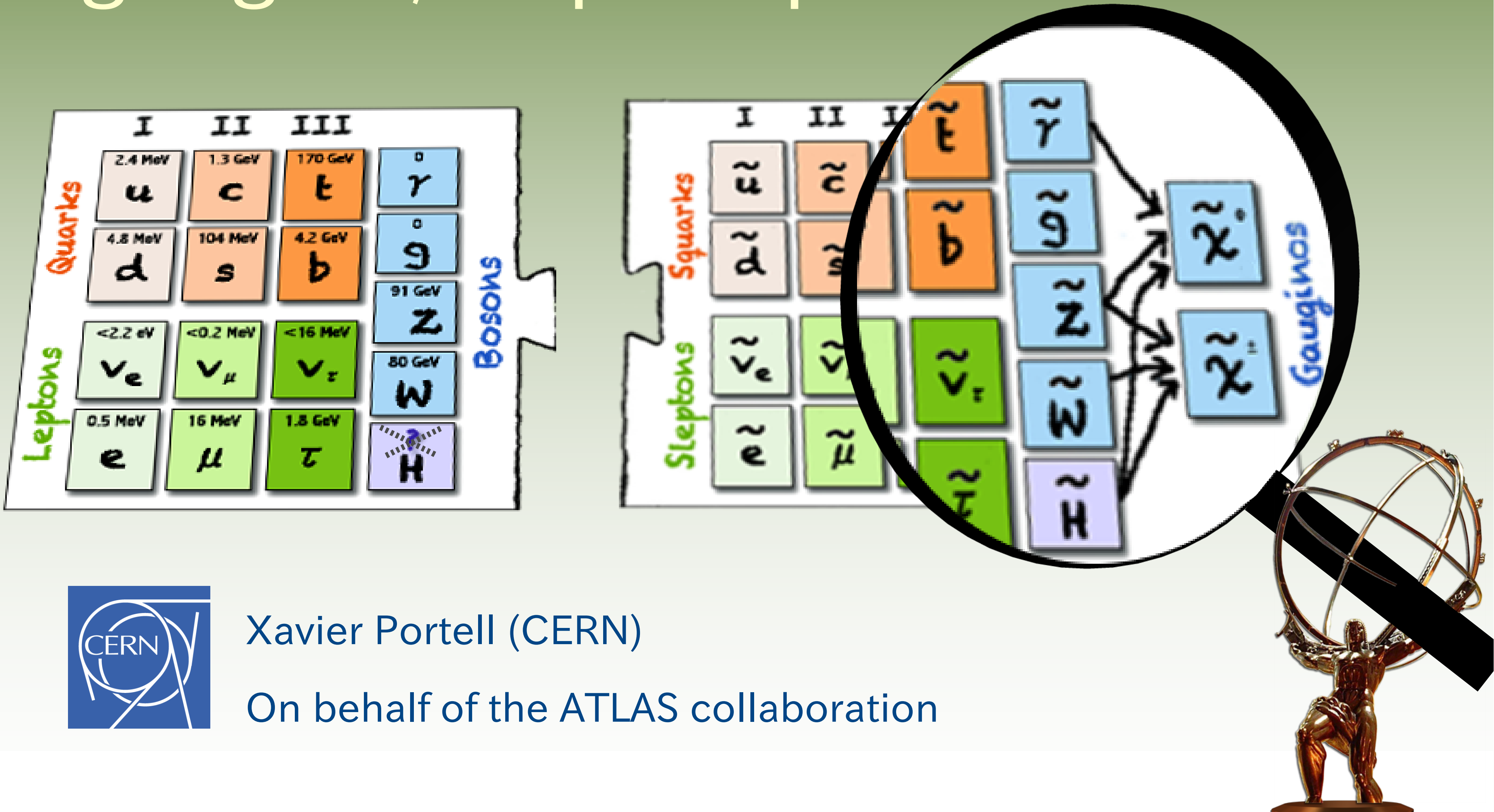
ATLAS searches for 3rd generation squarks and direct gaugino/slepton productions



Xavier Portell (CERN)

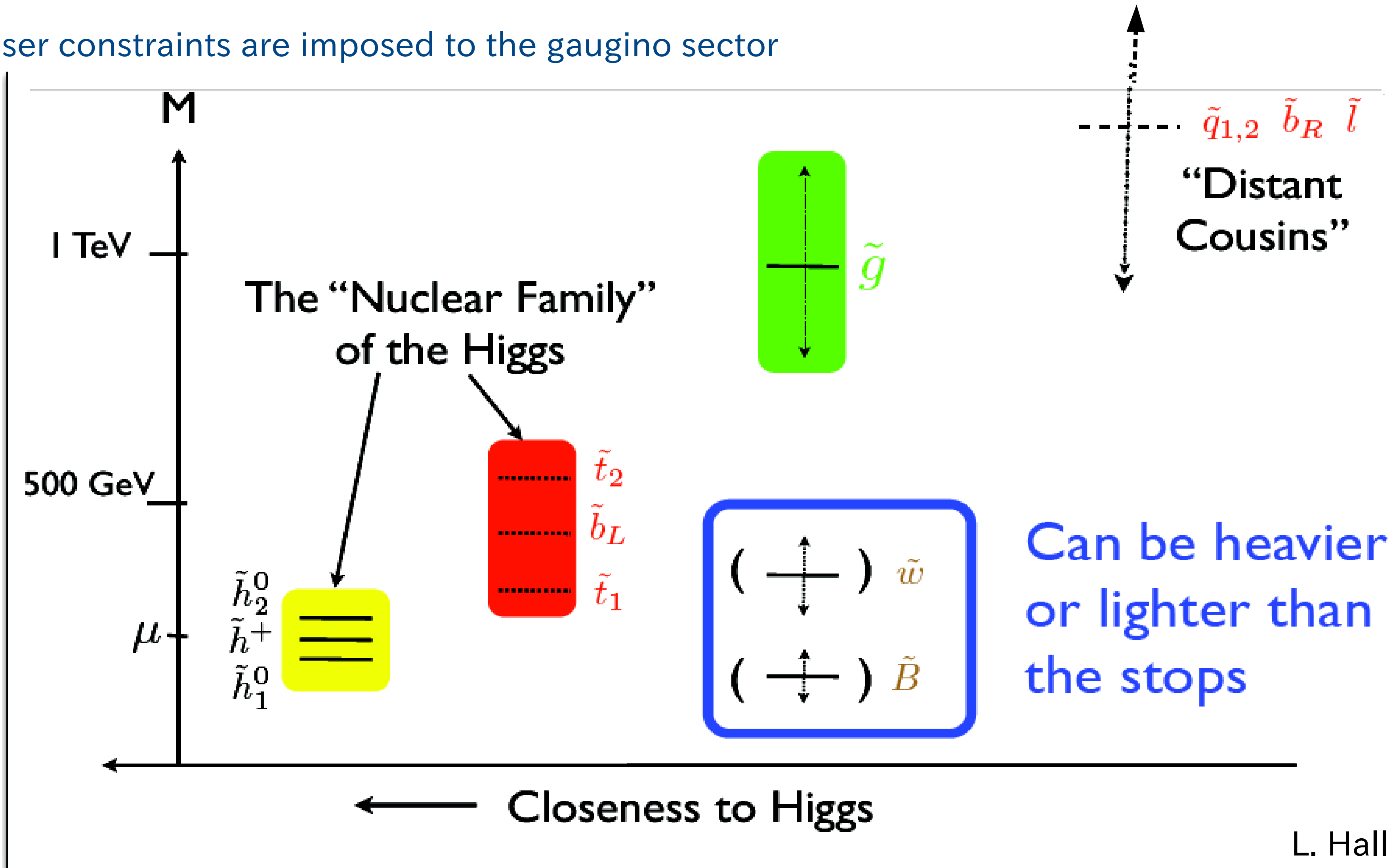
On behalf of the ATLAS collaboration

Implications workshop, 13th July 2012

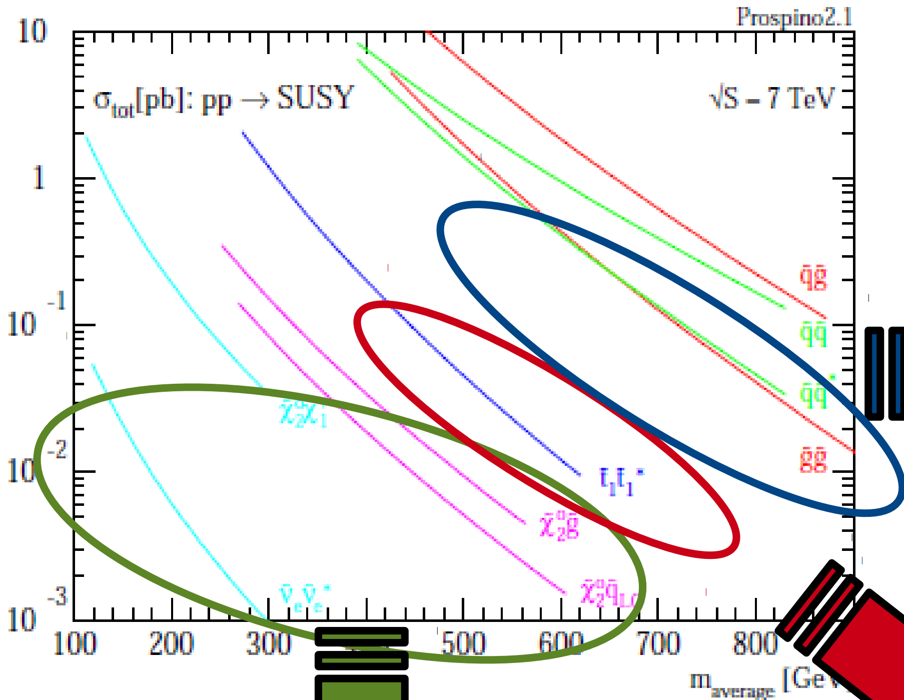
"Natural" scenario

If SUSY has to solve the gauge-hierarchy problem, the 3rd generation particles are bound to be relatively light and the gluino not too far away

Looser constraints are imposed to the gaugino sector

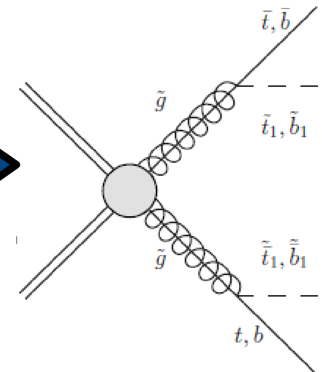


Production and challenges



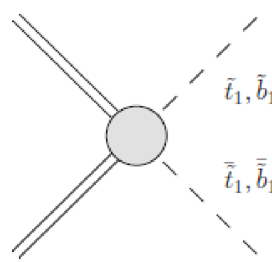
Moving from signature-based to model-based

Gluino-mediated stop/sbottom production



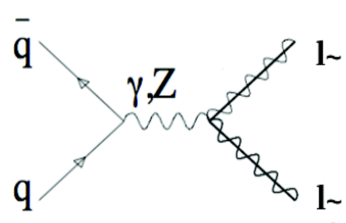
- Large cross sections (strong production)
- Large number of (b-)jets and leptons

Direct stop/sbottom production



- Low cross sections: isolated squark is 1/12 of the "squark" cross section and suppressed t-channel contribution (need b-/t-quark in the initial state)
- Large backgrounds: need dedicated analyses per topology.

Direct gaugino/slepton production



- Low cross sections: weak production
- Make use of leptonic final states to reduce backgrounds (in general, low branching ratios)

This talk cover R-parity conserving searches only

Large (increasing) activity

1-lepton + b-jets (1.03 fb^{-1})
ATLAS-CONF-2011-130
http://cdsweb.cern.ch/record/1383833

0-lepton + b-jets(0.83 fb^{-1})
ATLAS-CONF-2011-098
http://cdsweb.cern.ch/record/1369212

0-/1-lepton + b-jets (0.035 fb^{-1})
PLB 701 (2011) 398
(arXiv:1103.4344 [hep-ex])

2 SS leptons + jets (2.05 fb^{-1})
PRL 108 (2012) 241802
(arXiv:1203.5763 [hep-ex])

b-jets + 0/1-lepton (2.05 fb^{-1})
PRD 85 (2012) 112006
(arXiv:1203.6193 [hep-ex])

3 b-jets (4.7 fb^{-1})
ATLAS-CONF-2012-058
http://cdsweb.cern.ch/record/1453786

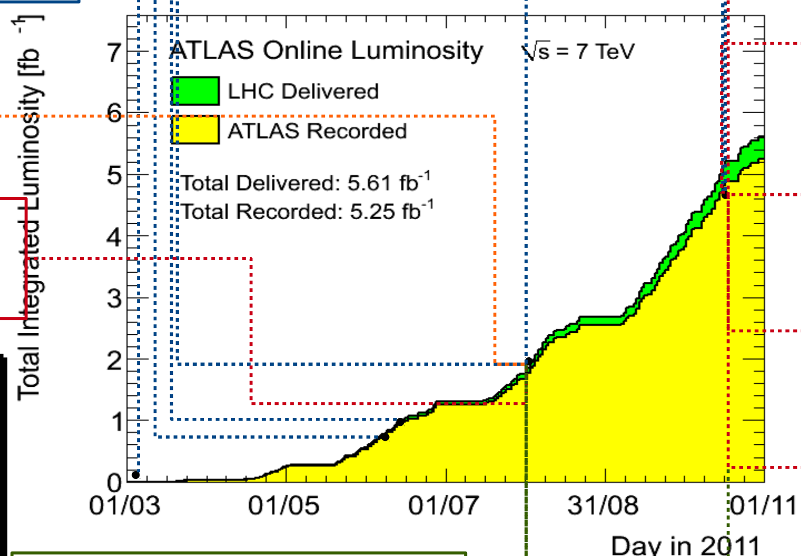
Multijets (6-9 jets) (4.7 fb^{-1})
Submitted to JHEP
(arXiv:1206.1760 [hep-ex])

2-lepton + jets (very light stop) (4.7 fb^{-1})
ATLAS-CONF-2012-059
http://cdsweb.cern.ch/record/1453787

b-jets + 1-2 lep. (light stop) (4.7 fb^{-1})
ATLAS-CONF-2012-070
http://cdsweb.cern.ch/record/1460267

2 b-jets (2.05 fb^{-1})
PRL 108 (2012) 181802
(arXiv:1112.3832 [hep-ex])

Z + (b-)jets (GMSB) (2.05 fb^{-1})
Accepted by PLB
(arXiv:1204.6736 [hep-ex])



2-leptons + jets (heavy stop) (4.7 fb^{-1})
ATLAS-CONF-2012-071
http://cdsweb.cern.ch/record/1460268

1-lepton + jets (heavy stop) (4.7 fb^{-1})
ATLAS-CONF-2012-073
http://cdsweb.cern.ch/record/1460270

0-lepton + jets (heavy stop) (4.7 fb^{-1})
ATLAS-CONF-2012-074
http://cdsweb.cern.ch/record/1460271

Legend:

- Gluino-mediated stop/sbottom
- Direct sbottom
- Direct stop
- Direct gaugino/slepton

3-leptons (2.05 fb^{-1})
PRL 108 (2012) 261804
(arXiv:1204.5638 [hep-ex])

3-leptons (4.7 fb^{-1})
ATLAS-CONF-2012-077
http://cdsweb.cern.ch/record/1460274

4-leptons (2.05 fb^{-1}) (RPV-targetted)
ATLAS-CONF-2012-001
http://cdsweb.cern.ch/record/1418920

4-leptons interpretation (2.05 fb^{-1})
ATLAS-CONF-2012-035 (RPV-targetted)
https://cdsweb.cern.ch/record/1432202

2-leptons (4.7 fb^{-1})
ATLAS-CONF-2012-076
http://cdsweb.cern.ch/record/1460273

General strategy

Some common variables:
- ✔ EtMiss
- ✔ HT: scalar sum of jets
- ✔ m_{eff}: scalar sum of EtMiss and jets

Technique

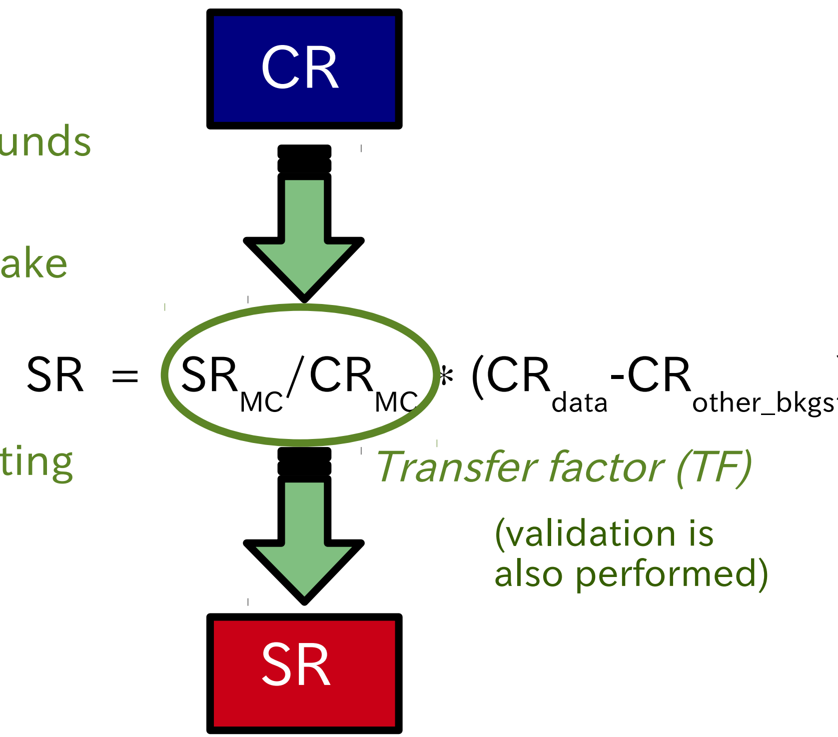
- Most analyses follow cut & count approach

Background strategy

- QCD multijet backgrounds: data-driven
  - 0-lepton: smearing technique with jet resolution function
  - >=1-lepton: matrix method (“loose”-->”tight” with efficiencies taken from dedicated regions)
- Major backgrounds: semi data-driven
  - Define a control region (CR) for each of the backgrounds to test MC performance
  - Control region kinematically close to signal region (take into account signal contamination)
  - Normalise MC yields to data
  - Transfer factor from CR to signal region (SR) subtracting other backgrounds in the region
  - Systematics reduced due to ratio SR/CR
- Minor backgrounds: MC-only estimation

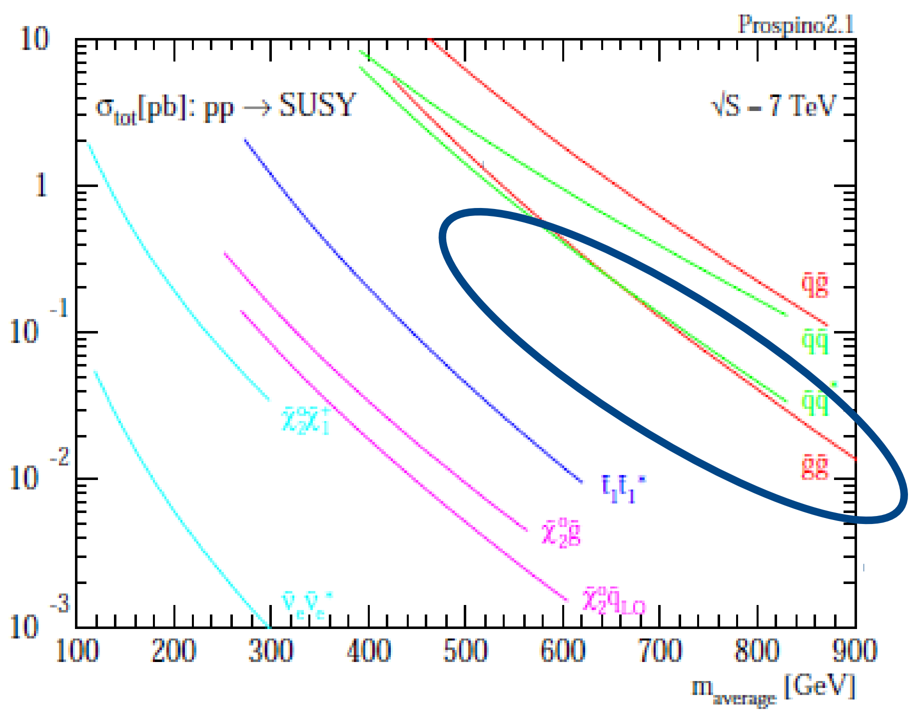
Interpretation

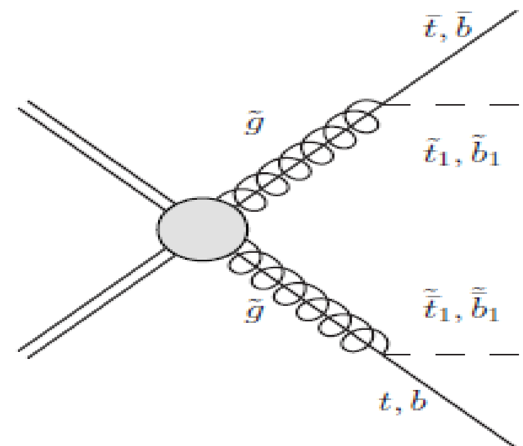
- Reduced spectra -> simple models (different combinations)



$$SR = SR_{MC}/CR_{MC} * (CR_{data} - CR_{other\_bkgs})$$

ATLAS searches for gluino-mediated stop/sbottom production





Many different decays considered:

On-shell: $\tilde{g} \to b\tilde{b}$ / $\tilde{g} \to \tilde{t}t$

Off-shell: $\tilde{g} \to tb\tilde{\chi}_1^-$ / $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ / $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$

b-jets + 0/1-lepton (2.05 fb^{-1})
PRD 85 (2012) 112006
(arXiv:1203.6193 [hep-ex])

Gluino-med. $\tilde{t}/\tilde{b}$: 0-/1-lepton

Two channels considered

0-lepton --> sbottom dominated decays

- ≥3 jets and dedicated QCD removal cuts
- 6 SRs defined (mass differences)

SR0-A1: ≥1 b-tag, m_{eff}>500 GeV
SR0-B1: ≥1 b-tag, m_{eff}>700 GeV
SR0-C1: ≥1 b-tag, m_{eff}>900 GeV
SR0-A2: ≥2 b-tag, m_{eff}>500 GeV
SR0-B2: ≥2 b-tag, m_{eff}>700 GeV
SR0-C2: ≥2 b-tag, m_{eff}>900 GeV

1-lepton --> stop dominated decays

- ≥4 jets with at least 1 b-tag
- m_T(lepton,EtMiss)>100 GeV
- 2 SRs defined (mass differences)

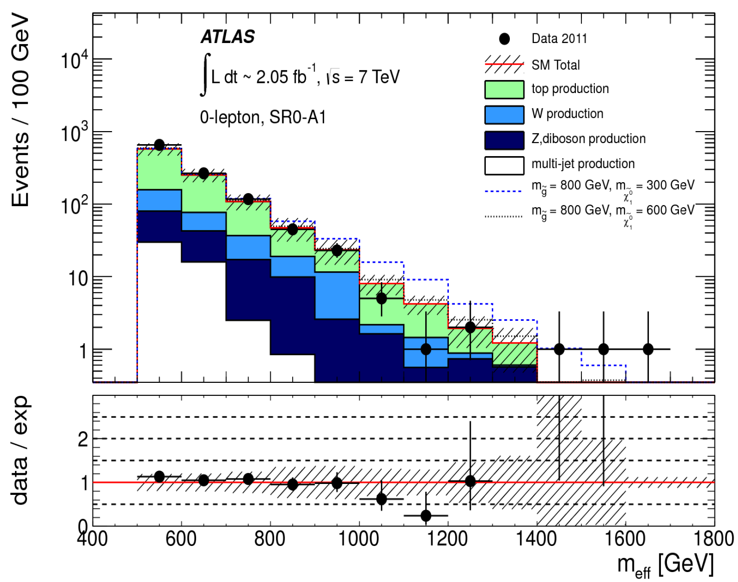
SR1-D: m_{eff}>700 GeV
SR1-E: EtMiss>200 GeV and m_{eff}>700 GeV

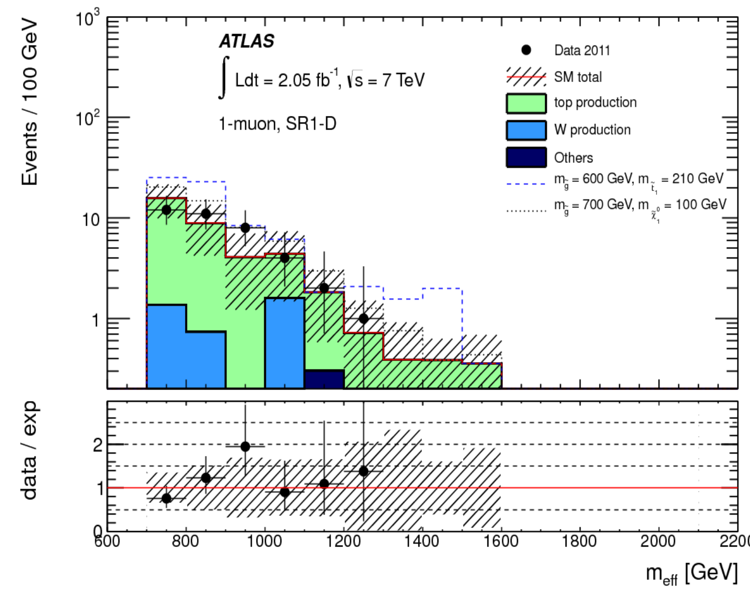
Main backgrounds: ttbar and W+hf (heavy flavour)

ttbar estimated using 1-lepton and low m_T (other cuts the same) and defining transfer factors

Multijets: smearing or matrix method

Theoretical uncertainties dominate





Gluino-med. $\tilde{t}/\tilde{b}$: 2-leptons

Targetting gluino-mediated stop production
Expected 4 tops in the final state --> same-sign (SS) leptons

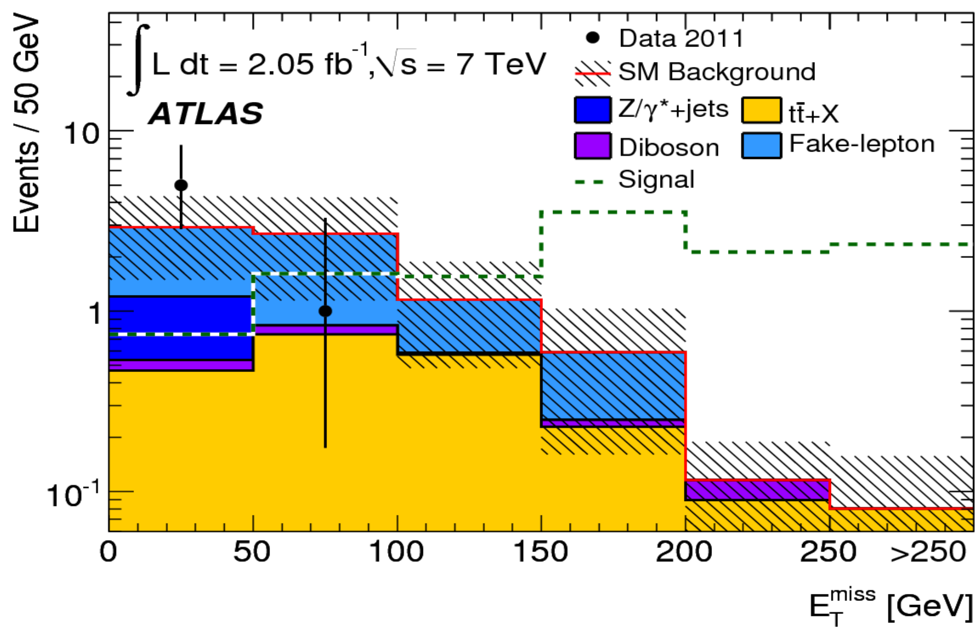
- ≥ 4 jets (pT>50 GeV)
- 2 SRs defined

  SR1: EtMiss>150 GeV
  SR2: EtMiss>150 GeV and m_T(lepton, EtMiss)>100 GeV

Main backgrounds:

- ✔ “Fake” leptons from jets: estimated using matrix method
- ✔ Charge misidentification: use SS |m(ll)-mZ| < 15 GeV
- ✔ ttbar+X: from MC (dominant background and dominates the uncertainty) (X=jets, W, Z, bbbar...)

	SR1	SR2
$t\bar{t}$ +X	0.37 ± 0.26	0.21 ± 0.16
Diboson	0.05 ± 0.02	0.02 ± 0.01
Fake-lepton	0.34 ± 0.20	< 0.17
Charge mis-ID	0.08 ± 0.01	0.039 ± 0.007
Total SM	0.84 ± 0.33	0.27 ± 0.24
Observed	0	0



3 b-jets (4.7 fb^{-1})
ATLAS-CONF-2012-058
http://cdsweb.cern.ch/record/1453786

Gluino-med. 3 b-jets

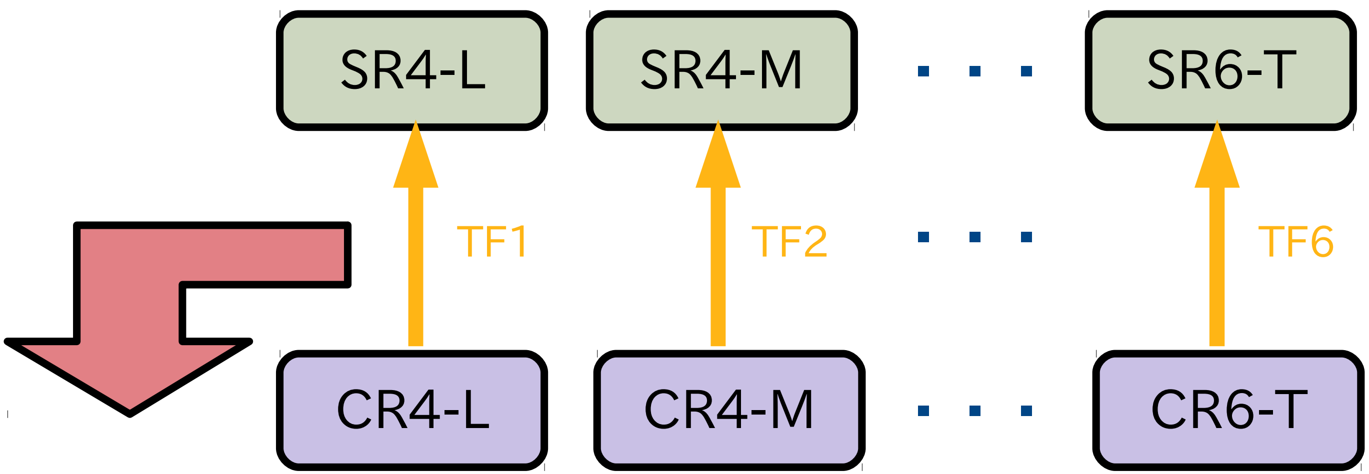
Exploit presence of b-jets to reduce backgrounds (not many SM processes with 3 b-jets)

- ✔Cuts to be above trigger threshold and reduce QCD multijets.
- ✔3 b-tags with different Operating Points (OP)
- ✔Defined 5 SRs: EtMiss and m_{eff}

Common criteria: lepton veto, $p_T^{j_1} > 130$ GeV, ≥ 3 b-jets, $E_T^{miss}/m_{eff} > 0.2$, $\Delta\phi_{min} > 0.4$

SR	N_J	E_T^{miss}	m_{eff}	b-tag OP
SR4-L	$\geq$ 4j	>160 GeV	>500 GeV	60%
SR4-M	$\geq$ 4j	>160 GeV	>700 GeV	60%
SR4-T	$\geq$ 4j	>160 GeV	>900 GeV	70%
SR6-L	$\geq$ 6j	>160 GeV	>700 GeV	70%
SR6-T	$\geq$ 6j	>200 GeV	>900 GeV	75%

Background strategy



MC-driven Transfer Factor (TF): from 2 to >=3 b-tags

CRs: same cuts as in SRs but EtMiss>160 GeV, meff>500 GeV and **exactly 2 b-tags**

Validations:

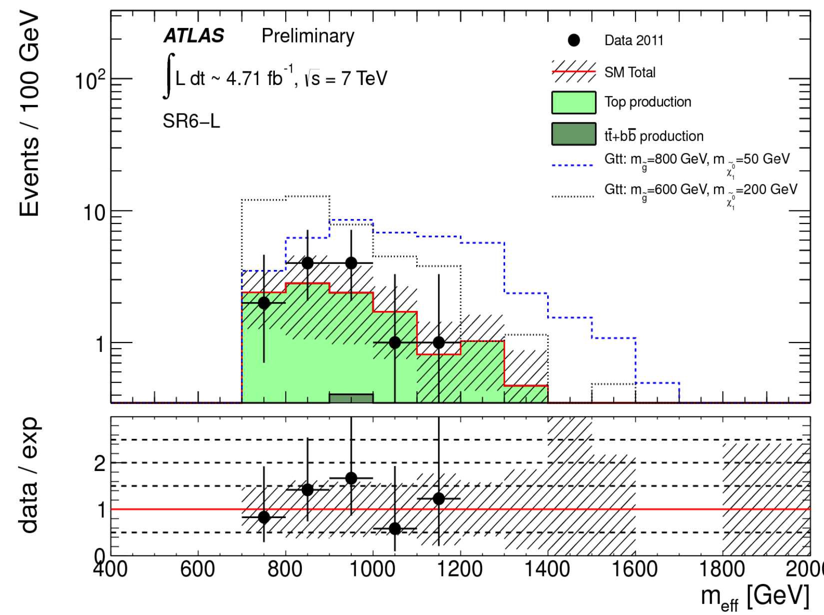
1) Procedure repeated requiring 1-lepton (m_T<100 GeV)

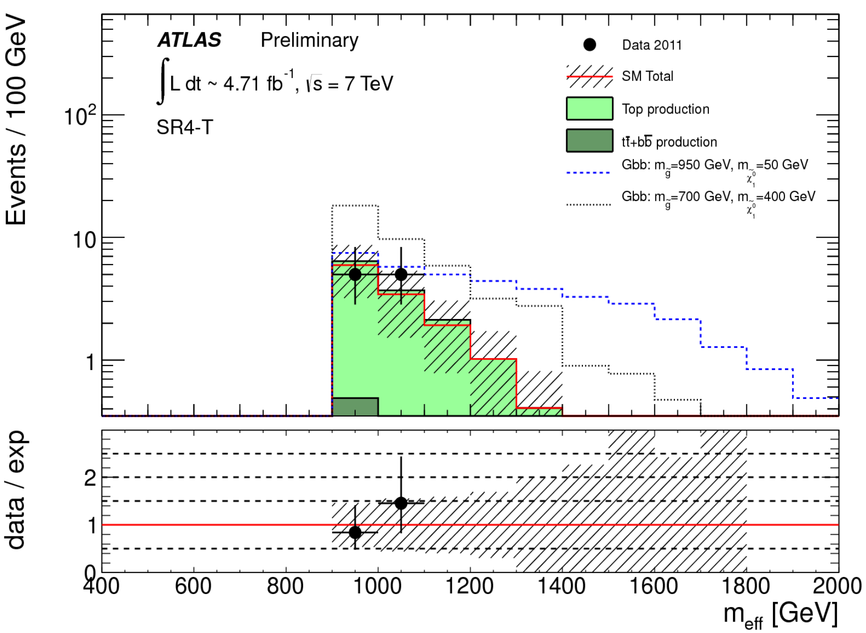
2) Use a data-driven method (~matrix method with b-tags)

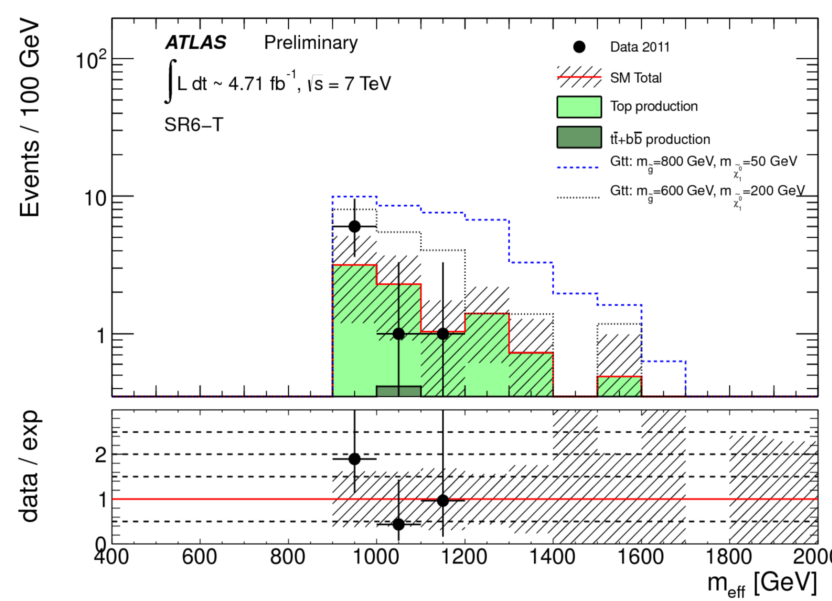
CR	$t\bar{t}$+jets	others	SM	data
CR4-60	329 ± 92	66 ± 26	395 ± 115	402
CR4-70	489 ± 125	102 ± 37	590 ± 160	515
CR6-70	38 ± 11	7 ± 3	45 ± 13	46
CR6-75	40 ± 12	10 ± 4	50 ± 15	52

Gluino-med. 3 b-jets: results

SR	$t\bar{t}$+jets (MC)	others	SM	data
SR4-L	33.3 ± 7.9 (32.6 ± 15.4)	11.1 ± 4.9	44.4 ± 10.0	45
SR4-M	16.4 ± 4.1 (16.1 ± 8.4)	6.6 ± 2.9	23.0 ± 5.4	14
SR4-T	9.7 ± 2.1 (11.4 ± 5.4)	3.8 ± 1.6	13.3 ± 2.6	10
SR6-L	10.3 ± 3.3 (10.0 ± 6.2)	2.4 ± 1.4	12.7 ± 3.6	12
SR6-T	8.3 ± 2.4 (7.9 ± 5.3)	1.6 ± 1.1	9.9 ± 2.6	8

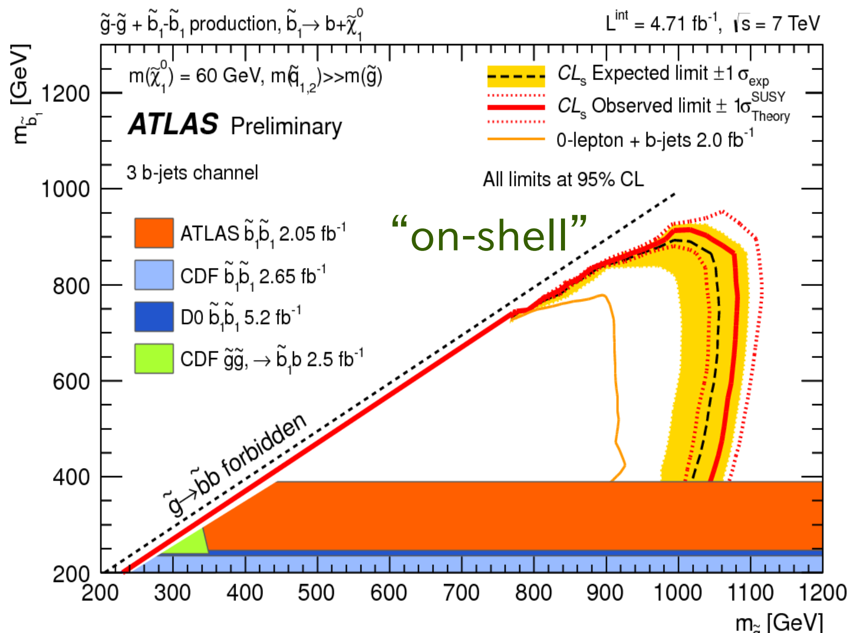


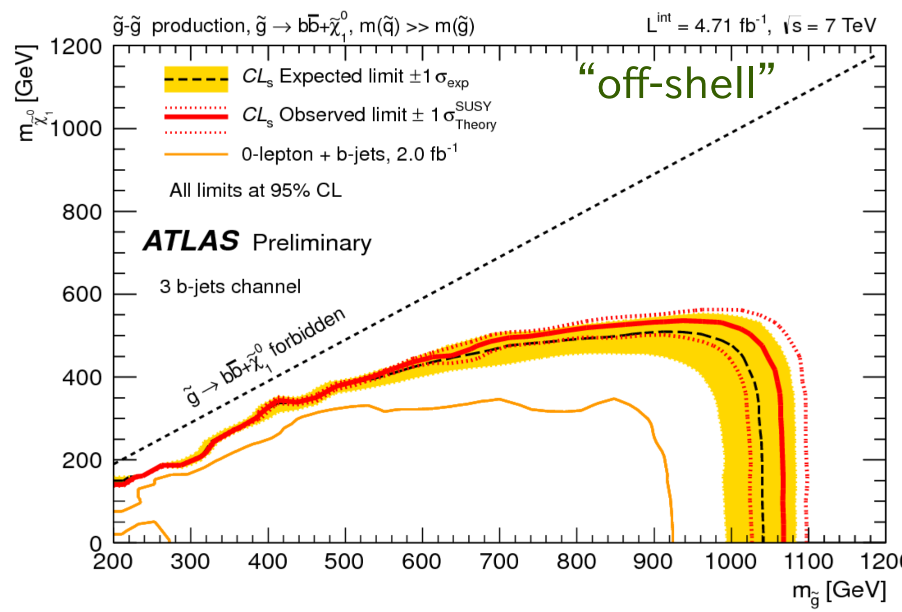




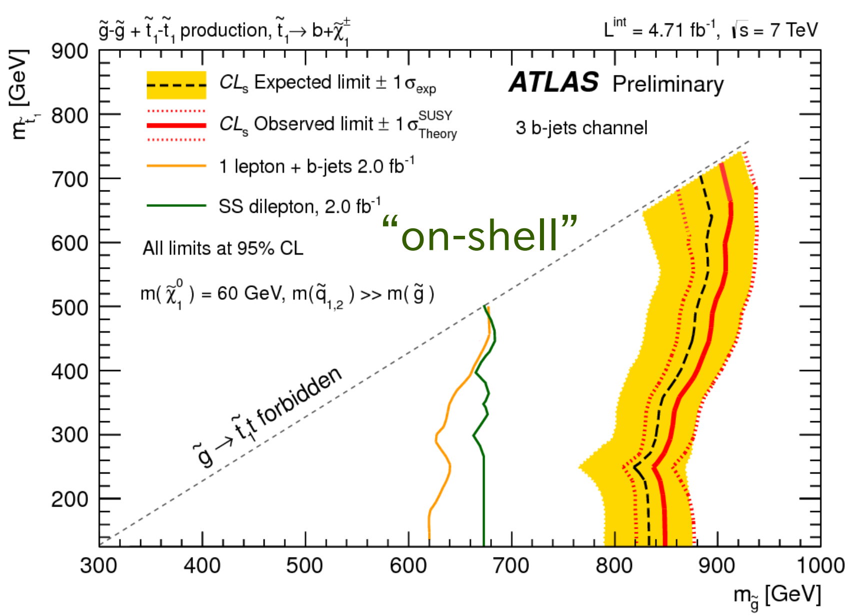
Gluino-mediated limits

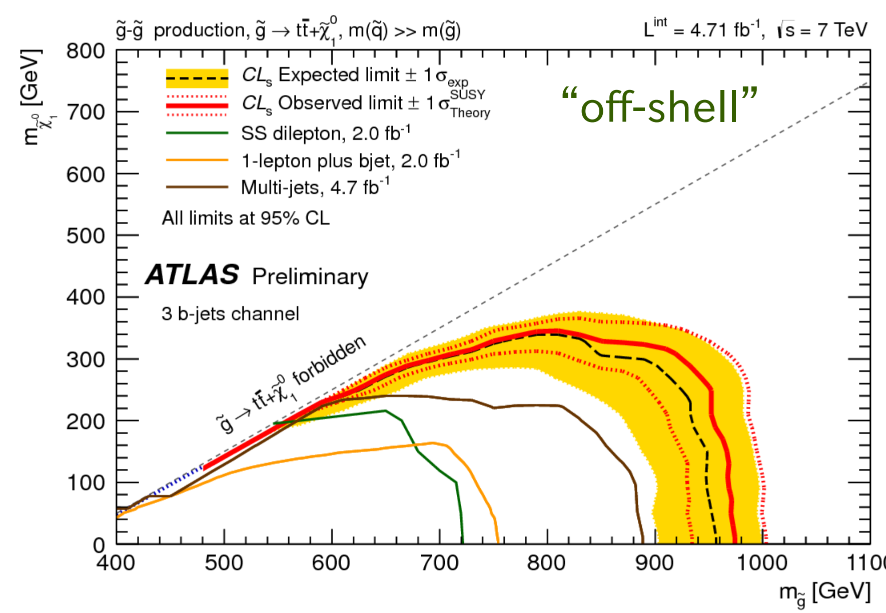
gluino-mediated sbottom



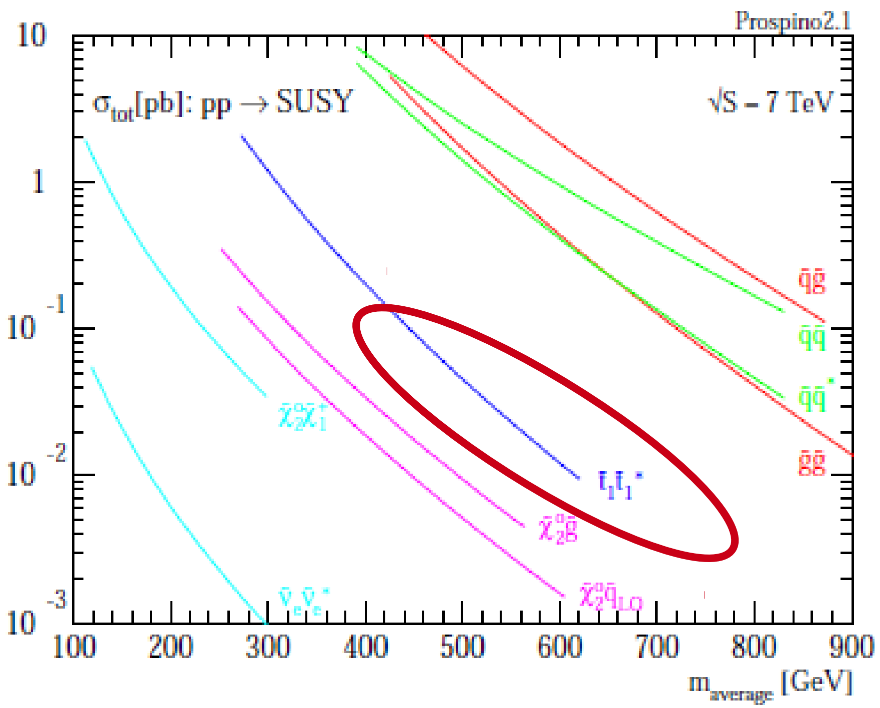


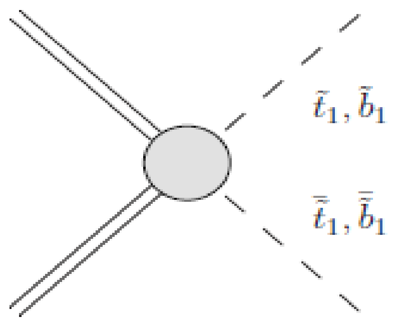
gluino-mediated stop



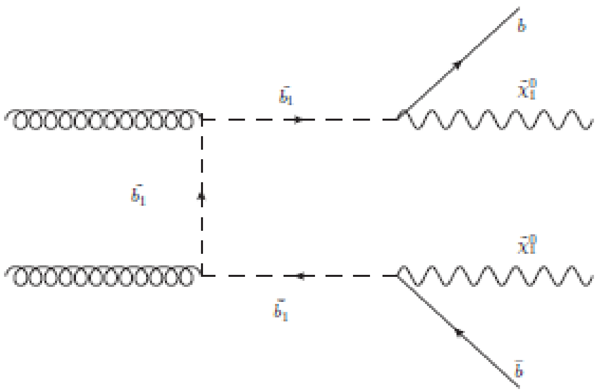


ATLAS searches for direct stop/sbottom production





Direct sbottom production search



Exploiting the "boost-corrected contransverse mass" m_{CT} variable:

$$m_{CT}^2 = [E_T(b_1) + E_T(b_2)]^2 - [\vec{p_T}(b_1) - \vec{p_T}(b_2)]$$

G. Polesello et al, JHEP 03, 030 (2010)

Expect endpoint at:

$$\frac{m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2}{m(\tilde{b}_1)}$$

The higher the LSP, the lower the endpoint (ttbar: ~135 GeV)

- Require **exactly** two jets with p_T>50 GeV (leading: p_T>130 GeV)
- EtMiss >130, EtMiss/meff and min. Δφ(jet, EtMiss)
- No leptons
- m_{CT}>100/150/200 GeV

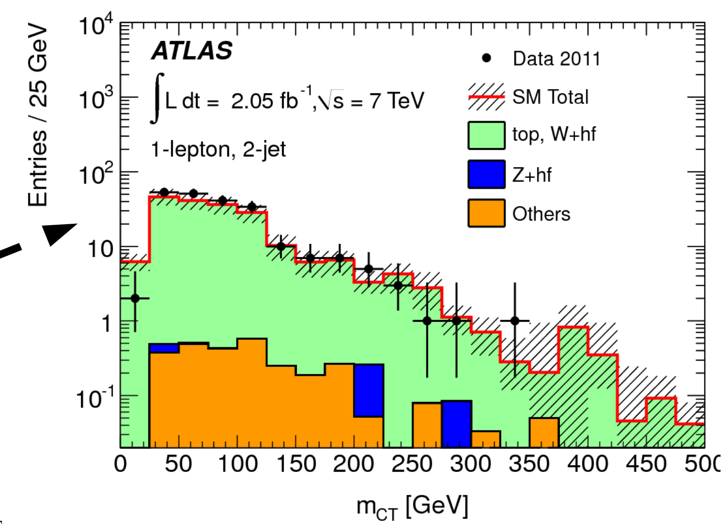
Dominant backgrounds:

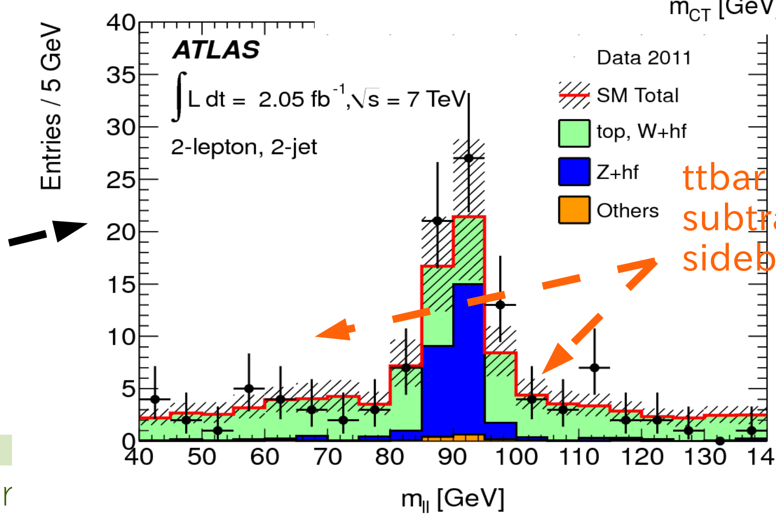
Low m_{CT}: ttbar

High m_{CT}: Z/W+hf and ttbar

Control ttbar and W+hf in 1-lepton region (low m_T)

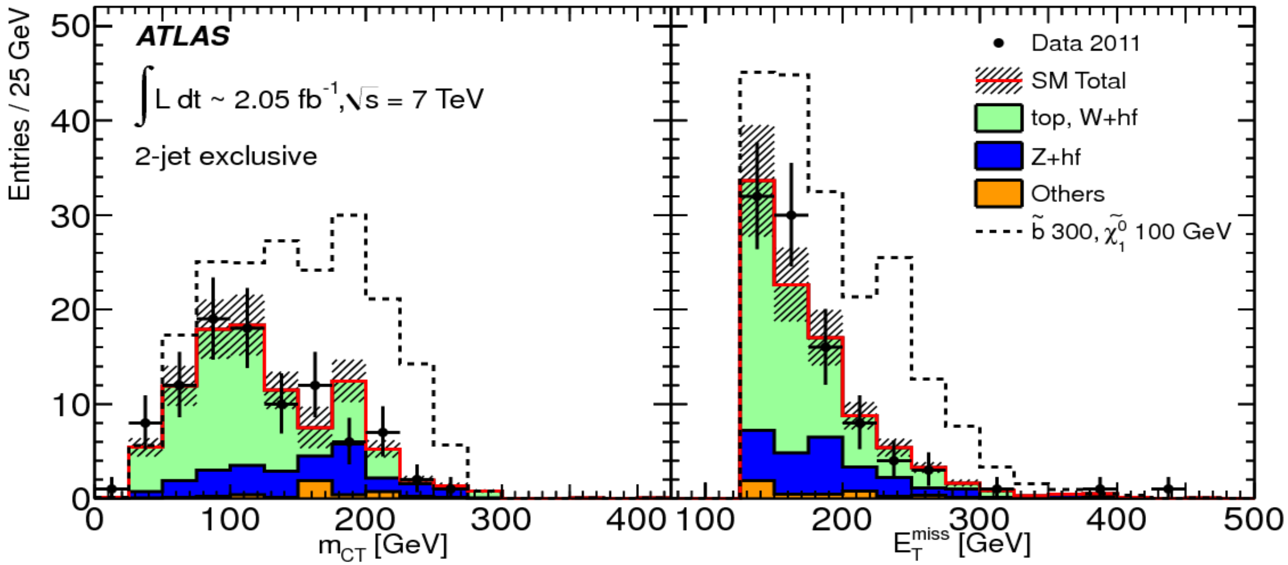
Control Z+hf in 2-lepton region (Z mass peak)





ttbar contamination subtracted from sidebands

Direct sbottom: results

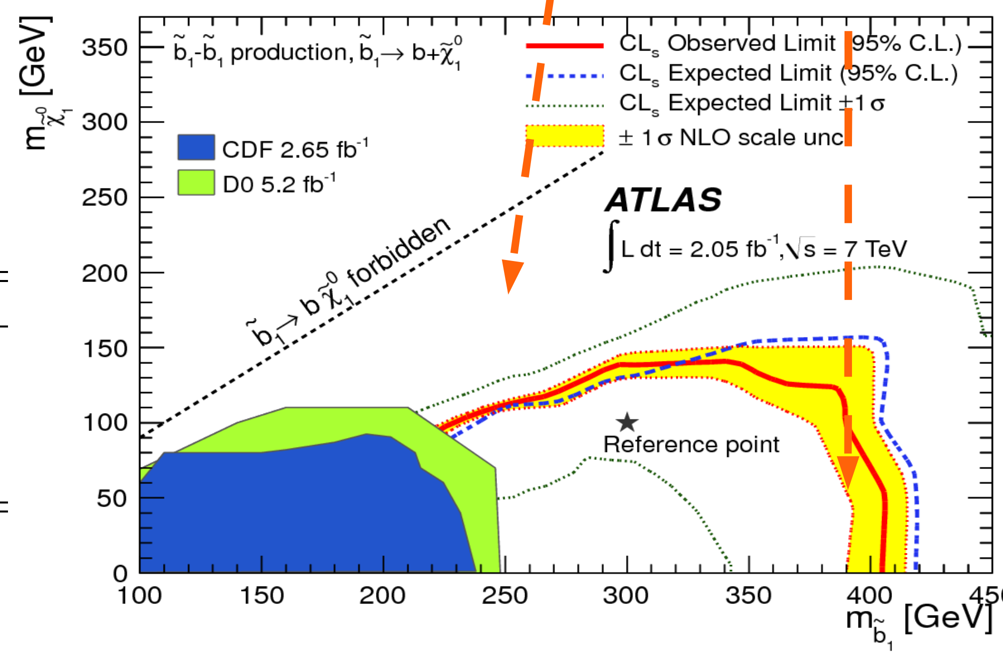


Close to diagonal is challenging: jet p_T, EtMiss, b-tagging and m_{CT} limitations

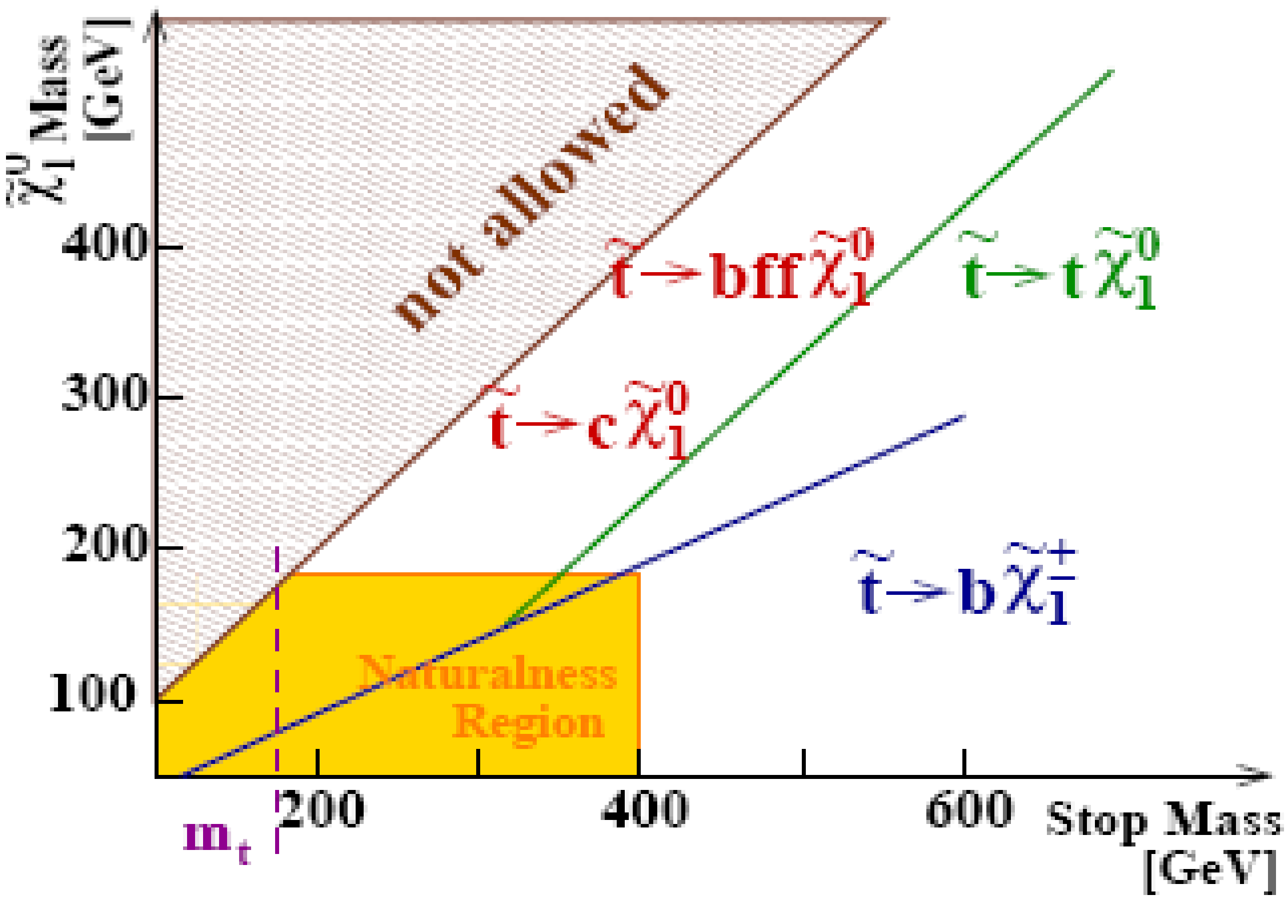
Excluding up to 390 GeV for low LSP masses

Good agreement between data and expectations in all the signal regions

m_{CT} (GeV)	top, Wbb	Zbb	Others	Total SM	Data
0	67 ± 10	23 ± 8	3.6 ± 1.5	94 ± 16	96
100	36 ± 10	23 ± 9	3.1 ± 1.6	62 ± 13	56
150	12 ± 5	12 ± 6	2.7 ± 0.9	27 ± 8	28
200	3.2± 1.6	3.9± 3.2	1.0 ± 0.9	8.1± 3.5	10



Stop phenomenology



Rich phenomenology:

- ✔ Mass difference: stop and LSP
- ✔ Presence of other sparticles (e.g. charginos, neutralino2, sleptons…) in between.

Stop decay preference (general):

- top+LSP *if kinematically allowed (and gauginos not around)*
- chargino+b *if chargino is present*
- virtual W *If chargino is not present*
- charm+LSP *as a last option, via loop*

Other options (not represented) are also possible if sparticles available: chi02, sleptons…

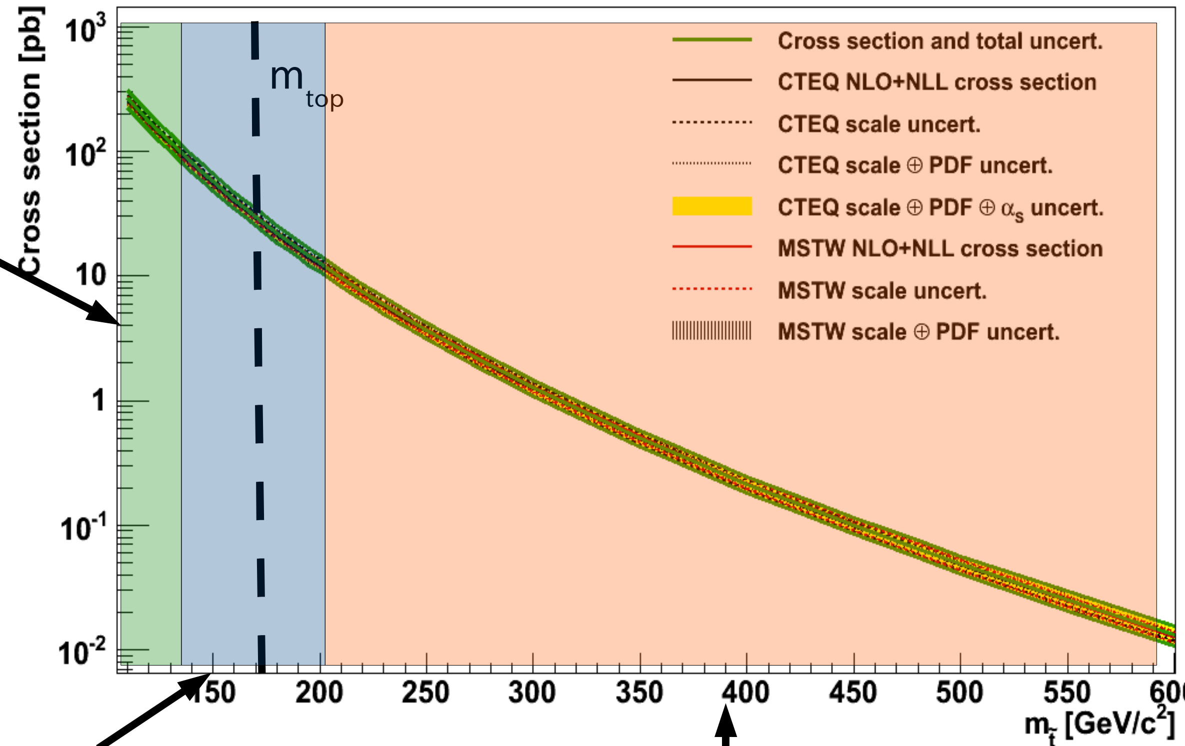
Some theoretical models offer different phenomenology: GMSB…

General strategy for 4.7 fb^{-1}

The large number of topologies require a dedicated strategy to cover the maximum number of possibilities in a coherent way.

Challenge: large SM background and soft objects

2-lepton + jets (very light stop) (4.7 fb^{-1})
ATLAS-CONF-2012-059
http://cdsweb.cern.ch/record/1453787



b-jets + 1-2 lep. (light stop) (4.7 fb^{-1})
ATLAS-CONF-2012-070
http://cdsweb.cern.ch/record/1460267

Challenge: signatures mimic ttbar decay

Challenge: low cross sections

2-leptons + jets (heavy stop) (4.7 fb^{-1})
ATLAS-CONF-2012-071
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0-lepton + jets (heavy stop) (4.7 fb^{-1})
ATLAS-CONF-2012-074
http://cdsweb.cern.ch/record/1460271

1-lepton + jets (heavy stop) (4.7 fb^{-1})
ATLAS-CONF-2012-073
http://cdsweb.cern.ch/record/1460270

Very light stop: 2-leptons

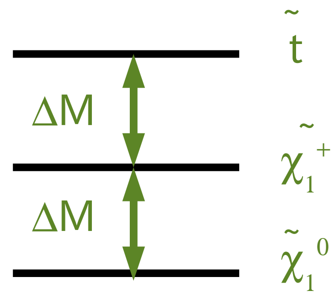
Explore very light stop masses.

Assume:

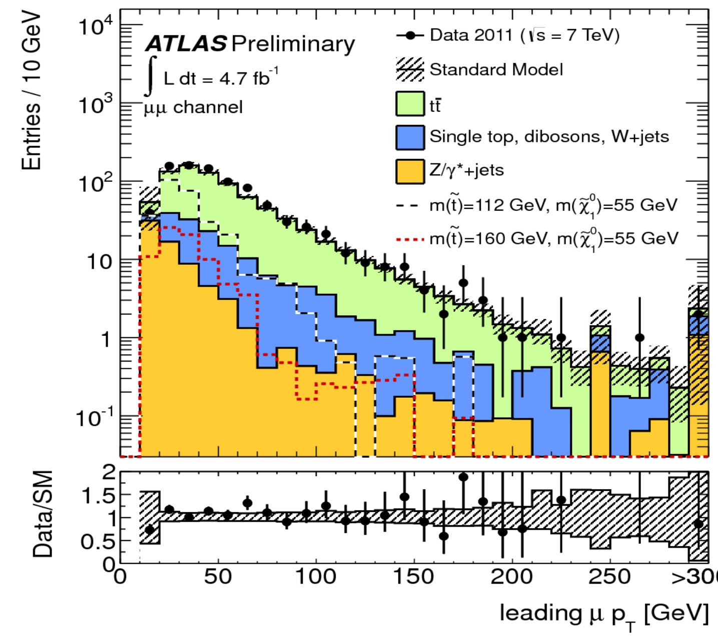
$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow b\tilde{\chi}_1^0 W^{\pm(*)} \rightarrow b\tilde{\chi}_1^0 l\nu$$

100% 100% ~26% (no hadr taus)

Fixed at 106 GeV (just above LEP limits)



For light stop and fixed chargino, small b-jet p_T (b-tagging is very inefficient) and soft products



- Use dileptons: e (p_T>17 GeV) and μ (p_T>12 GeV)
- Use m_{ll}
- >=1 jets: p_T>25 GeV
- Upper cut on the lepton p_T (<30 GeV) and m_{ll}>20 GeV
- EtMiss>20 GeV and EtMiss significance > 7.5 GeV$^{1/2}$

Main backgrounds: ttbar and Z+jets

Minor backgrounds:

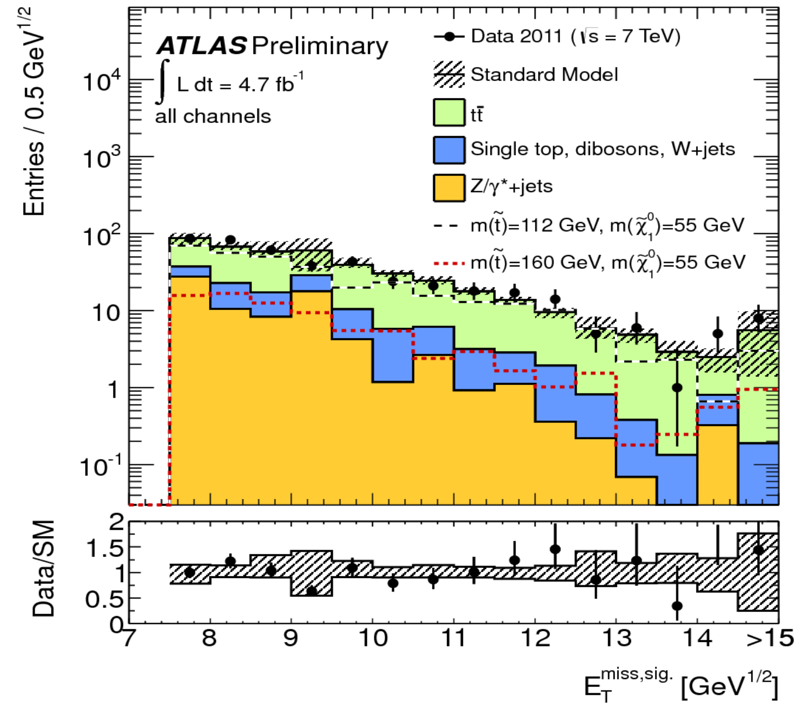
- ✔ single top, diboson, W+jets and Z to emu (from taus): Estimated directly from MC
- ✔ Multijet: template fitting method (~negligible)

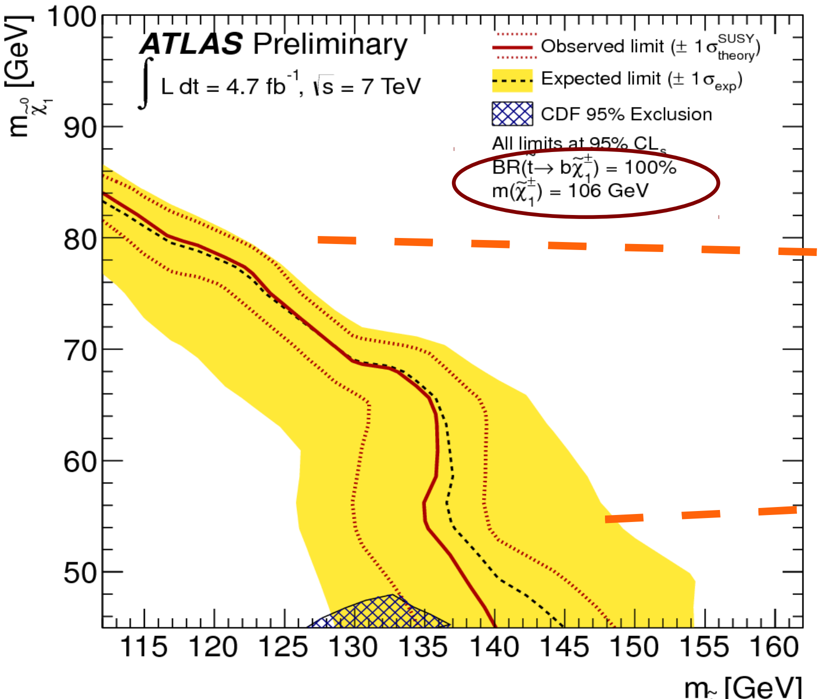
- Top CR: same cuts but require at least one b-tagged jet
- Z CR: require ee and μμ within Z mass window (81<m_{ll}<101 GeV)

Very light stop: results

Results

	ee	$e\mu$	$\mu\mu$	all
$t\bar{t}$	$44 \pm 4 \pm 5$	$139 \pm 7 \pm 22$	$111 \pm 8 \pm 10$	$293 \pm 12 \pm 34$
Z/γ^*+jets	$5 \pm 1 \pm 2$	$23 \pm 2 \pm 8$	$48 \pm 16 \pm 27$	$76 \pm 16 \pm 27$
Single top	$3 \pm 0.5 \pm 1$	$12 \pm 1 \pm 2$	$12 \pm 1 \pm 2$	$28 \pm 2 \pm 5$
W+jets	$3 \pm 3 \pm 3$	$5 \pm 2 \pm 1$	$6 \pm 2 \pm 1$	$13 \pm 3 \pm 3$
Diboson	$4 \pm 0.4 \pm 0.5$	$9 \pm 0.7 \pm 2$	$10 \pm 0.7 \pm 1$	$22 \pm 1 \pm 3$
multijet	$2.9 ^{+3.2}_{-2.9} \pm 2.2$	$2.0 \pm 1.4 \pm 0.3$	$3.0 \pm 2.8 \pm 0.3$	$8.0 \pm 3.7 \pm 2.3$
Total	$61 \pm 6 \pm 6$	$189 \pm 8 \pm 21$	$190 \pm 19 \pm 31$	$440 \pm 21 \pm 43$
Data	48	188	195	431
σ_{vis} (exp. limit) [fb]	4.9	11.1	16.2	22.0
σ_{vis} (obs. limit) [fb]	3.3	10.9	16.9	21.0





Reaching the low p_T regime for the lepton (neutralino closer to chargino)

Lepton p_T is similar to the top and the cross section is lower

Light stop: 1-/2-lepton channels

Explore stop masses below and around the top mass

Assume:

$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow b\tilde{\chi}_1^0 W^{\pm(*)} \rightarrow b\tilde{\chi}_1^0 l\nu$$

100% 100% ~26% (no hadr taus)

1-lepton

- Only 1-lepton: e (p_T>25 GeV) and μ (p_T>20 GeV)
- Top mass objects: >=4 jets (2 b-tagged) and EtMiss
- m_T(lepton, EtMiss)>30 GeV
- Exploit hadronic top mass (upper cut)

2-leptons

- Exactly 2 OS leptons: ee, μμ, eμ
- Top mass objects: >=2 jets (1 b-tagged) and EtMiss
- Exploit m(lljj) distribution (upper cut)

Final discriminating variable:

$$\sqrt{s}_{min}^{(sub)} = \left[\left(\sqrt{m_{sub}^2 + p_{T,sub}^2} + \sqrt{m_{miss}^2 + E_{T,miss}^2} \right)^2 - \left(p_{T,sub} + p_{T,miss} \right)^2 \right]^{1/2}$$

P. Konar et al, JHEP 1106:041,2011

It is the global minimum mass compatible with the hard-scattering (built from Mandelstam variables)

Expect peak below the 2∗m_{top} when:

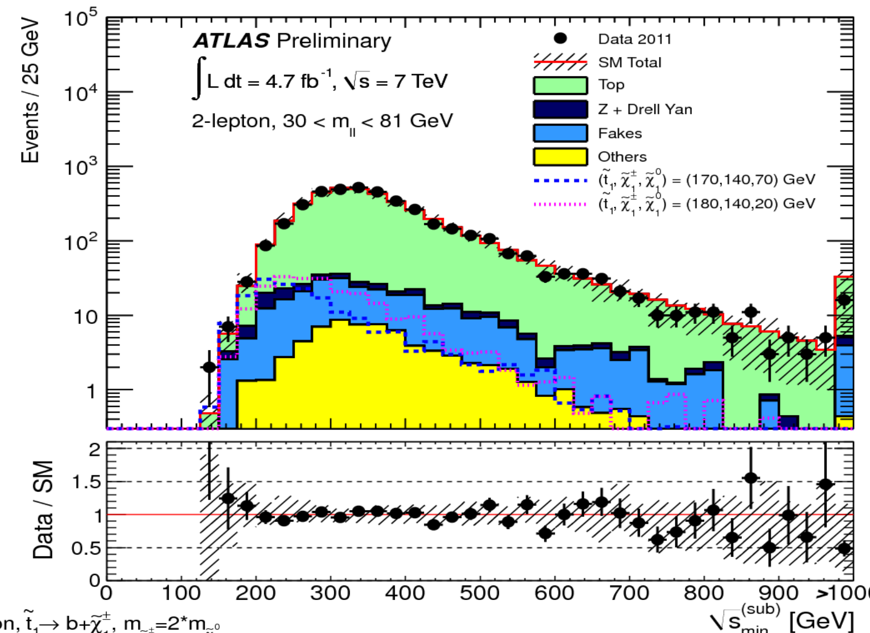
- ✔ $m_{stop} < m_{top}$
- ✔ $m_{stop} - m_{LSP} < m_{top}$

Main backgrounds: top and boson+heavy flavour
Controlled in dedicated signal-suppressed regions

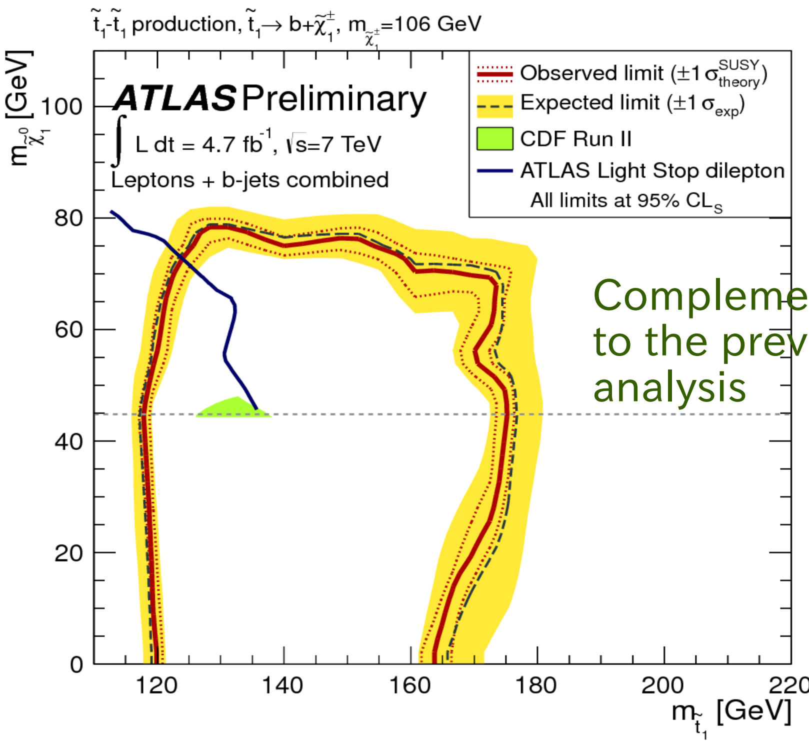
Light stop: results

Results

Process	1LSR	2LSR1	2LSR2
	Number of events		
Top	$24 \pm 3 \pm 5$	$89 \pm 6 \pm 10$	$36 \pm 2 \pm 5$
W+jets	$6 \pm 1 \pm 2$	n/a	n/a
Z+jets	$0.5 \pm 0.3 \pm 0.3$	$11 \pm 4 \pm 3$	$3 \pm 1 \pm 1$
Fake leptons	$7 \pm 1 \pm 2$	$12 \pm 5 \pm 11$	$6 \pm 4 \pm 4$
Others	$0.3 \pm 0.1 \pm 0.1$	$2.7 \pm 0.9 \pm 0.7$	$0.9 \pm 0.2 \pm 0.5$
Total SM	$38 \pm 3 \pm 7$	$115 \pm 8 \pm 15$	$46 \pm 4 \pm 7$
Data	50	123	47

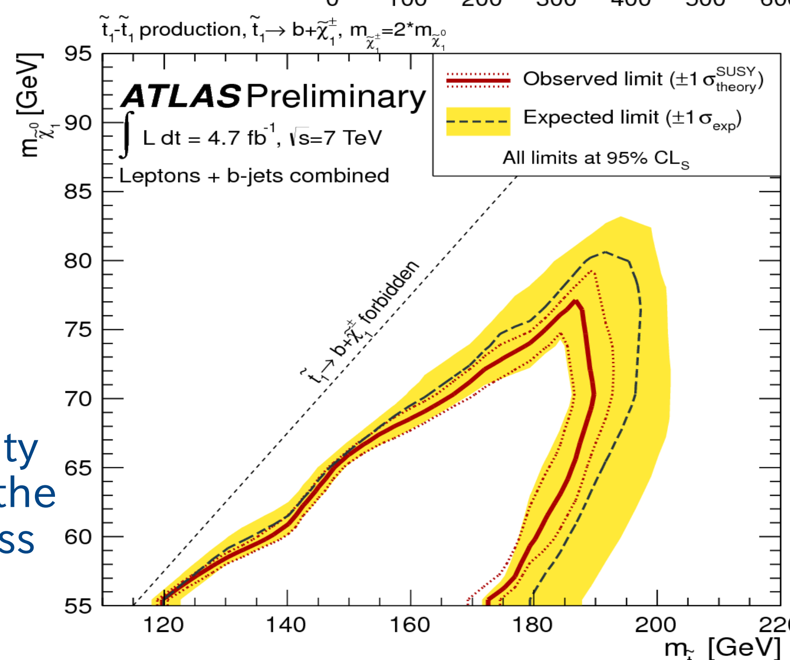


The sensitivity of the two analyses is combined



Complementary to the previous analysis

Sensitivity around the stop mass



Interpretation in the gaugino unification case ($m_{charg}=2*m_{LSP}$)

See backup slides for relaxed unification condition

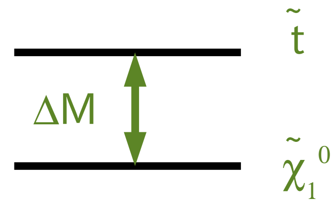
Heavy stop: 0-lepton

Explore stop masses above top with 0-lepton

Assume:

$$\tilde{t}\bar{\tilde{t}} \rightarrow \tilde{\chi}_1^0 t \tilde{\chi}_1^0 \bar{t}$$

100%

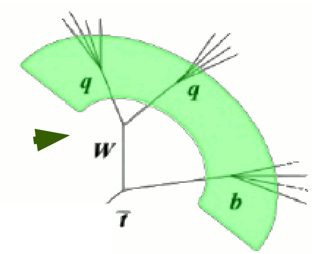


→ Determines the p_T spectrum of the final state

Exploiting the fact that exist two hadronic top decays with significant EtMiss

- >= 6 jets (p_T>130 GeV and 30 GeV) (>=1 b-tag)
- Several topological cuts applied (EtMiss angles, tracking vs calorimeter information, m_{jjj}...)
- Reduce taus with tracking information and m_T

Minimum ΔR technique



Backgrounds:

Dominated by ttbar (esp. taus)

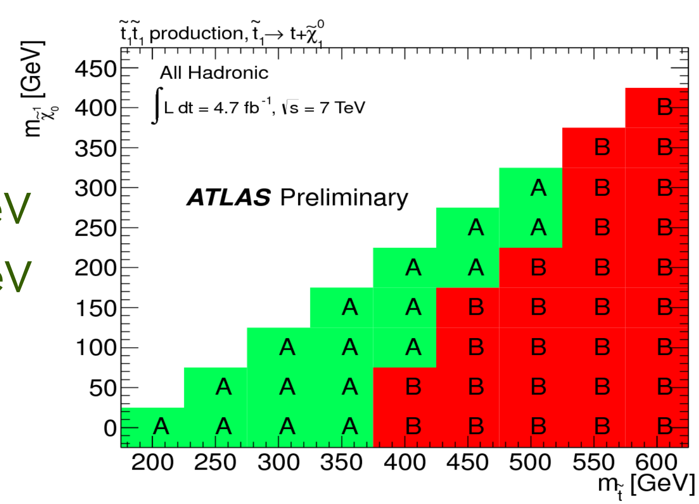
Controlled with lepton:

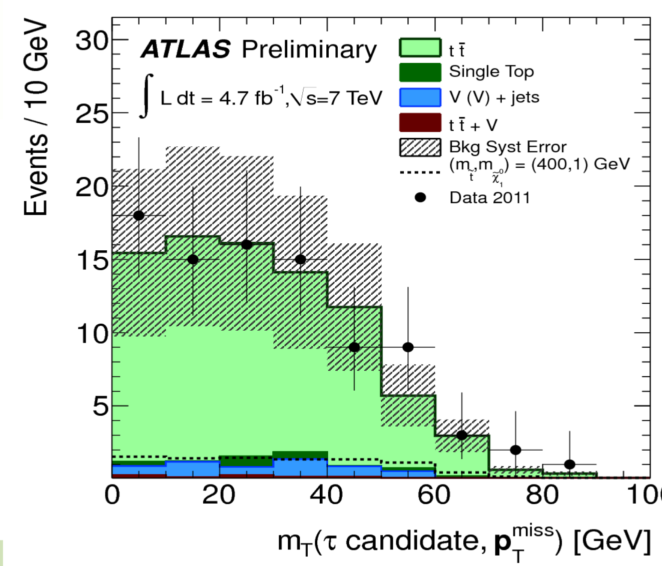
- ✔ 60<m_T(l,EtMiss)<120 GeV
- ✔ >=5 jets
- ✔ Assume lepton is a jet

2 SRs defined:

A: EtMiss>150 GeV

B: EtMiss>260 GeV

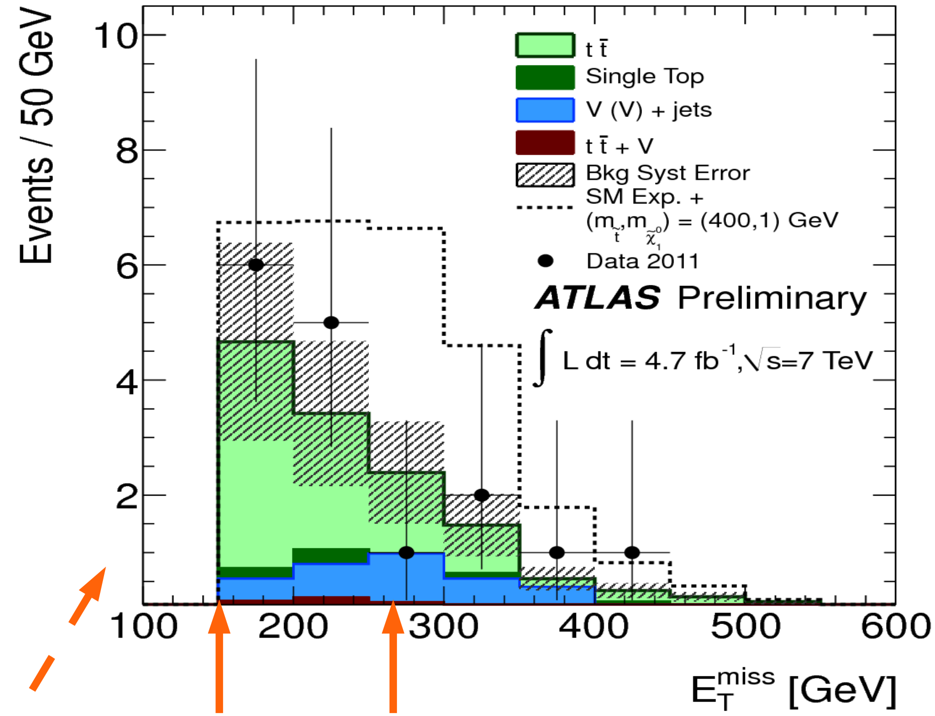




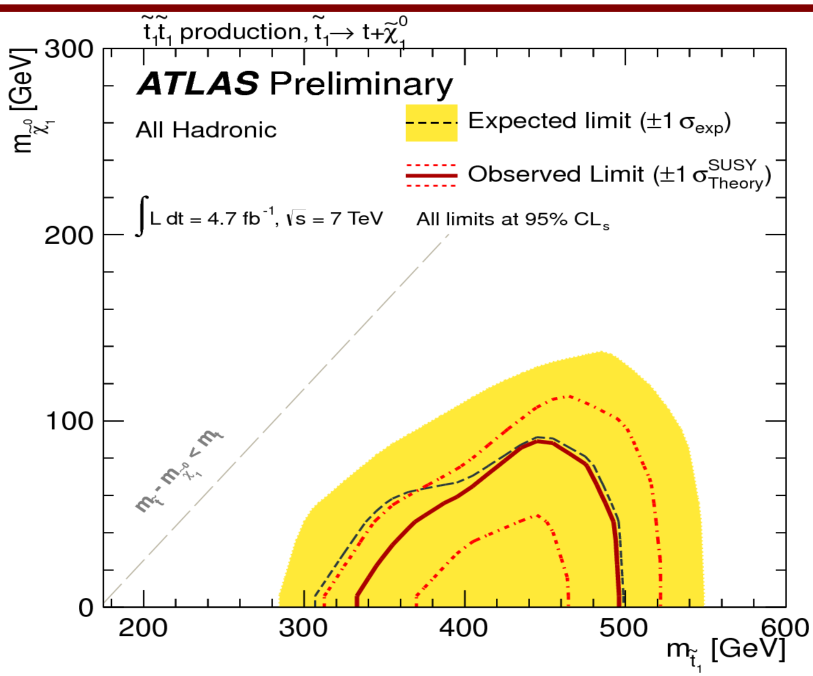
Heavy stop: 0-lepton results

Results

	SRA	SRB
E_T^{miss}	> 150 GeV	> 260 GeV
$t\bar{t}$	9.2 ± 2.7	2.3 ± 0.6
$t\bar{t} + W/Z$	0.8 ± 0.2	0.4 ± 0.1
Single top	0.7 ± 0.4	$0.2\ ^{+0.3}_{-0.2}$
Z+jets	$1.3\ ^{+1.1}_{-1.0}$	$0.9\ ^{+0.8}_{-0.7}$
W+jets	$1.2\ ^{+1.4}_{-1.0}$	0.5 ± 0.4
Diboson	$0.1\ ^{+0.2}_{-0.1}$	$0.1\ ^{+0.2}_{-0.1}$
Multi-jets	0.2 ± 0.2	0.02 ± 0.02
Total SM	$13.5\ ^{+3.7}_{-3.6}$	$4.4\ ^{+1.7}_{-1.3}$
SUSY $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (400, 1)$ GeV	14.8 ± 4.0	8.9 ± 3.1
Data (observed)	16	4



150 GeV 260 GeV



ttbar is the only significant background

No significant excess found.
Systematic uncertainties are challenging.
Dominated by theoretical uncertainties in ttbar (large jet multiplicity)

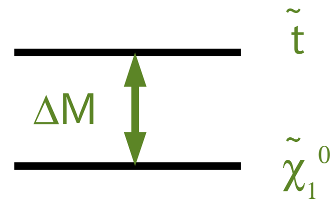
Heavy stop: 1-lepton

Explore stop masses above top with 1-lepton

Assume:

$$\tilde{t}\bar{\tilde{t}} \rightarrow \tilde{\chi}_1^0 t \tilde{\chi}_1^0 \bar{t}$$

100%

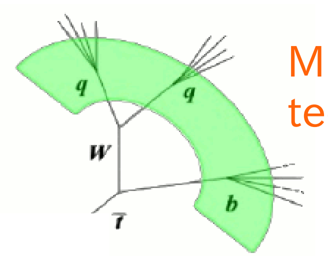


Determines the p_T spectrum of the final state. Lepton provides extra handles.

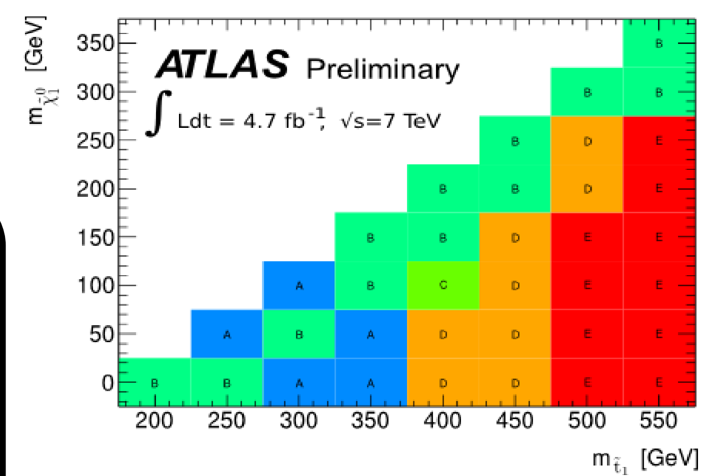
- One lepton (veto a second)
- >= 4 jets p_T>(80/60/40/25) GeV (>=1 b-tag)
- $\Delta\phi$(2 leading jets,EtMiss)>0.8
- Require 130<m_{jjj}<205 GeV

Increase thresholds →

Requirement	SR A	SR B	SR C	SR D	SR E
E_T^{miss} [GeV] >	150	150	150	225	275
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	7	9	11	11	11
m_T [GeV] >	120	120	120	130	140



Minimum ΔR technique



Backgrounds

ttbar
W+jets } →
Multijets, Z, ttbar+X (minor)

Perform simultaneous fit in three regions to normalise:

- ✔ Top 2-l: with relaxed jet and m_T criteria
- ✔ Top 1-l: with 60<m_T<90 GeV
- ✔ W: anti-b-tag

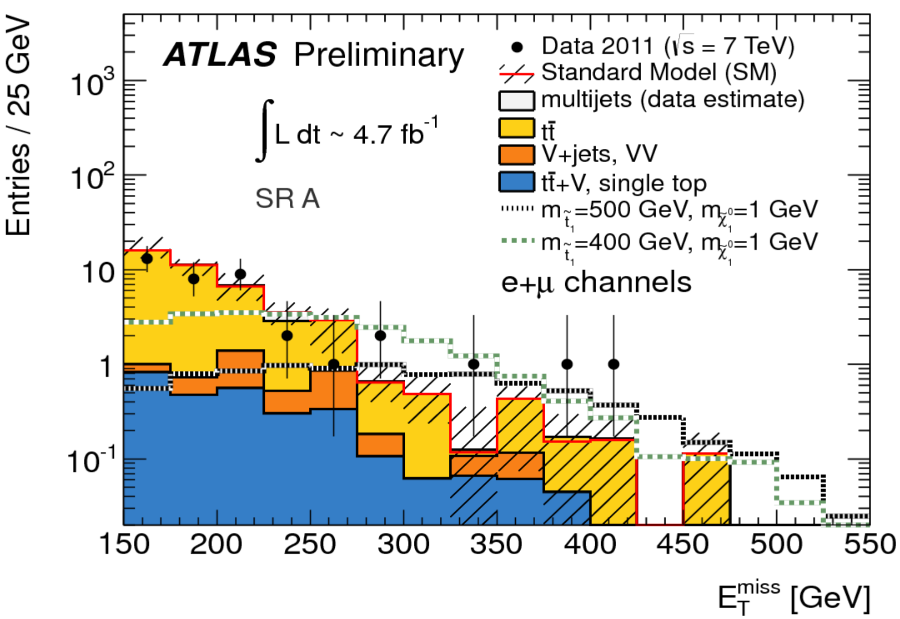
Dominating systematics: theory uncertainties on ttbar modelling

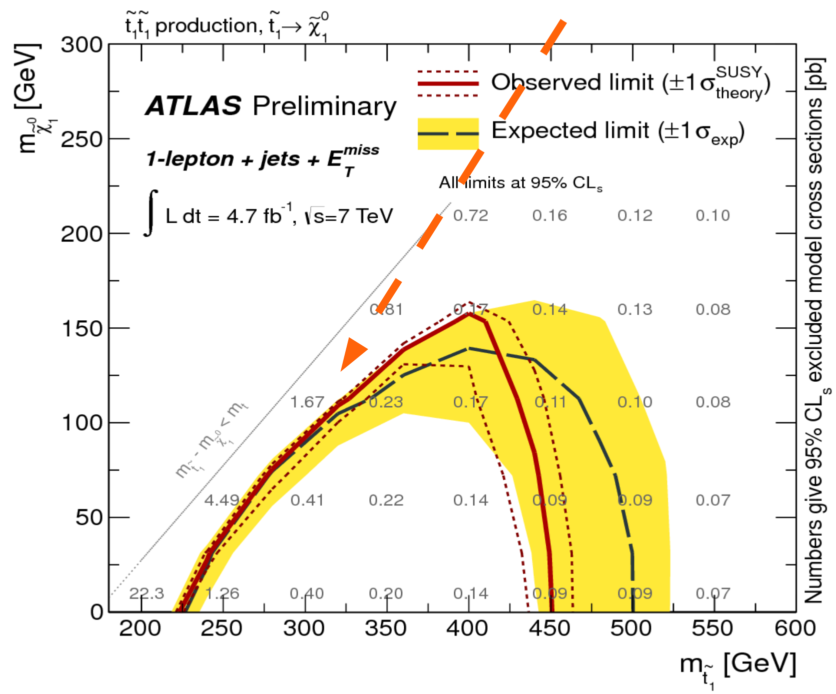
Heavy stop: 1-lepton results

Results

Regions	SR A	SR B	SR C	SR D	SR E
$t\bar{t}$	36 ± 5	27 ± 4	11 ± 2	4.9 ± 1.3	1.3 ± 0.6
$t\bar{t} + V$, single top	2.9 ± 0.7	2.5 ± 0.6	1.6 ± 0.3	0.9 ± 0.3	0.4 ± 0.1
V+jets, VV	2.5 ± 1.3	1.7 ± 0.8	0.4 ± 0.1	0.3 ± 0.1	0.1 ± 0.1
Multijet	$0.4^{+0.4}_{-0.4}$	$0.3^{+0.3}_{-0.3}$	$0.3^{+0.3}_{-0.3}$	$0.3^{+0.3}_{-0.3}$	$0.0^{+0.3}_{-0.0}$
Total background	42 ± 6	31 ± 4	13 ± 2	6.4 ± 1.4	1.8 ± 0.7
Signal benchmark 1 (2)	25.6 (8.8)	23.0 (8.1)	17.5 (6.9)	13.5 (6.2)	7.1 (4.5)
Observed events	38	25	15	8	5
p_0-values	0.5	0.5	0.32	0.24	0.015

Diagonal: getting closer to ttbar topologies





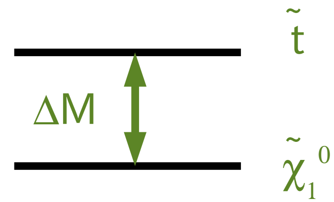
Medium stop: 2-leptons

Explore stop masses above top with 2-leptons

Assume:

$$\tilde{t}\bar{\tilde{t}} \rightarrow \tilde{\chi}_1^0 t \tilde{\chi}_1^0 \bar{t}$$

100%



→ Determines how soft is the final state

Exploiting the m_{T2} variable:

$$m_{T2} = \min_{\vec{q}_T^{\,1} + \vec{q}_T^{\,2} = \vec{p}_T^{\,miss}} \{\max[m_T(p_T^{l_1}, \vec{q}_T^{\,1}), m_T(p_T^{l_2}, \vec{q}_T^{\,2})]\}$$

A. Barr et al, J. Phys. G29 (2003) 2343-2363

- ✔ Signal: kinematic edge around the stop-LSP mass difference
- ✔ Background (esp. top): sharp edge around W mass)

- Exactly two leptons with m(ll)>20 GeV
- Two jets with p_T>(50,25) GeV

Same Flavour (SF) →

- >=1 b-jet
- m_{ll}<71 and >111 GeV
- m_{T2} >120 GeV

Different Flavour (DF) →

- m_{T2} >120 GeV

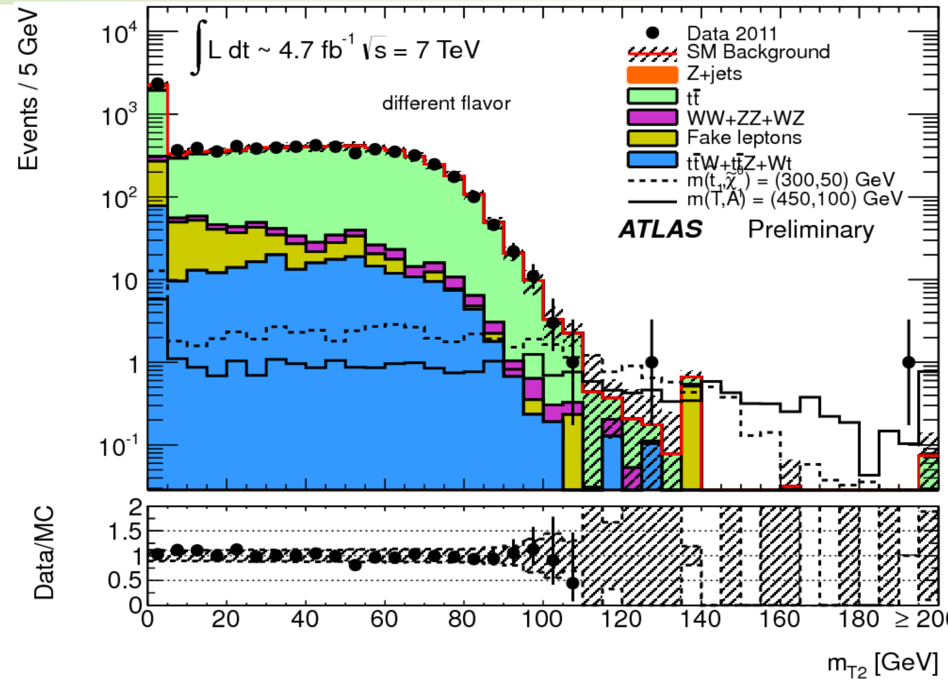
Backgrounds:
- ttbar: same selections but 85<m_{T2}<100 GeV
- Z+jets: use Z mass peak
- QCD multijets: matrix method
- Diboson and ttbar+X: MC-only

Systematics dominated by theory uncertainties. Larger in the DF case because top relative contribution is larger.

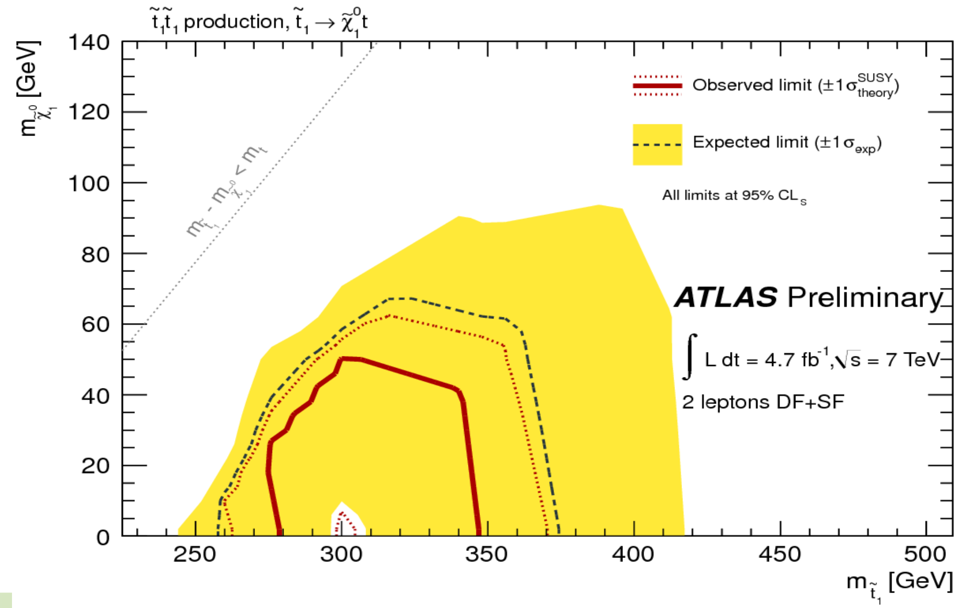
Medium stop: 2-leptons results

Results

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



The SF and DF categories are combined to maximise the sensitivity

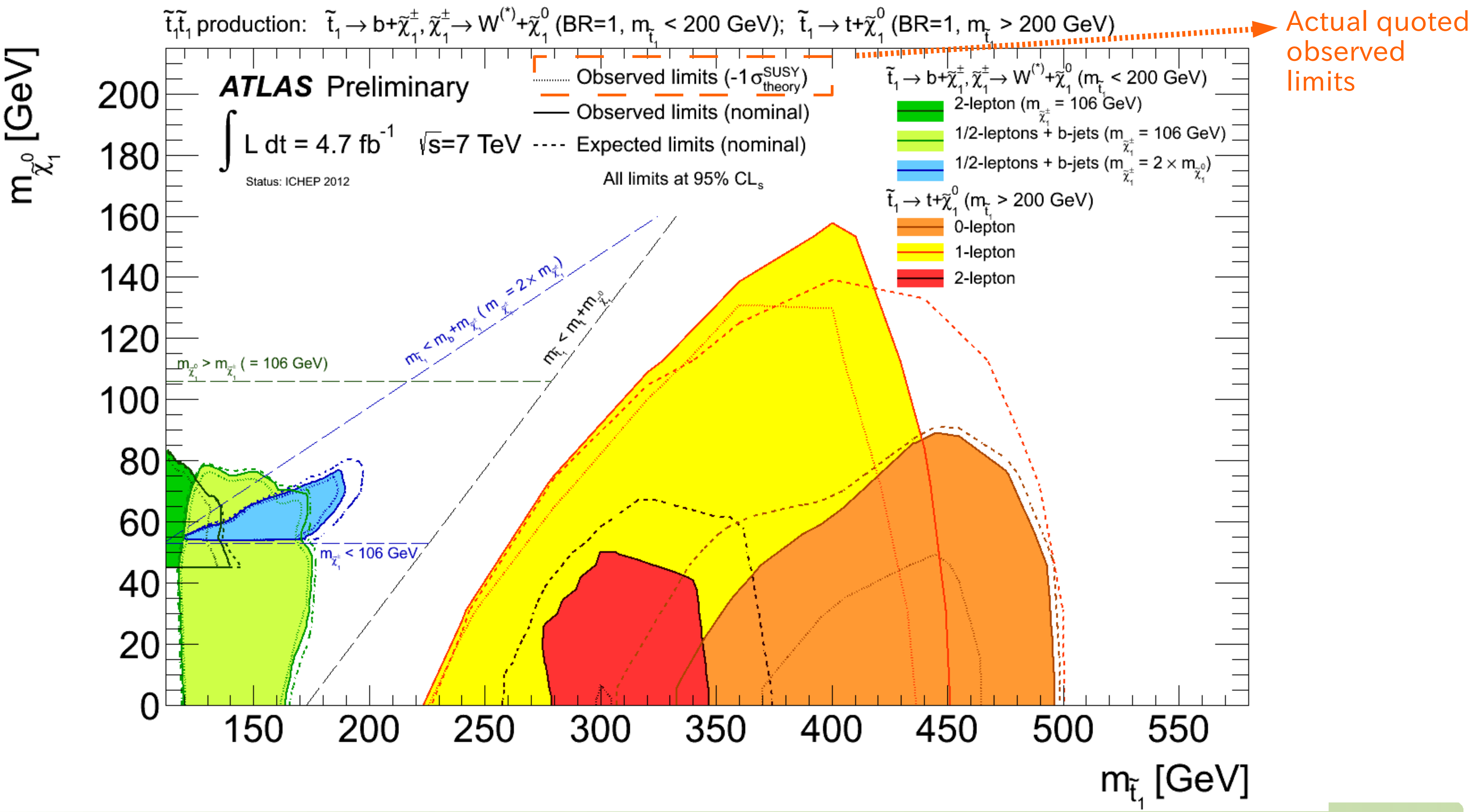


Note: signature is identical to T (spin ½ partner of the top quark). Interpretation also in this theory. Better limits in these scenarios due to 6 times larger cross sections due to spin effects (see backup).

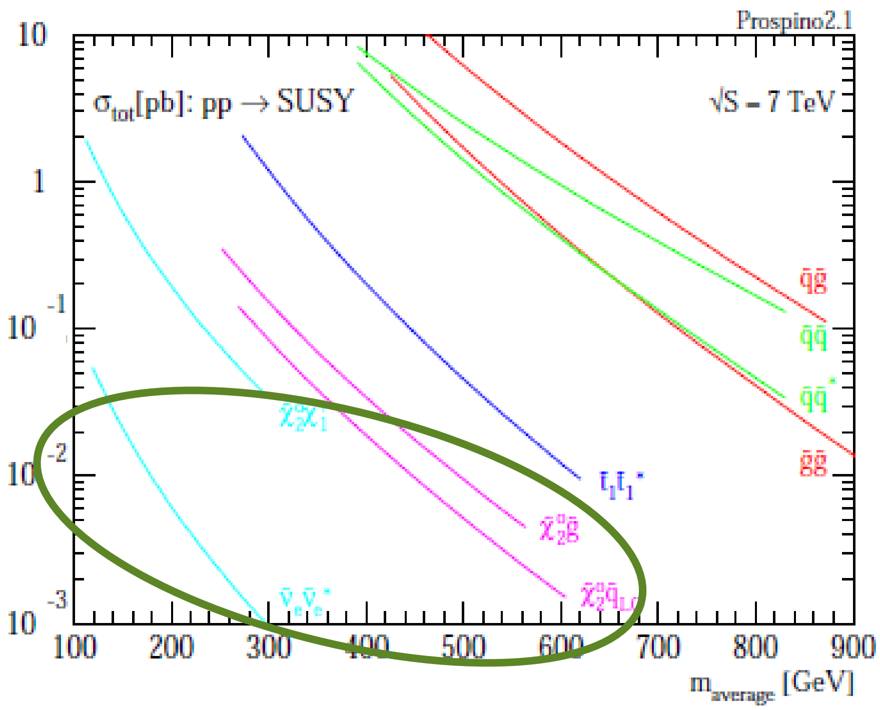
Stop searches: summary

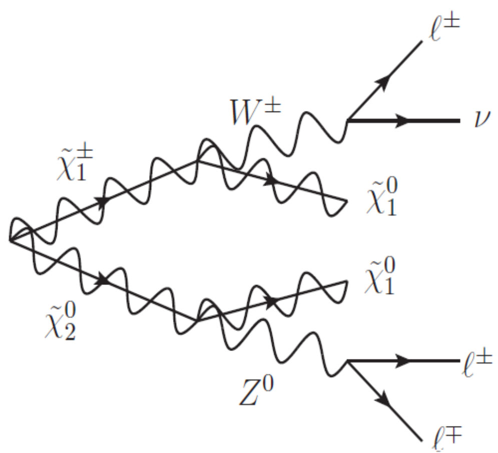
The different dedicated strategies developed help covering most of the stop mass range for which there is reasonable sensitivity.

The absence of significant excesses is translated into observed 95% CL exclusion limits.



ATLAS searches for direct gaugino/slepton production

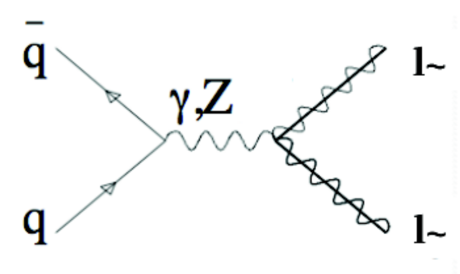




Benchmark for direct gaugino: 3-lepton

Benchmark for slepton: 2-lepton

But 2-lepton is also important for direct gaugino searches

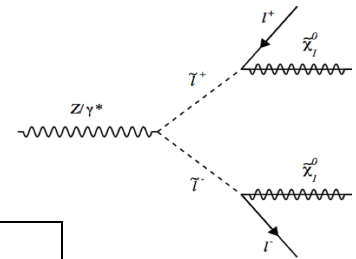


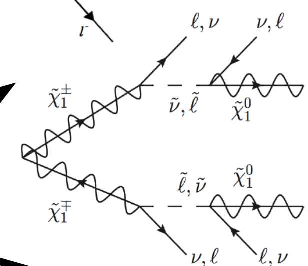
2-leptons (4.7 fb^{-1})
ATLAS-CONF-2012-076
http://cdsweb.cern.ch/record/1460273

Direct gaugino/slepton: 2-leptons

Explore scenarios with sleptons (BR to leptons enhanced)
Many different possibilities:

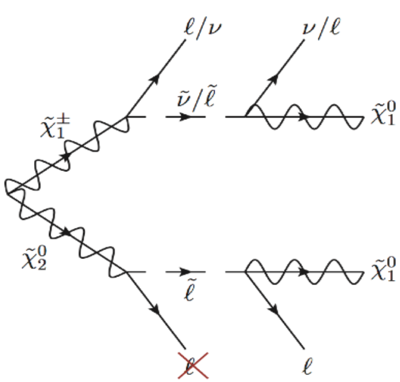
Targeted Process	Signal Region
Two Lepton Final States	
$\tilde{l}^{\pm}\tilde{l}^{\mp} \rightarrow (l^{\pm}\tilde{\chi}_1^0) + (l^{\mp}\tilde{\chi}_1^0)$	SR-m_{T2}
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \rightarrow (l^{\pm}\nu\tilde{\chi}_1^0) + (l^{\mp}\nu\tilde{\chi}_1^0)$	SR-m_{T2}, SR-OSjveto
$\tilde{\chi}_2^0\tilde{\chi}_i \rightarrow (l^{\pm}l^{\mp}\tilde{\chi}_1^0) + (q\bar{q}'\tilde{\chi}_1^0)$	SR-2jets
Three Lepton Final States	
$\tilde{\chi}_2^0\tilde{\chi}_1^{\pm} \rightarrow (l^{\pm}l^{\mp}\tilde{\chi}_1^0) + (l^{\pm}\nu\tilde{\chi}_1^0)$	SR-OSjveto, SR-SSjveto





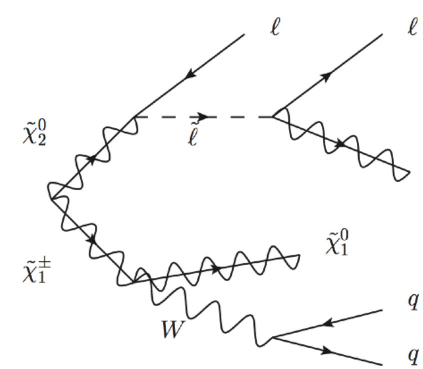
SR-m_{T2}
- ✔ 2 OS leptons
- ✔ Z-veto
- ✔ No jets
- ✔ **EtMiss^{Rel}>40 GeV**
- ✔ **m_{T2}>90 GeV**

SR-OSjveto
- ✔ 2 OS leptons
- ✔ Z-veto
- ✔ No jets
- ✔ **EtMiss^{Rel}>100 GeV**



SR-SSjveto
- ✔ 2 SS leptons
- ✔ No jets
- ✔ **EtMiss^{Rel}>100 GeV**

SR-2-jets
- ✔ 2 OSSF leptons
- ✔ Z-veto
- ✔ >=2 jets (no b-jet)
- ✔ **EtMiss^{Rel}>50 GeV**
- ✔ **m_{CT}-veto**



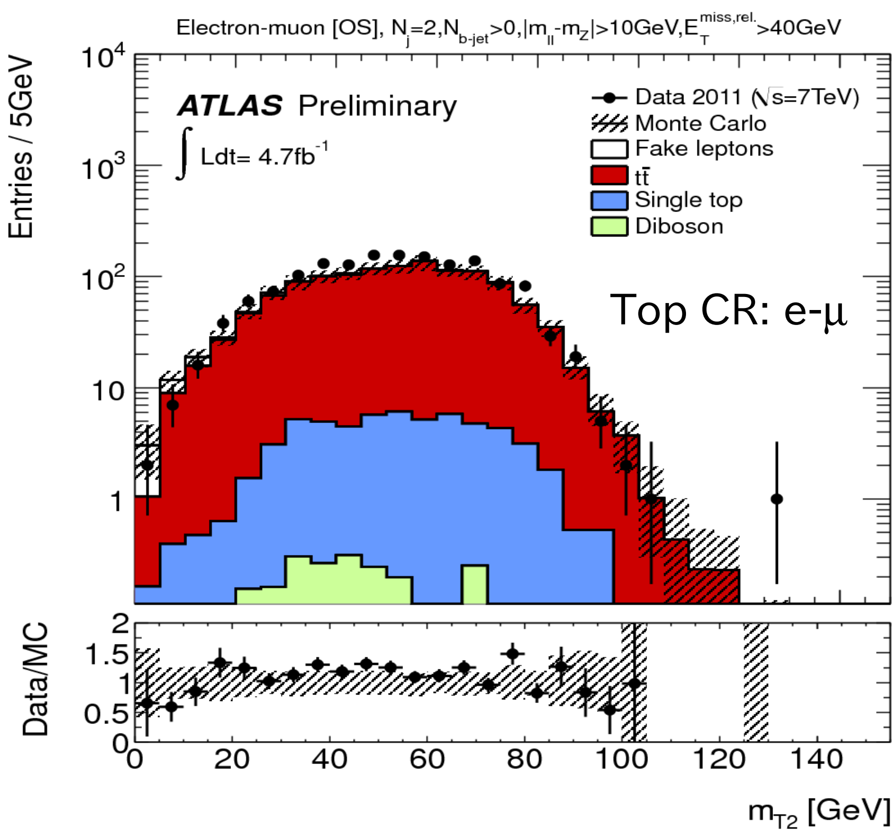
$$E_{T,rel}^{miss} = \begin{cases} E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \\ E_T^{miss} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \end{cases}$$

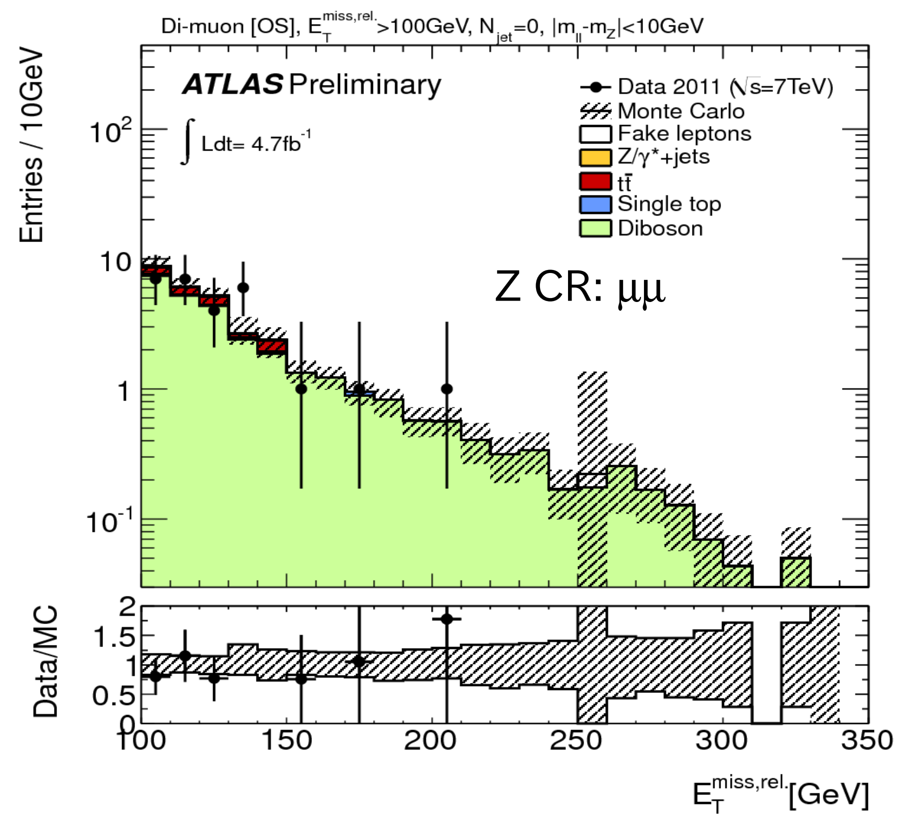
2-leptons background validation

Different techniques used depending on the background:

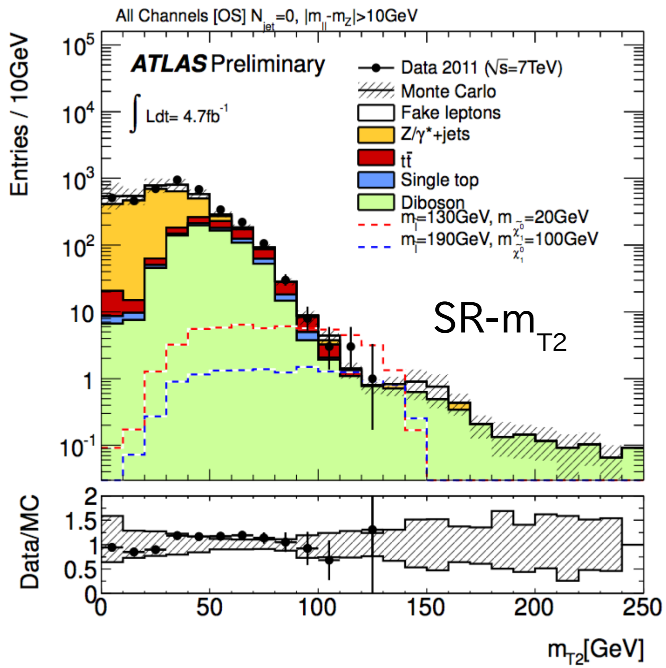
- Top background and Z+X (X=jets,W,Z) is normalised to data in the CRs. Used transfer factor.
- WW from MC
- Reducible background (W+jets and multijets): matrix method

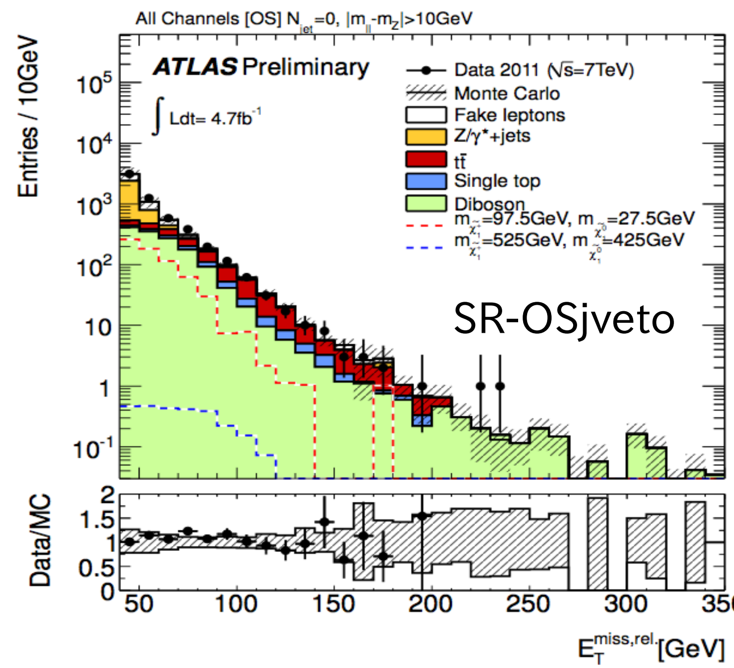
Every SR has an associated CR. Just showing 2 examples



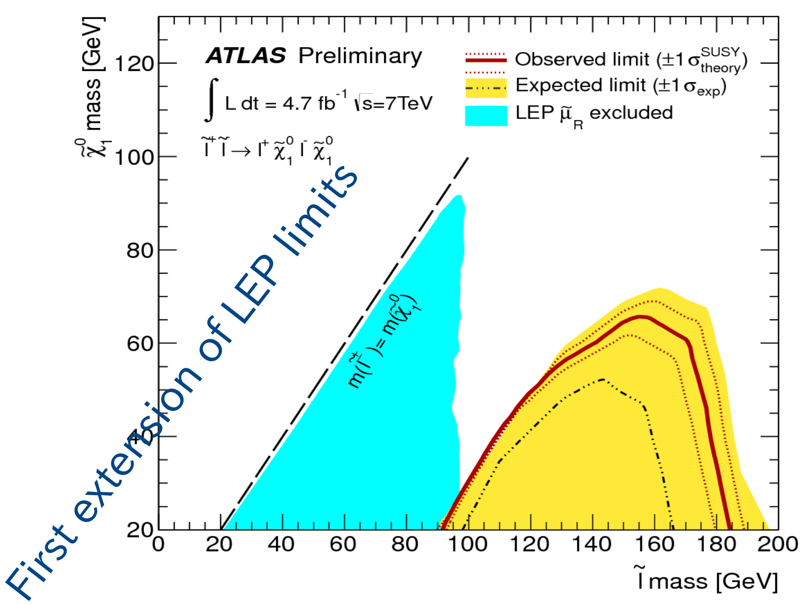


2-lepton: results

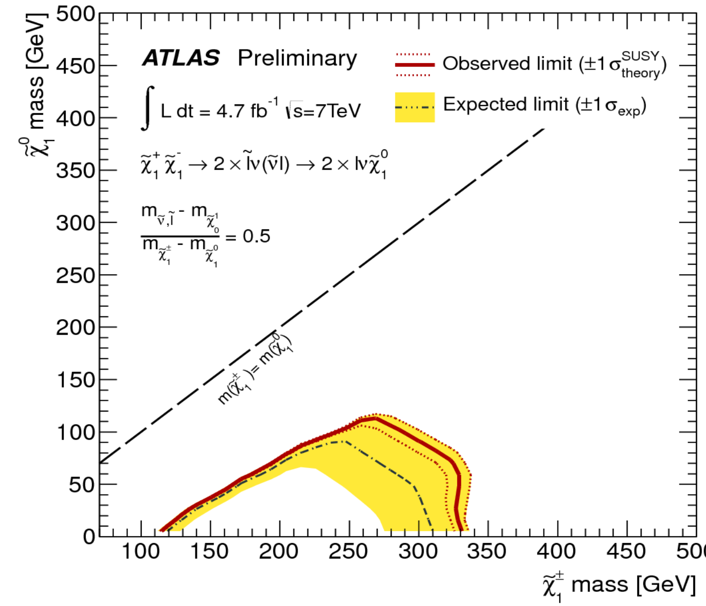




Detailed results for all SRs in the backup



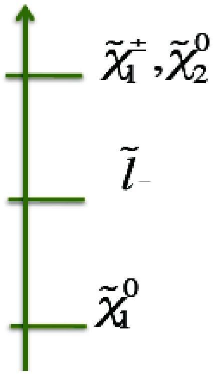
Interpretation in simplified/pMSSM models



2-leptons (4.7 fb^{-1})
ATLAS-CONF-2012-076
http://cdsweb.cern.ch/record/1460273

Direct gaugino: 3-leptons

Explore scenarios with sleptons (BR to leptons enhanced)



slepton in the middle between the gauginos. *Including sneutrinos (50% BR)*

- Exactly 3 leptons (at least one OSSF pair)
- EtMiss>75 GeV

Many different trigger combinations used to maximise sensitivity

SR1a
- ✔ Z-depleted (no OSSF with mass within 10 GeV of Z)
- ✔ 0 b-jets
- ✔ lepton p_T>10 GeV

Low mass splittings

SR1b
- ✔ Z-depleted (no OSSF with mass within 10 GeV of Z)
- ✔ 0 b-jets
- ✔ lepton p_T>30 GeV
- ✔ m_T>90 GeV

Large mass splittings

SR2
- ✔ Z-enriched (OSSF within 10 GeV of Z)
- ✔ lepton p_T>10 GeV
- ✔ m_T>90 GeV

On-shell Z decays

Two main types of backgrounds:

Reducible: a jet is **misidentified** as a lepton (top, WW or W/Z with jets/photons) → Matrix Method (leading lepton to be real) Efficiencies and rejections in dedicated regions

Irreducible: all three leptons are **real** (WZ, ZZ and ttbar+W/Z) → Estimated with MC if minor. For WZ, semi data-driven approach (fit in a CR)

80% purity of WZ

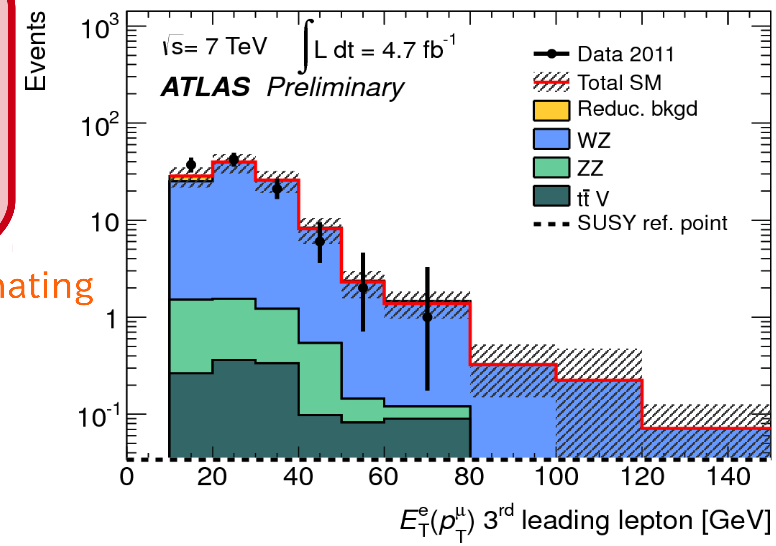
CR (WZ): 3-leptons (at least one OSSF compatible with Z), EtMiss<50 GeV, no b-jet and m_T>40 GeV

3-leptons background validation

Selection	VR1	VR2	VR3
$t\bar{t}Z$	0.17±0.14	0.12±0.10	1.1±0.9
$t\bar{t}W$	0.6±0.5	0.7±0.5	0.10±0.08
$t\bar{t}WW$	0.017±0.014	0.022±0.017	0.0023±0.0019
ZZ	17±15	0.10±0.05	3.9±0.6
WZ	46±8	0.93±0.29	98±12
Reducible Bkg.	50±28	13±7	$3.1^{+4.7}_{-3.1}$
Total Bkg.	114±32	15±7	106±13
Data	126	18	109

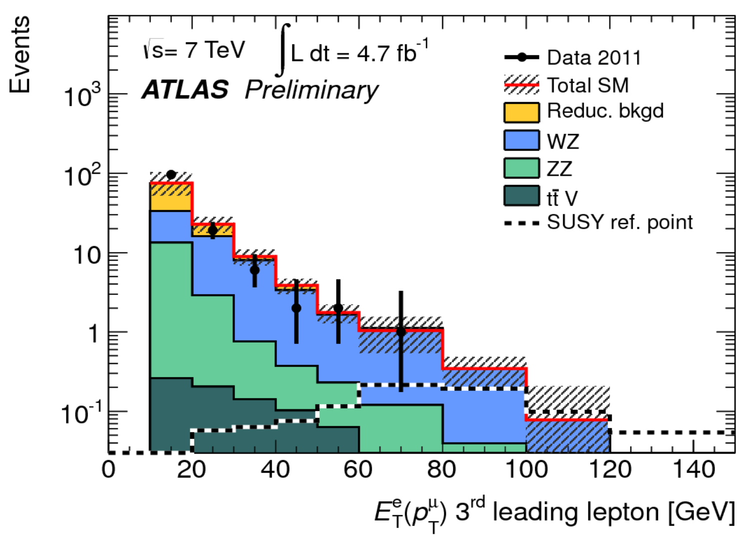
VR3
- ✔ 3-leptons
- ✔ OSSF compatible with Z
- ✔ 50<EtMiss<75 GeV

WZ dominating



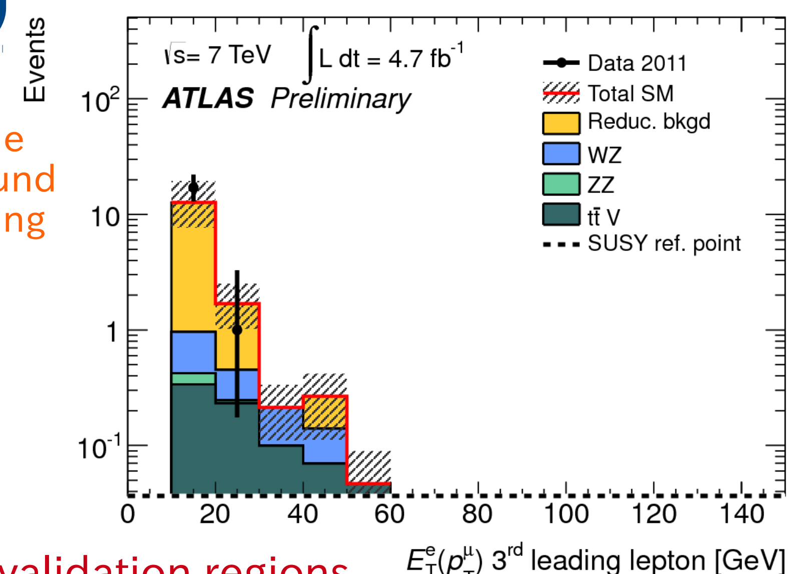
VR1
- ✔ 3-leptons
- ✔ OSSF not compatible with Z mass)
- ✔ 30<EtMiss<75 GeV

VR2
- ✔ 3-leptons
- ✔ No OSSF
- ✔ EtMiss<50 GeV



WZ and Drell-Yan dominating

Reducible background dominating



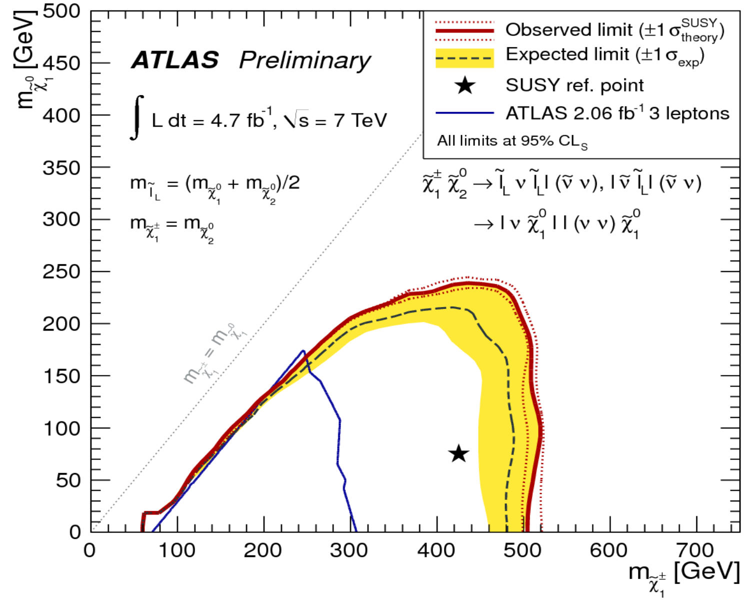
Good agreement in all validation regions

3-lepton: results

Results

Selection	SR1a	SR1b	SR2
SUSY ref. point	8.0±0.8	6.5±0.6	0.46±0.05
$t\bar{t}Z$	0.06±0.05	0.025±0.023	0.6±0.5
$t\bar{t}W$	0.36±0.29	0.10±0.08	0.09±0.08
$t\bar{t}WW$	0.010±0.008	0.0023±0.0019	0.004±0.004
ZZ	0.67±0.21	0.09±0.08	0.34±0.17
WZ	13.5±3.2	1.1±0.28	9.3±2.2
Reducible Bkg.	10±5	0.35±0.34	$0.5^{+1.0}_{-0.5}$
Total Bkg.	25±6	1.6±0.5	10.9±2.4
Data	24	0	11

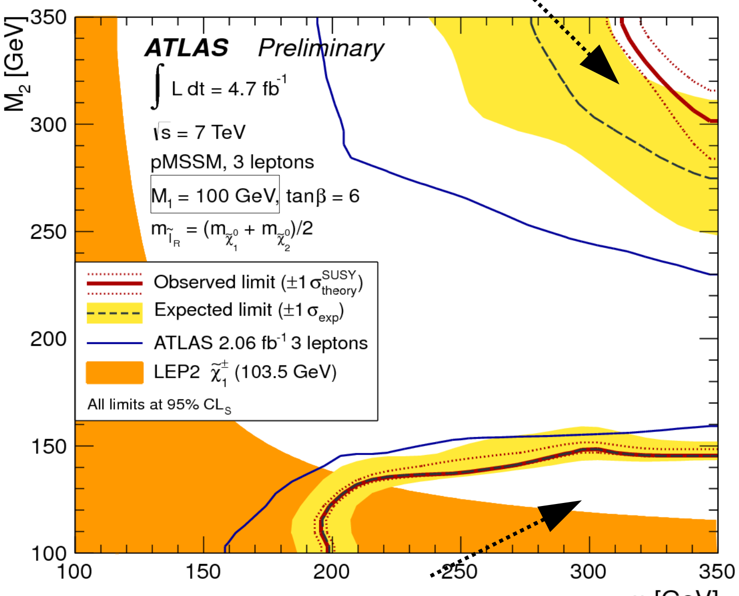
Close to the diagonal soft objects (plus sleptons in the middle...)



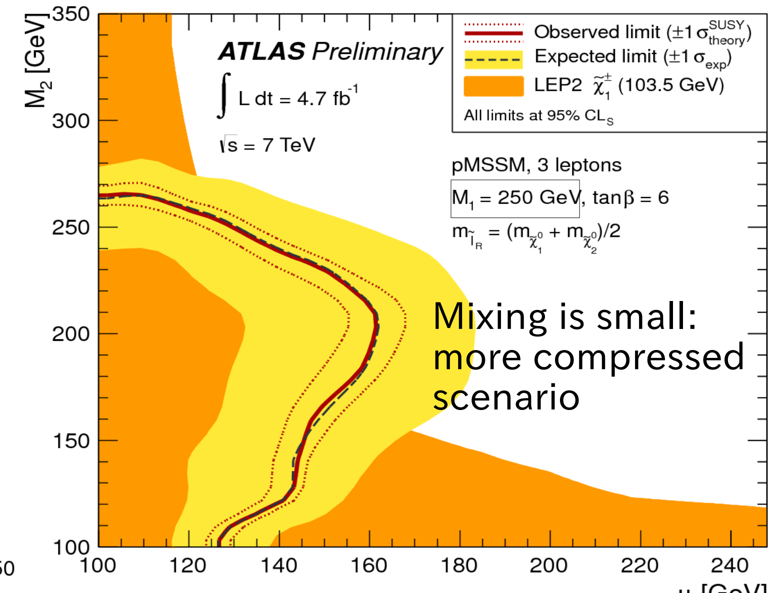
Interpretation in pMSSM scenario:

M1 and M2: common gaugino masses
μ: Higgs mass parameter
tanβ: ratio of Higgs vevs

Large mixing (SR1b)



Small mixing (SR1a)



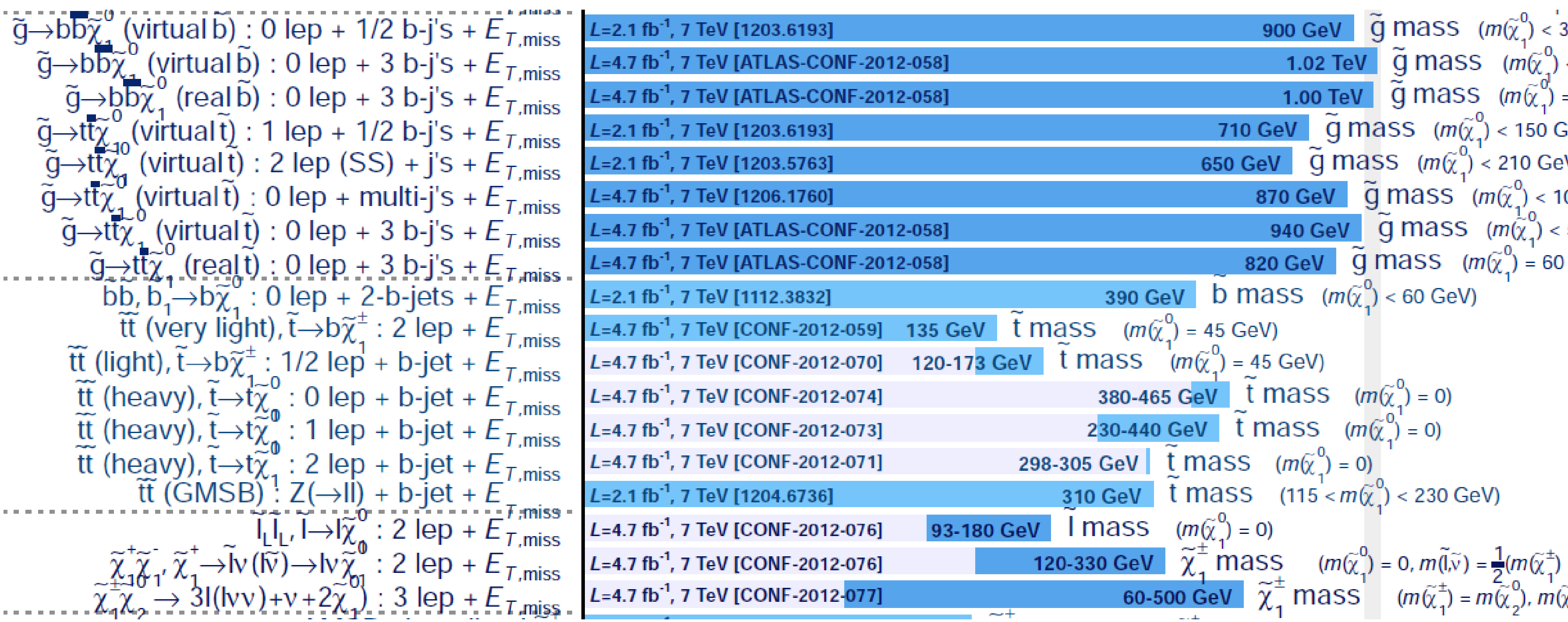
Mixing is small: more compressed scenario

Interpretation guide:

- ✔ **σ**: increases with M2 and μ
- ✔ **Mixing**: increases at low M1; decreases at low M2 and large μ
- ✔ **tanβ**: almost no impact

Summary and conclusions

- With large datasets, searches for 3[rd] generation SUSY particles are becoming more popular given their role in the "natural SUSY spectrum".
- Larger datasets also opens the door to scrutinize the SUSY electroweak sector.
- ATLAS has defined a comprehensive strategy to cover different scenarios and limits extending previous constraints have been released:



- Don't get disappointed too fast: the different searches are currently on-going...
  The Higgs has already been found and now is the turn of SUSY!

Backups

Gluino-mediated: 0-/1-lepton

SR	Top	W/Z	multi-jet/ di-boson	Total	Data
SR0-A1	705 ± 110 (725)	248 ± 150	53 ± 21	1000 ± 180	1112
SR0-B1	119 ± 26 (122)	67 ± 42	7.3 ± 4.7	190 ± 50	197
SR0-C1	22 ± 8 (22)	16 ± 11	1.5 ± 1	39 ± 14	34
SR0-A2	272 ± 52 (212)	23 ± 15	21 ± 12	316 ± 54	299
SR0-B2	47 ± 10 (37)	4.5 ± 3	2.8 ± 1.7	54 ± 11	43
SR0-C2	8.5 ± 3 (6.6)	0.8 ± 1	0.5 ± 0.4	9.8 ± 3.2	8

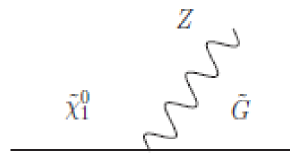
SR	SM background	Data
SR1-D (e)	39 ± 12 (39)	43
SR1-D (μ)	38 ± 14 (37)	38
SR1-E (e)	8.1 ± 3.4 (7.9)	11
SR1-E (μ)	6.3 ± 4.2 (6.1)	6

Direct stop in GMSB

Z + (b-)jets (GMSB) (2.05 fb^{-1})
Accepted by PLB
(arXiv:1204.6736 [hep-ex])

First search for direct stop @ LHC

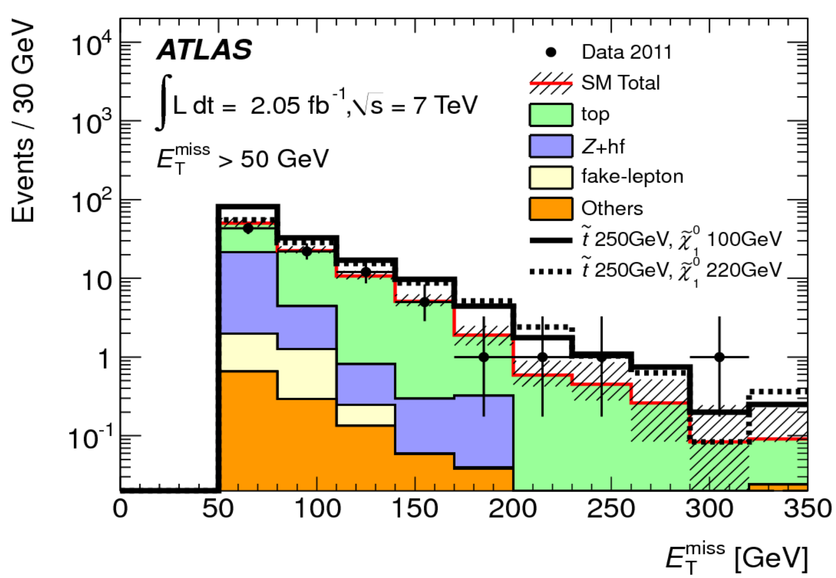
$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow b\tilde{\chi}_1^0 W^{\pm(*)} \rightarrow b\tilde{\chi}_1^0 l\nu$$

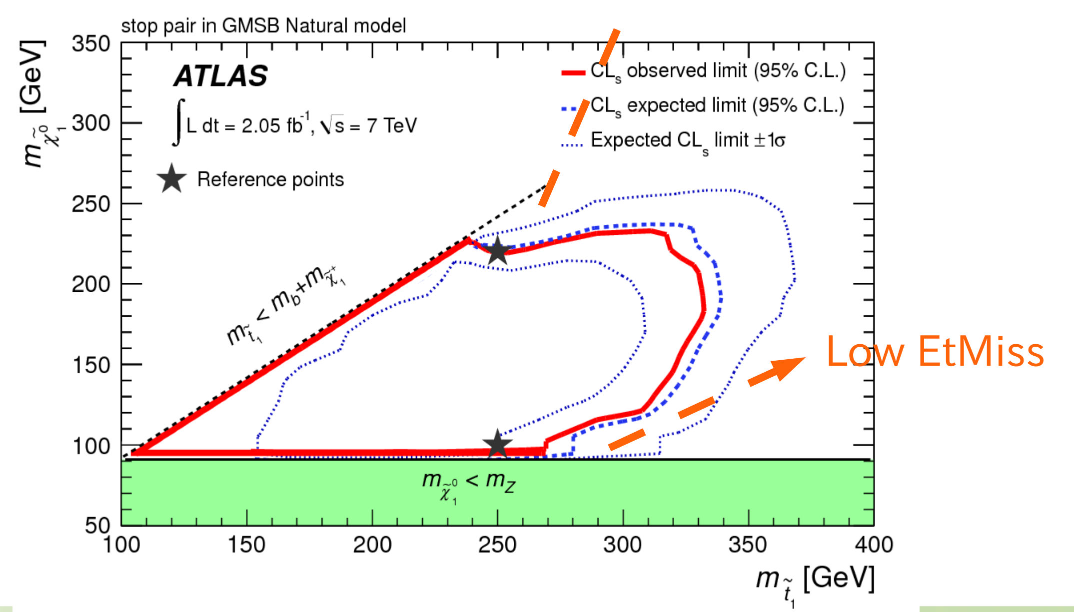


The LSP is the gravitino

- NLSP higgsino-like: decays via Z or Higgs and chargino decay products very soft (mass degeneracy)
- Use decay products from Z or Higgs
- 2 jets (>=1 b-tag), 2 opposite-sign same flavour (OSSF) leptons within 86 and 96 GeV and large EtMiss
- Two signal regions: EtMiss>50 and 80 GeV

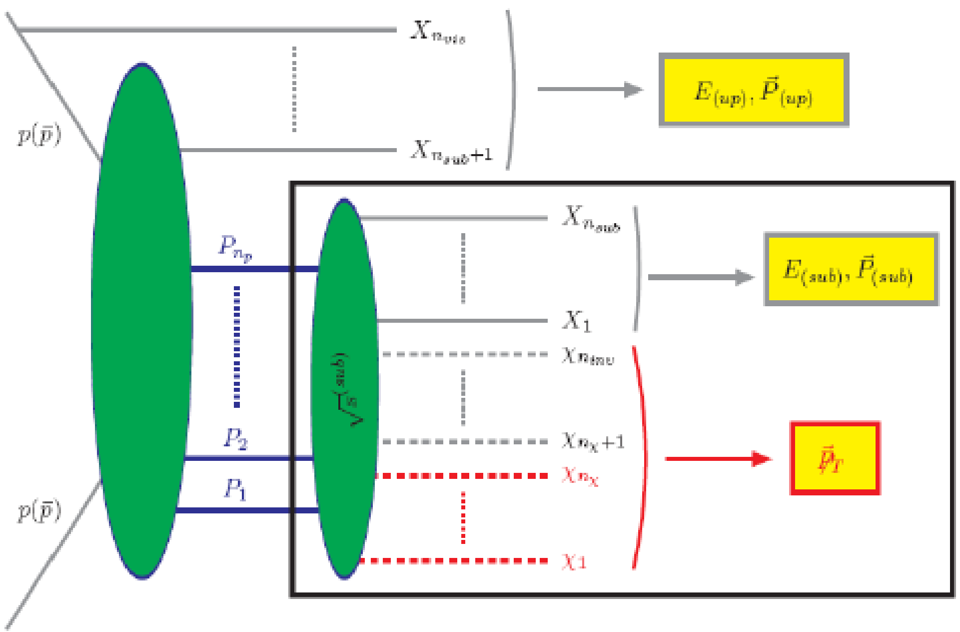
E_T^{miss} >	50GeV	80GeV
top	64.3±7.7	34.8 ± 5.0
Z+hf	24±16	4.2±3.2
fake lepton	2.4 ± 0.9	1.1 ± 0.6
Others	1.2 ± 1.2	0.6 ± 0.6
Data (2.05 fb^{-1})	86	43
Total SM	92±19	40.7 ± 6.0



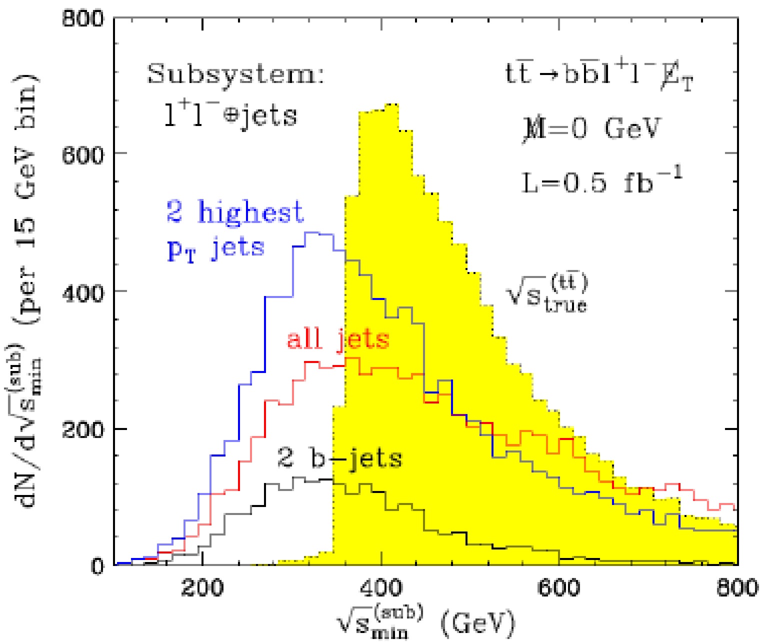


sqrt(s)$_{min}$ variable (light stop)

Main discriminating variable: sqrt(s)$_{min}^{(sub)}$



Reco level:

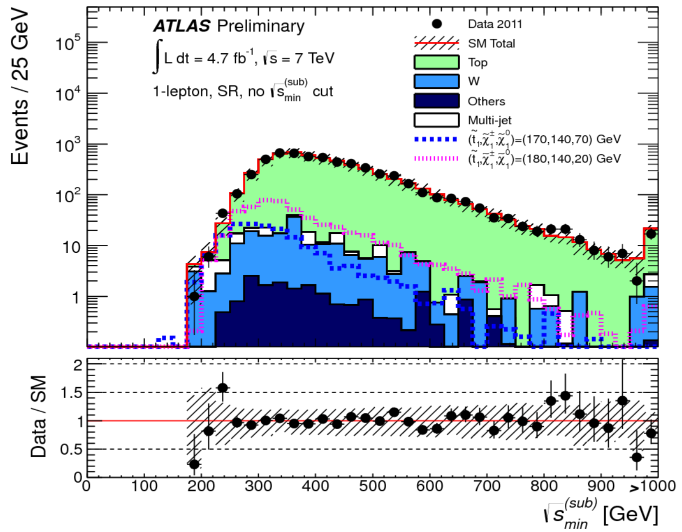


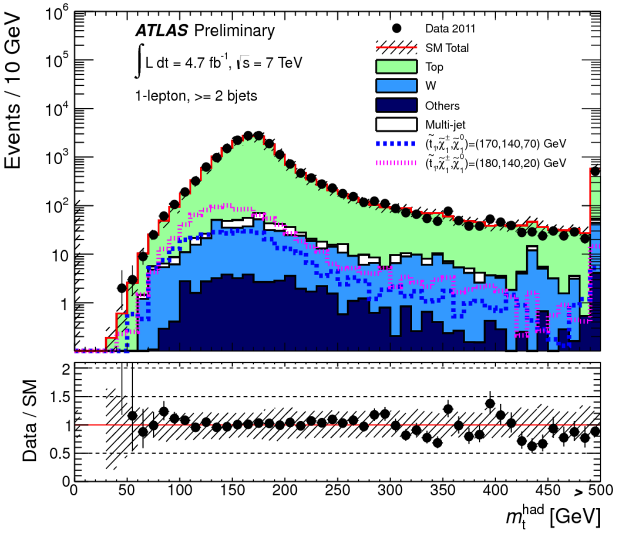
- Minimum mass compatible with subsystem
  - http://arxiv.org/abs/1006.0653v1
- Subsystem defined from $t\bar{t}$ decay products
  - $\not{M} = 0$ due to neutrinos
  - $\sqrt{s}_{min}^{(sub)}$ expected to peak at $\sim m(t\bar{t}) = 2m(t)$

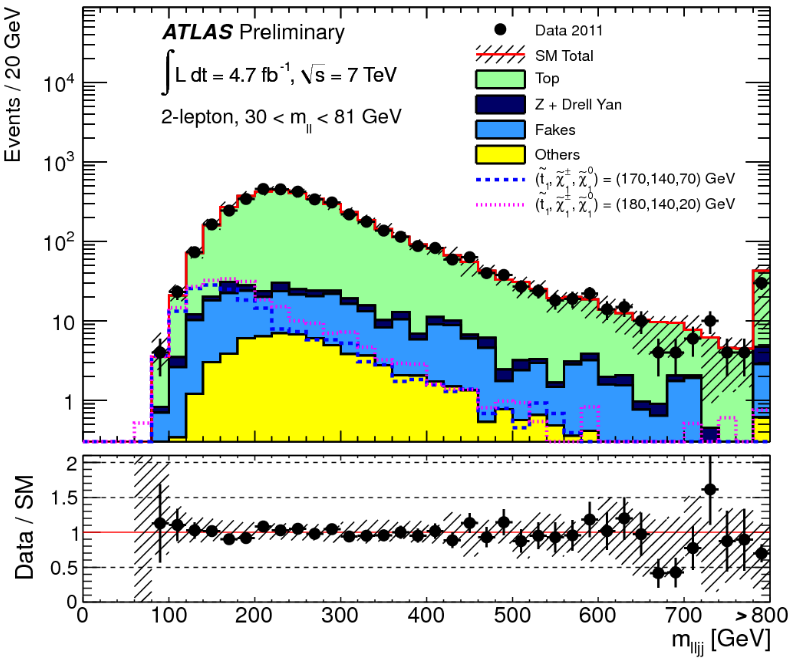
Expect to exclude below the top and above the top if mass of neutralino is high (peak shifted to the left due to M̸ != 0)

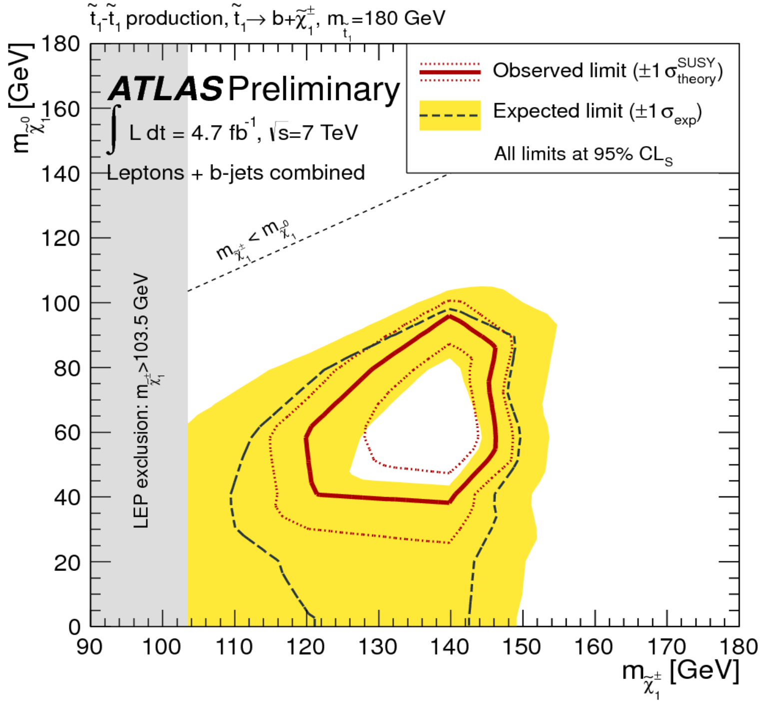
$$\sqrt{s}_{min}^{(sub)}(\not{M}) = \left\{ \left(\sqrt{M_{(sub)}^2 + P_{T(sub)}^2} + \sqrt{\not{M}^2 + \not{P}_T^2} \right)^2 - \left(\vec{P}_{T(sub)} + \vec{\not{P}}_T \right)^2 \right\}^{\frac{1}{2}}$$

Light stop: extra information



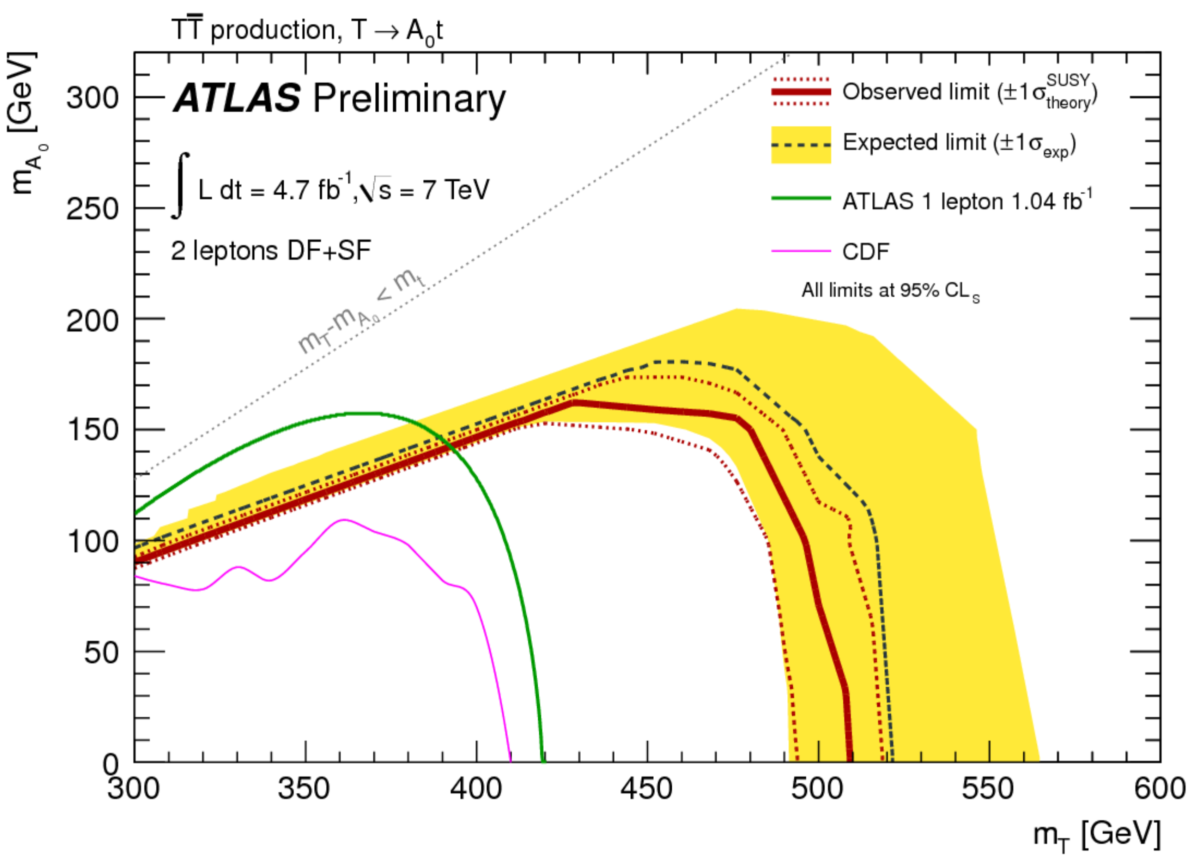






Medium stop: 2-leptons

Extra interpretation on T (spin ½ partner of the top channel)



2-lepton direct gaugino/slepton

SR-m_{T2}					
	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all	SF
Z+X	$3.2 \pm 1.1 \pm 1.7$	$0.3 \pm 0.1 \pm 0.2$	$3.6 \pm 1.3 \pm 1.7$	$7.1 \pm 1.7 \pm 2.1$	$6.8 \pm 1.7 \pm 2.1$
WW	$2.3 \pm 0.3 \pm 0.4$	$4.8 \pm 0.4 \pm 0.7$	$3.5 \pm 0.3 \pm 0.5$	$10.6 \pm 0.6 \pm 1.5$	$5.8 \pm 0.4 \pm 0.9$
$t\bar{t}$, single top	$2.6 \pm 1.2 \pm 1.3$	$6.2 \pm 1.6 \pm 2.9$	$4.1 \pm 1.3 \pm 1.6$	$12.9 \pm 2.4 \pm 4.6$	$6.8 \pm 1.8 \pm 2.3$
Fake leptons	$1.0 \pm 0.6 \pm 0.6$	$1.1 \pm 0.6 \pm 0.8$	$-0.02 \pm 0.01 \pm 0.05$	$2.2 \pm 0.9 \pm 1.4$	$1.0 \pm 0.6 \pm 0.6$
Total	$9.2 \pm 1.8 \pm 2.5$	$12.4 \pm 1.7 \pm 3.1$	$11.2 \pm 1.9 \pm 3.0$	$32.8 \pm 3.2 \pm 6.3$	$20.4 \pm 2.6 \pm 3.9$
Data	7	9	8	24	15
$\sigma_{vis}^{obs(exp)}$ (fb)	1.6 (1.9)	1.7 (2.2)	1.7 (2.1)	2.6 (3.8)	2.0 (2.7)

SR-OSjveto				
	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all
Z+X	$4.5 \pm 1.2 \pm 1.2$	$3.0 \pm 0.9 \pm 0.5$	$4.7 \pm 1.1 \pm 1.2$	$12.2 \pm 1.8 \pm 1.8$
WW	$8.8 \pm 1.8 \pm 4.4$	$20.9 \pm 2.6 \pm 6.2$	$13.3 \pm 1.9 \pm 3.5$	$43.0 \pm 3.7 \pm 12.2$
$t\bar{t}$, single top	$21.1 \pm 2.3 \pm 4.2$	$47.7 \pm 3.4 \pm 20.5$	$27.5 \pm 2.5 \pm 9.0$	$96.2 \pm 4.8 \pm 29.5$
Fake leptons	$2.9 \pm 1.2 \pm 1.2$	$6.9 \pm 1.8 \pm 2.6$	$0.4 \pm 0.6 \pm 0.3$	$10.3 \pm 2.2 \pm 4.1$
Total	$37.2 \pm 3.3 \pm 6.4$	$78.5 \pm 4.7 \pm 20.9$	$45.9 \pm 3.4 \pm 9.4$	$161.7 \pm 6.7 \pm 30.8$
Data	33	66	40	139
$\sigma_{vis}^{obs(exp)}$ (fb)	3.5 (4.0)	8.1 (9.6)	4.3 (5.1)	11.4 (14.1)

SR-2jets				
	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	SF
Z+X	$3.8 \pm 1.3 \pm 2.7$	—	$5.8 \pm 1.6 \pm 3.9$	$9.6 \pm 2.0 \pm 5.1$
WW	$6.4 \pm 0.5 \pm 4.3$	—	$8.4 \pm 0.6 \pm 5.7$	$14.8 \pm 0.7 \pm 9.9$
$t\bar{t}$, single top	$14.8 \pm 1.9 \pm 9.2$	—	$22.1 \pm 2.1 \pm 20.7$	$36.9 \pm 2.9 \pm 29.6$
Fake leptons	$2.5 \pm 1.2 \pm 1.5$	—	$1.7 \pm 1.3 \pm 0.8$	$4.2 \pm 1.8 \pm 2.3$
Total	$27.5 \pm 2.6 \pm 10.6$	—	$37.9 \pm 3.0 \pm 21.0$	$65.5 \pm 4.0 \pm 31.8$
Data	39	—	39	78
$\sigma_{vis}^{obs(exp)}$ (fb)	7.1 (5.1)	—	9.7 (9.6)	15.6 (13.9)

SR-SSjveto				
	$e^\pm e^\pm$	$e^\pm\mu^\pm$	$\mu^\pm\mu^\pm$	all
Charge flip	$0.49 \pm 0.03 \pm 0.17$	$0.34 \pm 0.02 \pm 0.11$	—	$0.83 \pm 0.04 \pm 0.18$
Dibosons	$0.62 \pm 0.13 \pm 0.18$	$1.93 \pm 0.23 \pm 0.36$	$0.94 \pm 0.16 \pm 0.26$	$3.50 \pm 0.31 \pm 0.54$
Fake leptons	$3.2 \pm 0.9 \pm 1.7$	$2.9 \pm 0.9 \pm 1.9$	$0.6 \pm 0.6 \pm 0.3$	$6.6 \pm 1.4 \pm 3.8$
Total	$4.3 \pm 0.9 \pm 1.7$	$5.1 \pm 1.0 \pm 1.9$	$1.5 \pm 0.6 \pm 0.4$	$11.0 \pm 1.5 \pm 3.9$
Data	1	5	3	9
$\sigma_{vis}^{obs(exp)}$ (fb)	0.8 (1.2)	1.5 (1.5)	1.3 (0.8)	2.0 (2.3)

b-tagging in ATLAS