	400	500	600
$\tilde{t}_1\tilde{t}_1$ production	0.02%	7.7%	22.0%	35.6%	43.0%
TT production	-	5.3%	15.8%	27.3%	34.3%





Event Selection

Exactly two high-p_T leptons (veto a third lepton)

Two channels: **Different Flavour** *DF* (eμ)
Same Flavour *SF* (ee , μμ)

- ≥1 jet with p_T > 50 GeV - *Reduces diboson and Z+jets*
- ≥2 jets with p_T > 25 GeV *>90% signal efficiency*
- **M_{T2} > 120 GeV** - *Kills top pairs, Wt and WW*

SF candidates only

- Veto 71 GeV < m_{ll} < 111 GeV
- ≥1 btagged jet - *Against Z+jets, largest background in SF*

Background estimation

Processes with fake or not isolated leptons

- Small, includes double fakes (QCD) and fake-real lepton pairs (W+jets)
- Data-driven estimate using a *matrix method* (see below)

Top pair and Z+jets

- Dominant backgrounds
- Normalization from data in appropriate control regions (CR)
- MC used to relate the CR measurement to the signal region (SR) expectation

$$N(\mathrm{SR}) = \left(N^{\mathrm{Data}}(\mathrm{CR}) - N_{\mathrm{others}}(\mathrm{CR})\right) \frac{N^{\mathrm{MC}}(\mathrm{SR})}{N^{\mathrm{MC}}(\mathrm{CR})}$$

Diboson, Wt, ttW, ttZ

- Estimated from MC

Top Background Estimation

Define a **CR** with all selection cuts but **85 < M_{T2} < 100 GeV**
Good agreement between observed and expected rates
Good expected top purity

Data/MC scale factor is

- **1.21 ± 0.19** for SF channels
- **1.10 ± 0.13** for DF channels

The two channels are normalized independently

Process	$t\bar{t}$ CR DF	$t\bar{t}$ CR SF
$t\bar{t}$	68 ± 11	39 ± 11
$t\bar{t}W + t\bar{t}Z$	0.37 ± 0.07	0.20 ± 0.05
Wt	2.7 ± 1.0	1.8 ± 0.6
Z/γ^*+jets	-	3.5 ± 1.4
Fake leptons	0.4 ± 0.3	0.5 ± 1.6
Diboson	0.49 ± 0.14	0.10 ± 0.05
Total non-$t\bar{t}$	4.0 ± 1.5	6.1 ± 3.7
Total expected	72 ± 11	45 ± 12
Data	79	53

Z+jets Background Estimation

Define a **CR** with all selection cuts but **71 < m_{ll} < 111 GeV**

- The transfer factor is computed before the b-tagging requirement to improve MC statistics
- The transfer factor doesn't depend on b-tagging

Fake lepton background

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

T = tight is the **standard** electron and muon selection
L = baseline electrons or muons **with relaxed identification cuts**
The probability **f** of a fake lepton to pass *tight* is measured in two QCD control samples:

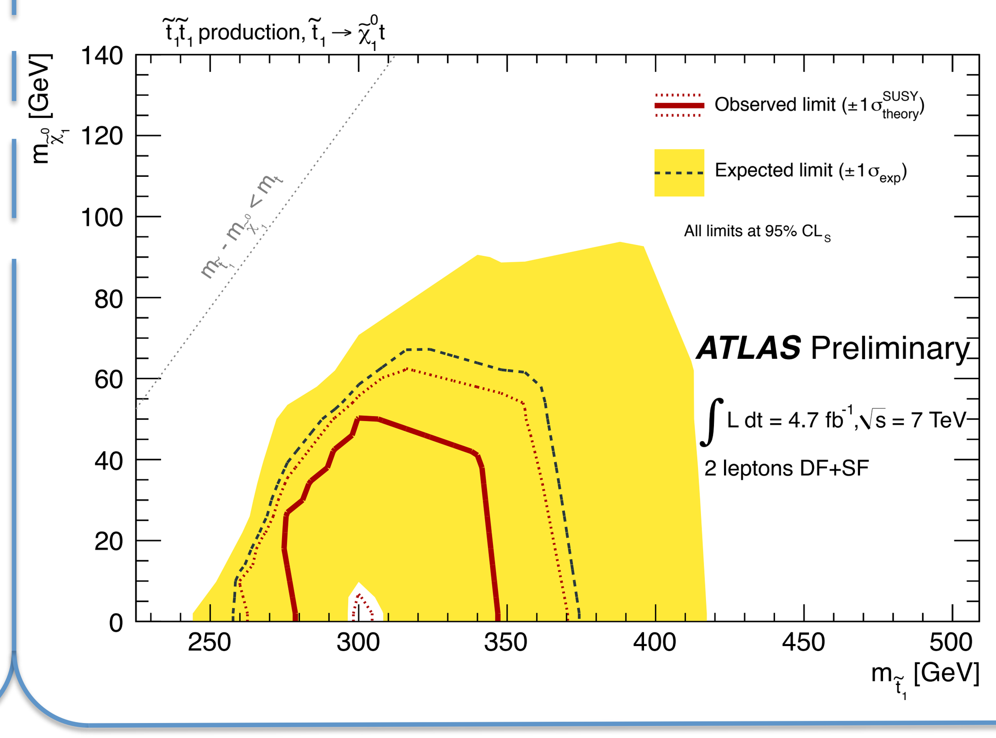
- 1 baseline lepton, 1 jet, $\Delta\phi$(lep-p_T^{miss}) < 0.5, E_T^{miss} < 25 GeV
- A baseline *not tight* same sign DF pair, no jets, E_T^{miss} < 25 GeV as a function of lepton η and p_T, ΣE_T, $\Delta R(\mathrm{lj})_{min}$

The probability **r** of a real lepton to pass *tight* is measured in Z events with a tag and probe technique.

	SF	DF
Z/γ^*+jets	1.2 ± 0.5	-
(Z/γ^*+jets scale factor)	(1.27)	-
$t\bar{t}$	0.23 ± 0.23	0.4 ± 0.3
($t\bar{t}$ scale factor)	(1.21)	(1.10)
$t\bar{t}W + t\bar{t}Z$	0.11 ± 0.07	0.19 ± 0.12
WW	$0.01^{+0.02}_{-0.01}$	0.19 ± 0.18
$WZ + ZZ$	0.05 ± 0.05	0.03 ± 0.03
Wt	$0.00^{+0.17}_{-0.00}$	$0.10^{+0.18}_{-0.10}$
Fake leptons	$0.00^{+0.14}_{-0.00}$	$0.00^{+0.09}_{-0.00}$
Total SM	1.6 ± 0.6	0.9 ± 0.6
Signal, m($\tilde{t}_1$) = 300 GeV, m($\tilde{\chi}_1^0$)= 50 GeV	2.15	3.73
Signal, m(T) = 450 GeV, m(A_0)= 100 GeV	3.10	5.78
Observed	1	2
95% CL limit on $\sigma_{\mathrm{vis}}^{\mathrm{obs}}$[fb]	0.86	1.08
95% CL limit on $\sigma_{\mathrm{vis}}^{\mathrm{exp}}$[fb]	0.89	0.79

Conclusions

We set 95% CL limits using the CLs method.
Limits on σ x A x ε are provided in the results table.
These **are model independent**: a theoretician can validate his/her detector response modeling against acceptance and compare signal yields with those limits for any given model.



Data are found to be in agreement with the SM expectations.

- Limits on a *spin ½ top partner* are significantly extended: **for m(A)<100 GeV, m(T)<483 GeV are excluded** (expected: **518 GeV**).
- Limits on a *scalar top* decaying into a top quark and $\tilde{\chi}_1^0$ are set: for massless $\tilde{\chi}_1^0$ the **observed exclusion** is **298 - 304 GeV** (expected **258 – 374 GeV**)