Searches for Higgs and BSM physics with ATLAS

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On behalf of the ATLAS Collaboration

Content

With more than 2.5 fb^{-1} of integrated luminosity collected by ATLAS, searches for new particles are on-going.

1. Standard Model Higgs-boson
   - H→WW→lvlv
   - H→ZZ→llvv
   - Combined results

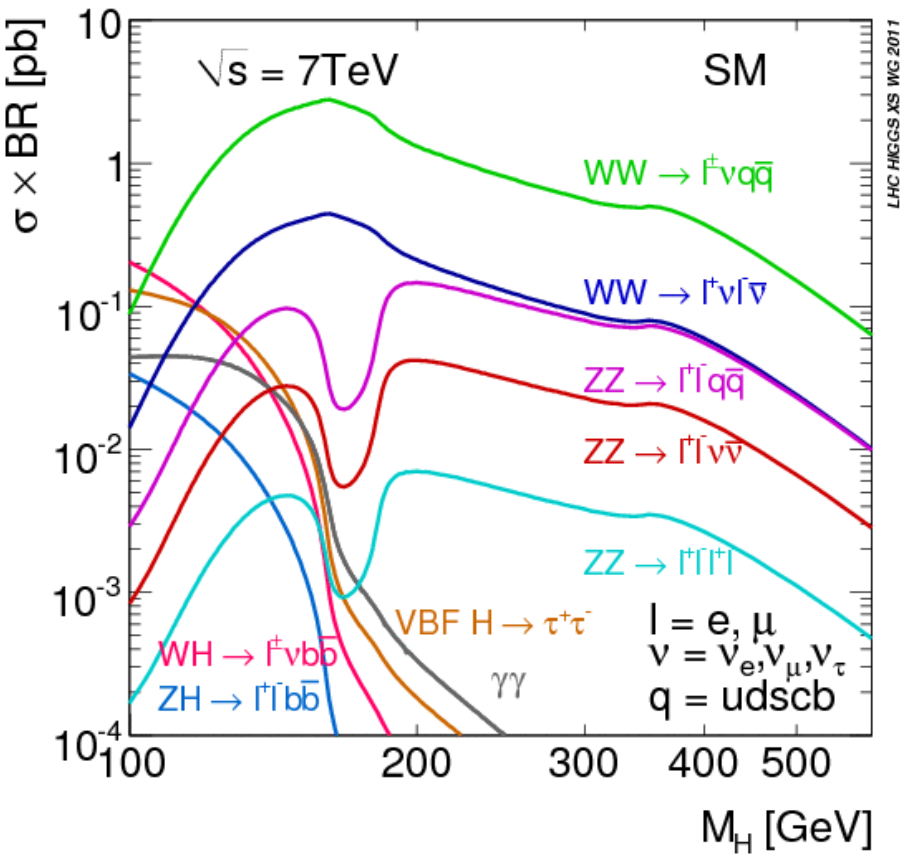
2. Beyond the SM physics:
   - R-parity conserving SUSY
   - W'
   - Prompt equal-charge muon pairs
   - Top-anti-top resonances

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Standard Model Higgs-boson

Higgs production at the LHC:
- Gluon-gluon fusion
- Vector boson fusion
- Associated production: WH, ZH, ttH

Signal (l = e, μ)	Mass range (GeV)
$H \to \gamma\gamma$	110-150
$WH \to l\upsilon bb$	110-130
$ZH \to llbb$	110-130
$H \to WW \to l\upsilon l\upsilon$	**110-300**
$H \to WW \to l\upsilon qq$	240-600
$H \to ZZ \to 4l$	110-600
$H \to ZZ \to ll\upsilon\upsilon$	**200-600**
$H \to ZZ \to llqq/llbb$	200-600



All cross section limits presented are CLs based limits determined using the profile likelihood method.

H→WW→lνlν (l=e,μ)

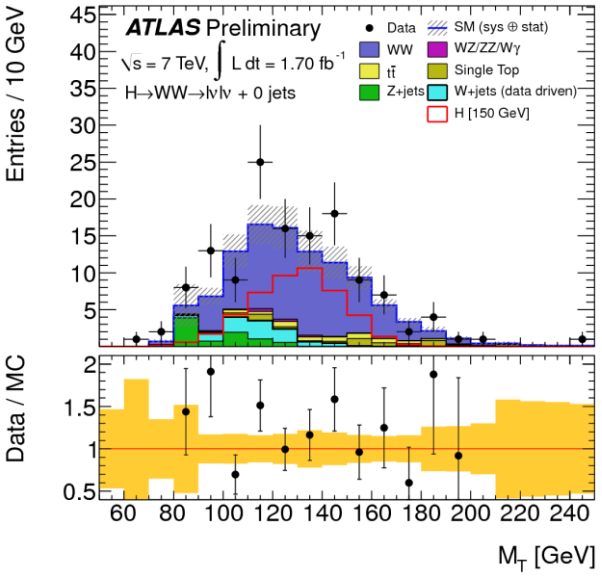
New

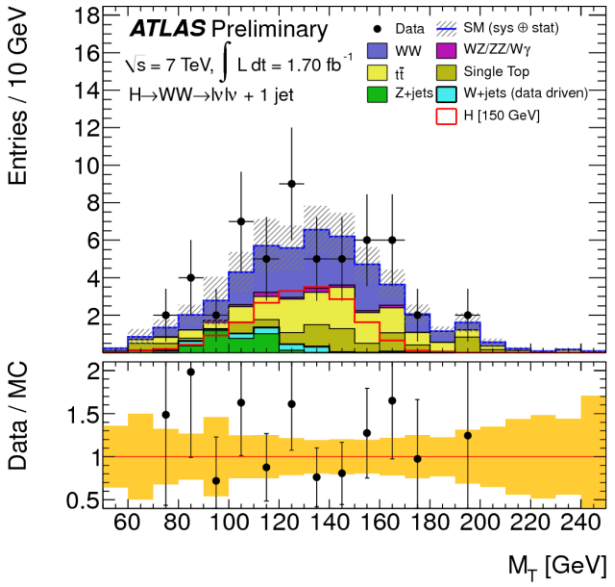
ATLAS-CONF-2011-134

Cut & Count method in 2 jet channels (0/1 jets (not b-tagged))

Base selection (not a full list):

- 2 leptons (veto Z-resonance)
  - p_T>25 GeV,
  - p_T>20(15) GeV
- E_T^{miss} relative to nearest jet/lepton > 40(25) GeV
- exploit spin correlation in signal
  - m_{ll} < 50 (65) GeV
  - $\Delta\varphi_{ll}$ < 1.3 (1.8)
- Higgs mass dependent cut on transverse mass





$$m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 - (P_T^{ll} + P_T^{miss})^2}$$

The exact cuts depend on the lepton and jet channel and the considered Higgs mass

Background normalized using control regions
In 0 jet channel dominated by WW
In 1 jet channel dominated by WW and tt

H→WW→lνlν (l=e,μ)

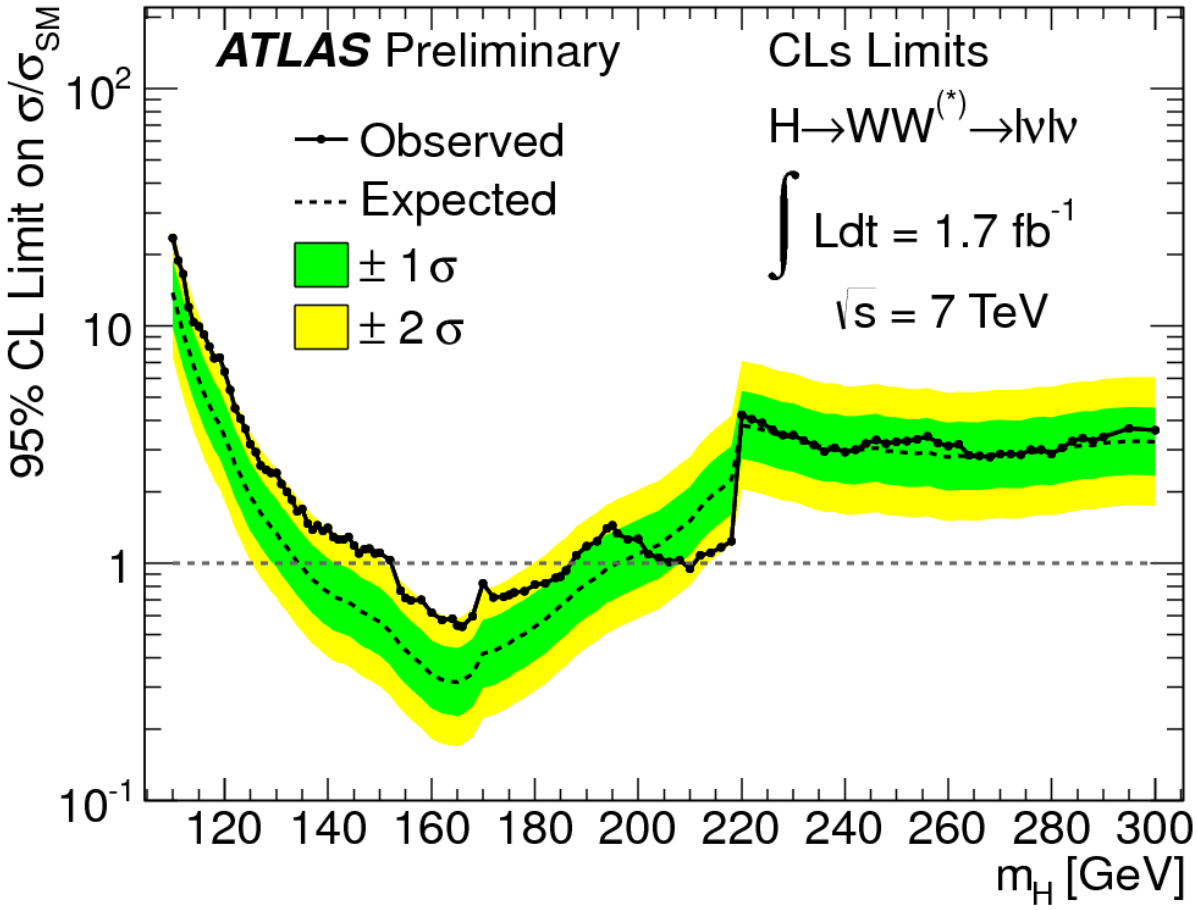
New

ATLAS-CONF-2011-134

For each Higgs-mass the 95% CL limit for the cross-section is calculated and compared with the SM cross-section and the expected limits.

With this data we can exclude the mass range $154 < m_H < 186$ GeV at 95% CL

No significant evidence for a SM Higgs-boson is found with the largest discrepancy being less than 2σ



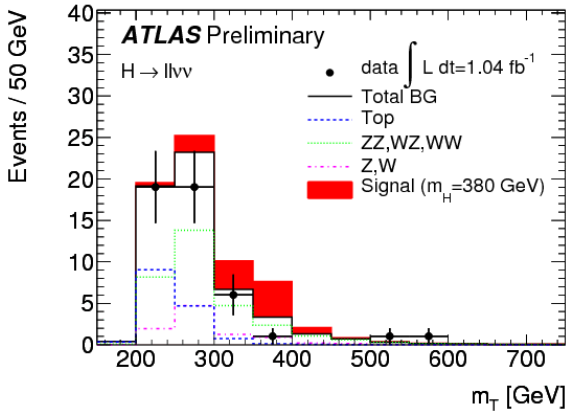
H→ZZ→llνν (l=e,μ)

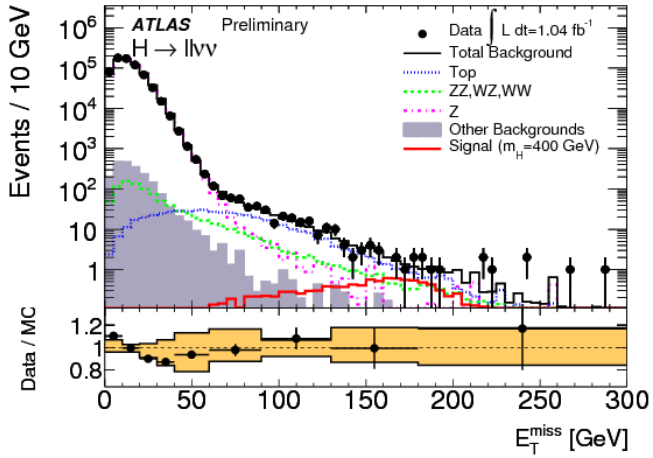
Limits set based on the transverse mass distribution

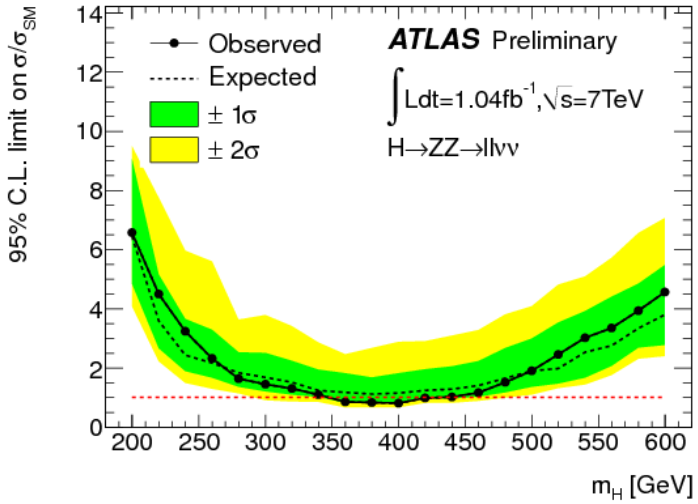
Base selection:
- lepton pairs consistent with Z decay
- E_T^{miss} (66/82 GeV)

Backgrounds:
- Top & W (estimated/verified from data)
- Di-boson (taken from theory)
- Z (from MC: relying on correct systematics for E_T^{miss} tails)

$$m_T^2 = \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,ll}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,miss}|^2}\right]^2 - \left[\vec{p}_T^{\,ll} + \vec{p}_T^{\,miss}\right]^2$$







<u>Results:</u>

mass range 350 to 460 GeV excluded at 95% CL

Combined limits

New

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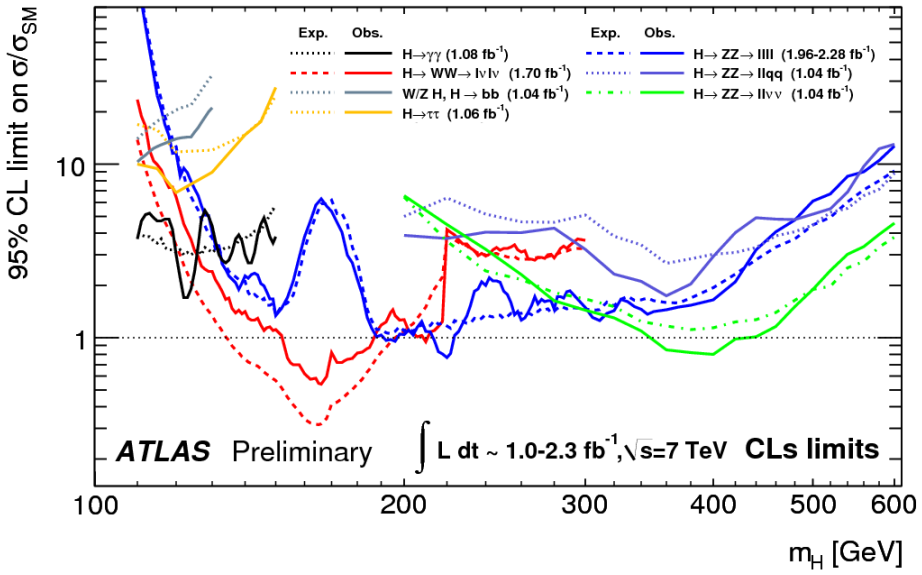
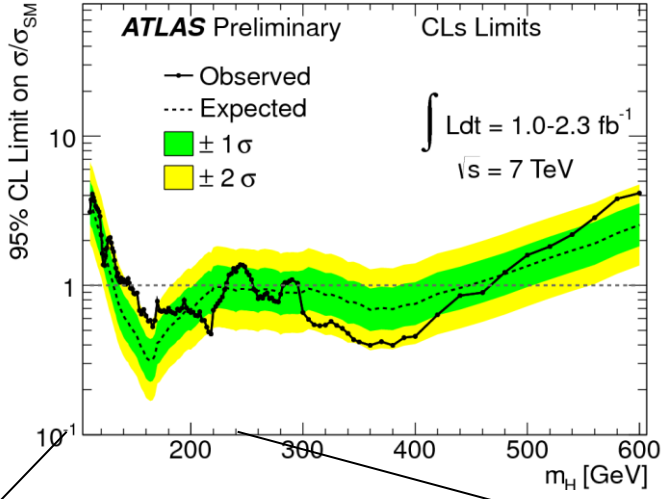
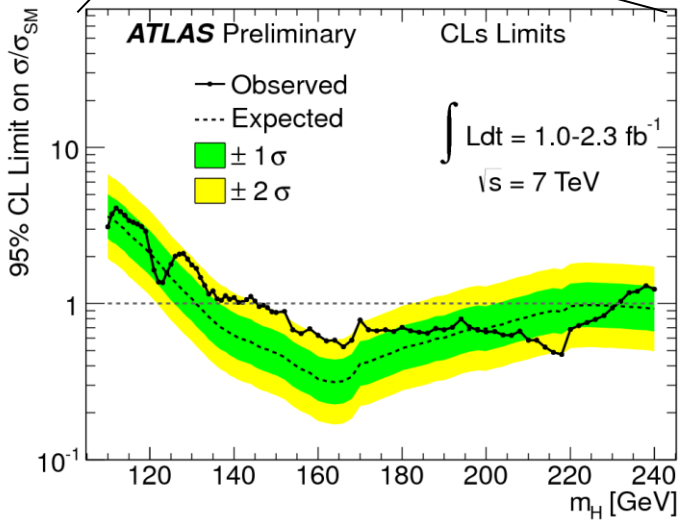






Combined limits based on 1.1to 2.3 fb^{-1} of 2011 data

Excluded at 95% CL:

$146 < m_H(\text{GeV}) < 232$

$256 < m_H(\text{GeV}) < 282$

$296 < m_H(\text{GeV}) < 466$

An excess of at most 2σ is found

Beyond the Standard Model

Many BSM models have been studied

- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valleys
- Leptoquarks
- Compositeness
- 4th generation (t', b')
- Heavy neutrino
- ……

General approach of BSM searches:

- Impossible to test all models separately and for full phase space.
- Analyses are aimed at specific signatures.
- Focus on several agreed representative benchmark models.
- Model independent cross-sections limits are computed.
- These limits are translated to model dependent results.

I will only discuss a few of these analyses:

- R-parity conserving SUSY
- W'
- Prompt like-sign muon pairs
- $t\bar{t}$ resonances

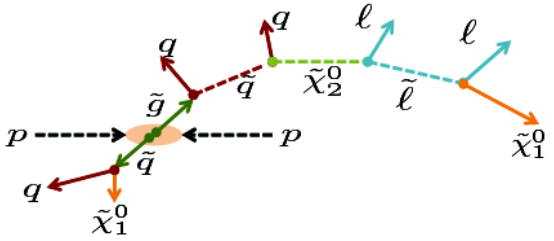
R-parity conserving SUSY

General properties:

- Lightest SUSY particle stable
- LSP often neutralino or gravitino
- SUSY particles created in pairs
- Cross-section dominated by squark and gluino production
- Minimum decays:

$$\tilde{q} \rightarrow q\tilde{\chi}_1^0 \qquad \tilde{g} \rightarrow qq\tilde{\chi}_1^0$$

→ **High E_T^{miss}**



→ **At least 2, 3 or 4 jets** for $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$ and $\tilde{g}\tilde{g}$

- Decay chains with charginos or sleptons → **Leptons** (searches with **0/1**/2 leptons)
- Long decay chains → High jet / lepton multiplicity
- Relatively light sbottoms, stops and staus (due to stronger mixing in third family) → Enhanced b-quark and tau production

In gauge mediated SUSY:

- LSP is the gravitino, NLSP is often bino
- Primary decay: $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$

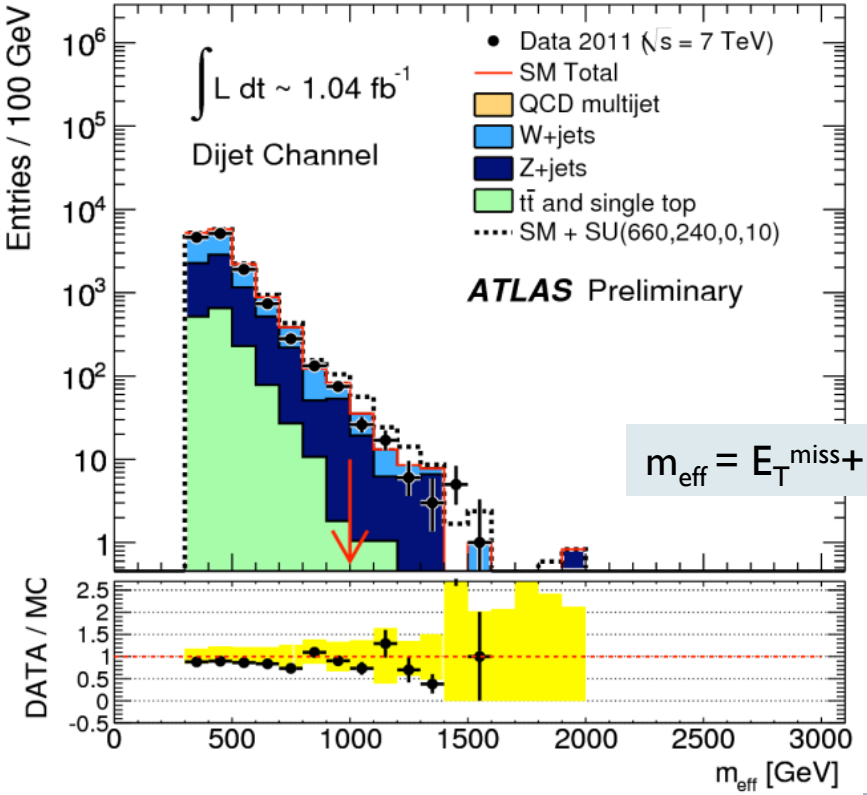
→ Two photons in the final state

SUSY channel: jets, E_T^{miss} and 0 leptons

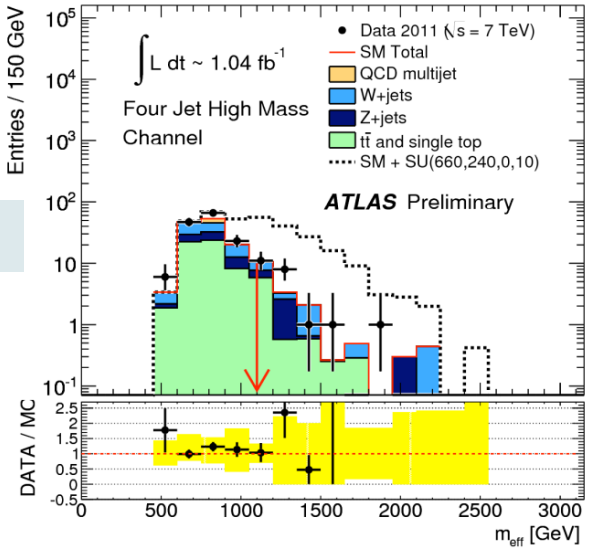
five signal regions: optimised for $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$ and $\tilde{g}\tilde{g}$

Background estimated in each channel with a combined likelihood fit on the signal region and five control regions.

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

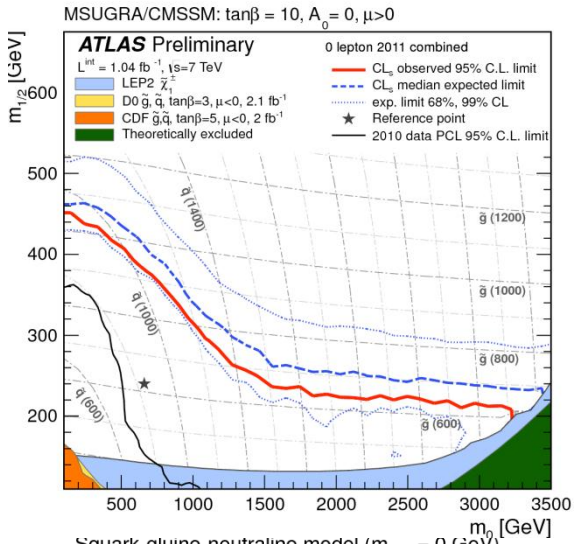


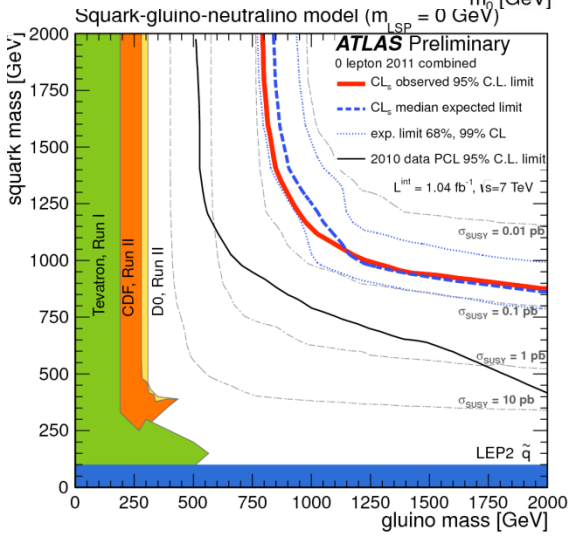
$m_{eff} = E_T^{miss} + p_T$ of jets



SUSY channel: jets, E_T^{miss} and 0 leptons

Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, m_{eff} > 500 GeV	≥ 4-jet, m_{eff} > 1000 GeV	High mass
Z/γ+jets	32.5 ± 2.6 ± 6.8	25.8 ± 2.6 ± 4.9	208 ± 9 ± 37	16.2 ± 2.1 ± 3.6	3.3 ± 1.0 ± 1.3
W+jets	26.2 ± 3.9 ± 6.7	22.7 ± 3.5 ± 5.8	367 ± 30 ± 126	12.7 ± 2.1 ± 4.7	2.2 ± 0.9 ± 1.2
$t\bar{t}$+ Single Top	3.4 ± 1.5 ± 1.6	5.6 ± 2.0 ± 2.2	375 ± 37 ± 74	3.7 ± 1.2 ± 2.0	5.6 ± 1.7 ± 2.1
QCD jets	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.74 ± 0.14 ± 0.51	2.10 ± 0.37 ± 0.83
Total	62.3 ± 4.3 ± 9.2	55 ± 3.8 ± 7.3	984 ± 39 ± 145	33.4 ± 2.9 ± 6.3	13.2 ± 1.9 ± 2.6
Data	58	59	1118	40	18





<u>Result:</u>

The five signal regions exclude non-SM cross section within acceptance of 24, 30, 477, 32 and 17 fb at 95% confidence.

New model dependent limits on gluino and squark masses:

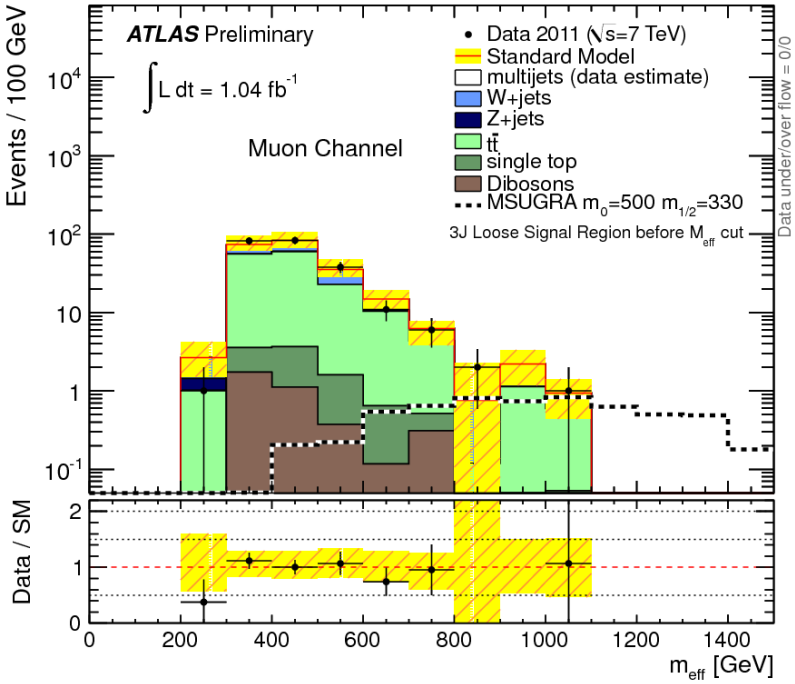
1. MSUGRA (tanβ=10, A_0=0, μ>0):
   Limit for $m_{1/2}$ extended to >450 GeV at low m_0
   Low $m_{1/2}$ excluded within allowed m_0 range
2. Squark-gluino-neutralino model (M_{LSP}=0, only gluinos and squarks)
   Mass limits on squarks and gluinos up to 1 TeV

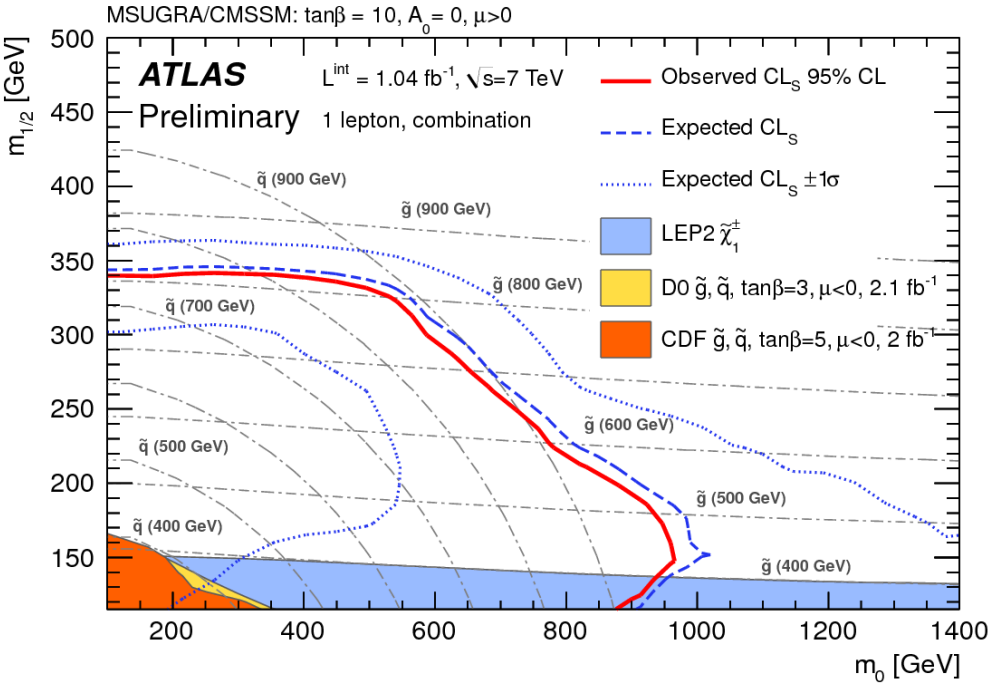
New

SUSY channel: jets, E_T^{miss} and 1 lepton

Base selection:

- 1 lepton (electron or muon)
- ≥ 3 or ≥ 4 jets
- High E_T^{miss}
- High transverse mass (lepton and E_T^{miss})
- High m_{eff}: E_T^{miss}+p_T of jets+p_T of lepton





<u>Result:</u>

Due to small branching ratio, limits are less strong than those obtained in the 0 jet channel

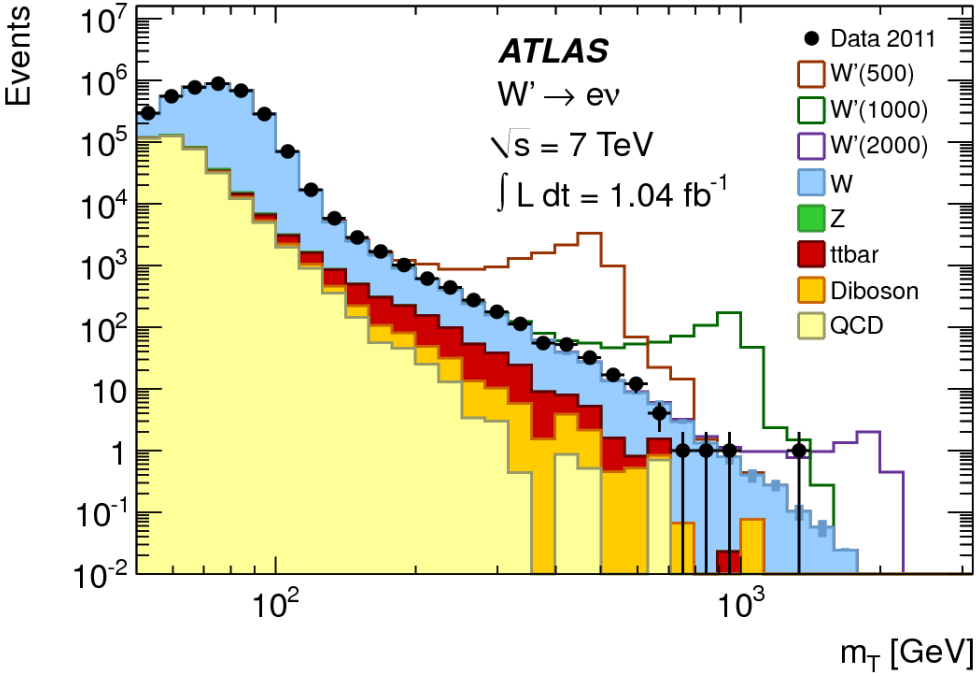
Other SUSY searches and conclusion

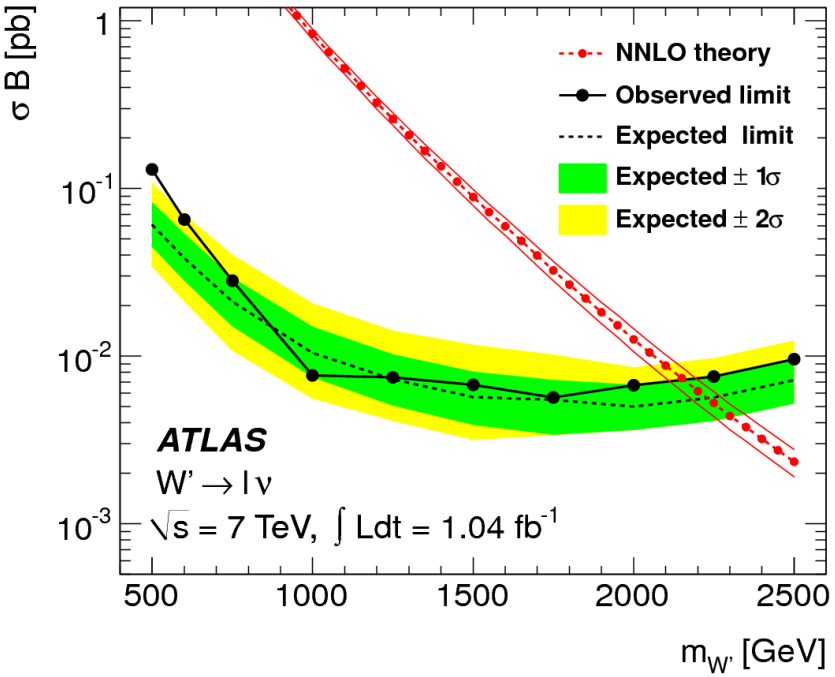
- Other SUSY analyses in ATLAS include searches with:
  - At least 1 b-jet
  - More than 6 jets
  - At least 2 photons (gauge mediated SUSY)
- No significant excess has been found in any channel

- Most of the "easy" phase-space has been excluded
  - Limits will increase with more luminosity
  - Upgrade of the LHC to 14 TeV will also result in a "jump" of the obtained limits
- Effort now mostly focused on the more "difficult" phase-space
  - Small mass-differences leading to soft particles
  - Light stops, but heavy gluino's and other squarks
  - Etc……

Heavy gauge bosons: W'

arXiv:1108.1316





Excellent correspondence between measured transverse mass and SM expectation, also in the muon channel.

Exclusion at 95% confidence level: W' with Sequential Standard Model couplings with $m_W < 2.15$ TeV. The Z' limit is 1.83 TeV (see talk by A. Ventura)

ATLAS-CONF-2011-126

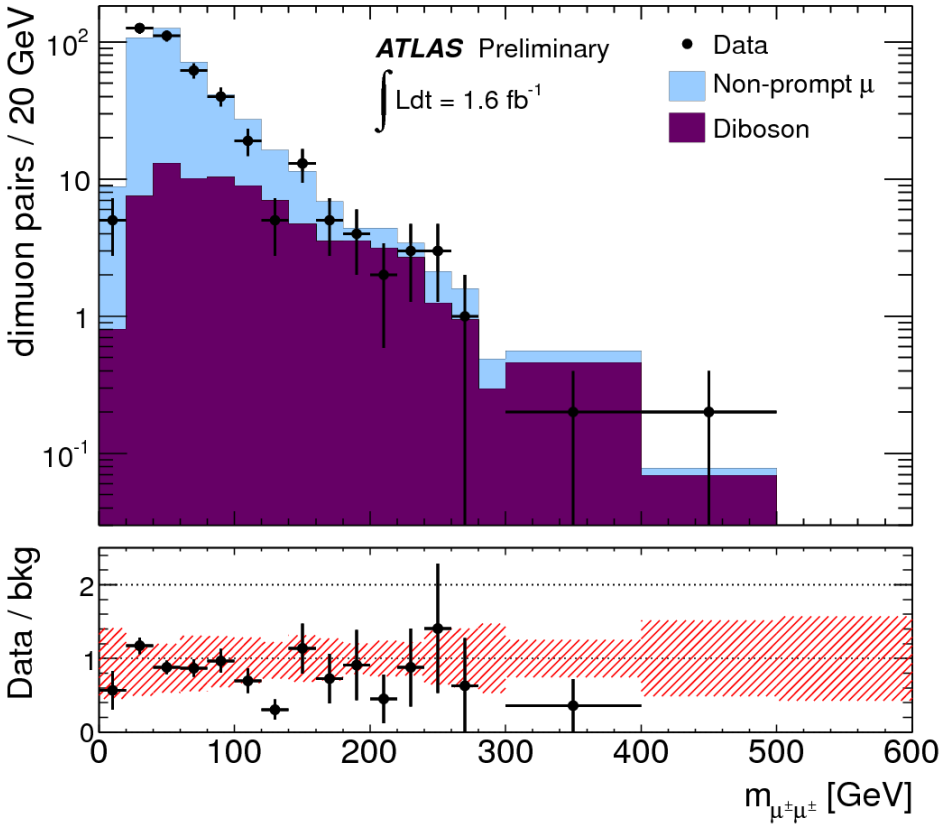
New

Prompt like-sign muon pairs

Prompt defined as produced at the interaction point.
SM signal dominated by: WZ, ZZ, $W^{\pm}W^{\pm}$, ttW, all with relatively small cross-section

Non-SM signal:
- Supersymmetry
- Universal extra dimensions
- Heavy Majorana neutrinos
- Fourth-family quarks
- Doubly charged Higgs
- Etc.

Non-prompt muons rejected by strong quality requirement on muons:
- charge $_{\text{Muon Spectrometer}}$ = charge $_{\text{Inner Detector}}$
- d0-significance < 3
- Strong isolation requirements



Prompt like-sign muon pairs: H^{++}/H^{--}

New

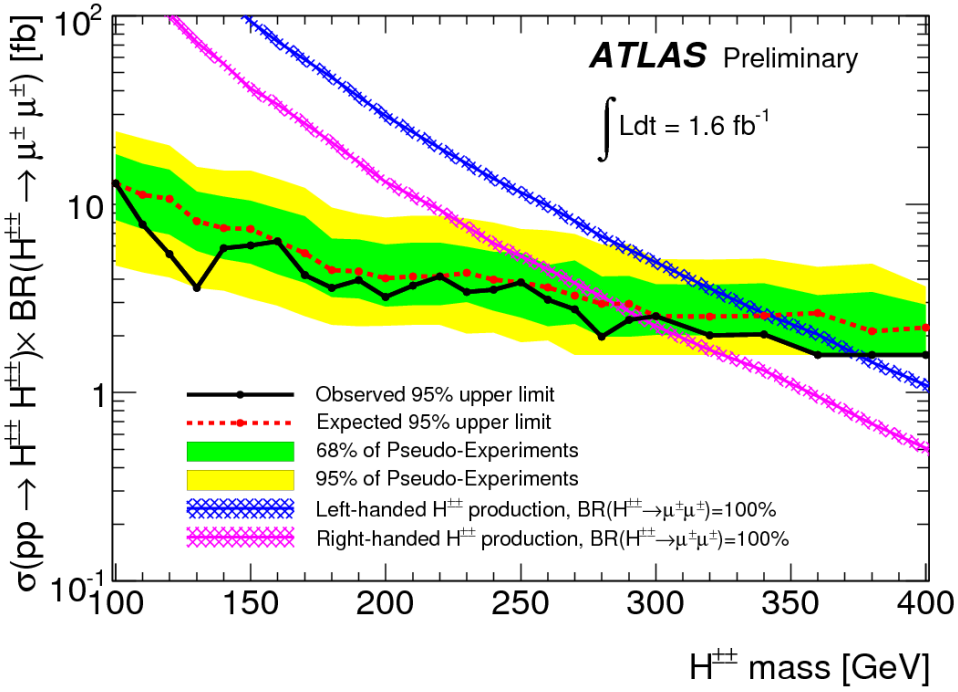
Result:

No excess has been found for any invariant mass bin. Limits on the cross-section for each bin are listed in the table below.

Model dependent limit: Double charged Higgs:

Upper limit of 13-1.6 fb for cross-section times branching ratio to two muons for Higgs masses between 100 and 400 GeV.

Mass range [GeV]	95% C.L. limit on dimuon pair σ [fb]	
	expected	observed
$m_{\mu\mu} > 15$ GeV	341^{+67}_{-125}	304
$m_{\mu\mu} > 100$ GeV	48^{+20}_{-18}	28
$m_{\mu\mu} > 200$ GeV	$12.6^{+5.3}_{-4.2}$	8.5
$m_{\mu\mu} > 300$ GeV	$7.0^{+2.5}_{-2.0}$	5.0

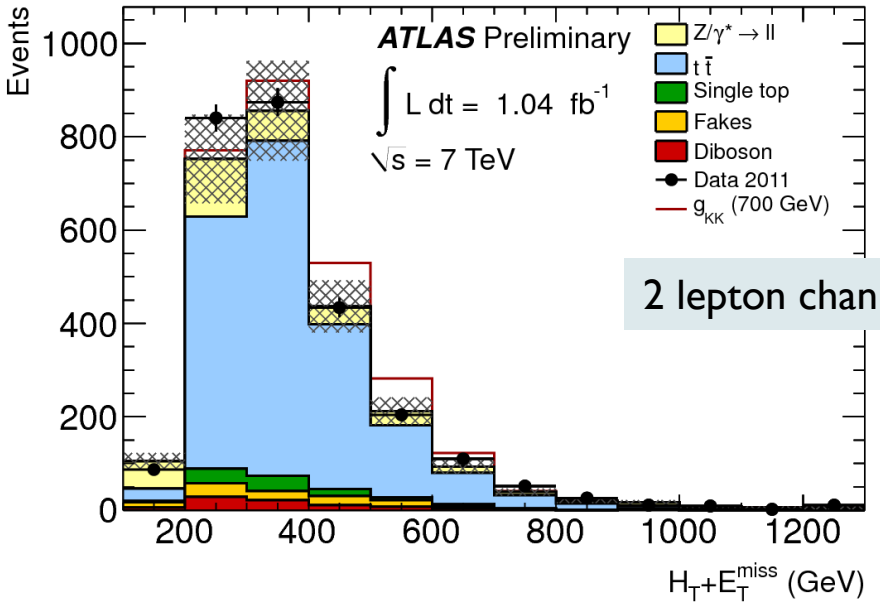


$t\bar{t}$ resonances

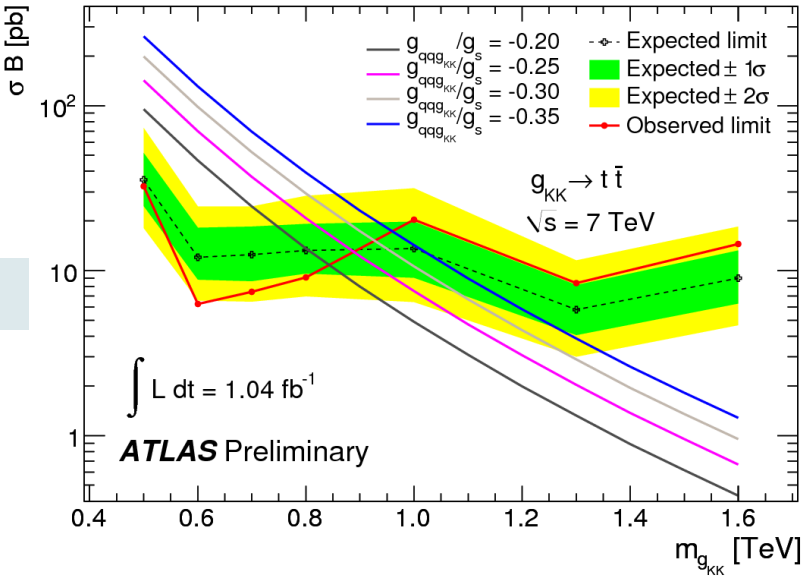
ATLAS-CONF-2011-123

Heavy particles coupling to the top quark can lead to resonances in the $t\bar{t}$ invariant mass spectrum.

This signal is sensitive to (for example):
- Kaluza-Klein gluons in Randall-Sundrum model (extra dimension)
- Leptophobic Z'



2 lepton channel



These results are from an analysis aimed at $t\bar{t}$ decays with two W's decaying leptonically
Analysis in the1 lepton channel also found no evidence for non-SM signal: ATLAS-CONF-2011-087

Conclusion and outlook

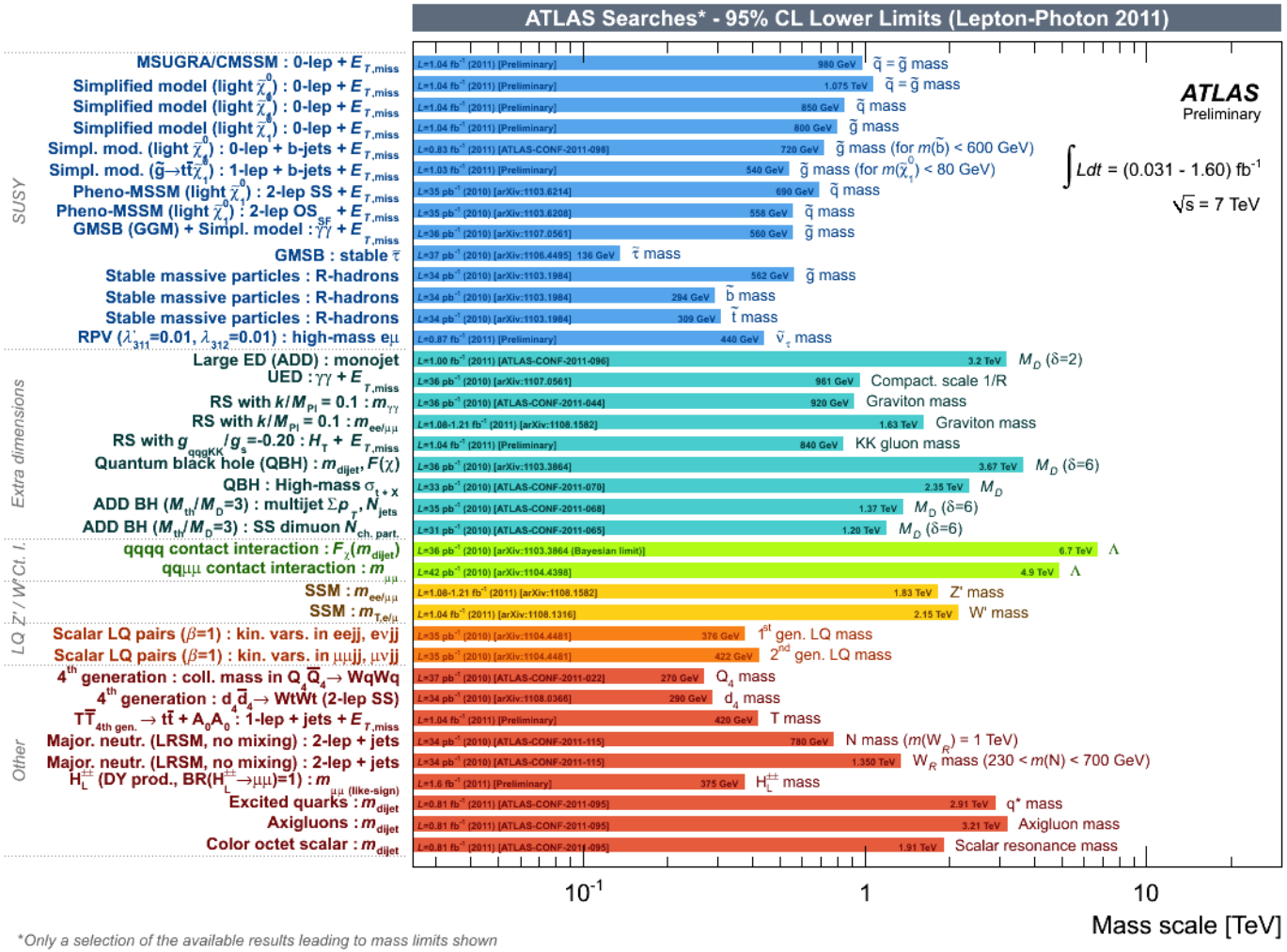
- Standard model Higgs-boson searches have excluded much of the available mass range:
  - $146 < m_H(GeV) < 232$
  - $256 < m_H(GeV) < 282$
  - $296 < m_H(GeV) < 466$
- No Higgs signal has been found yet (Maximum 2 σ)
- Next few months will be very exciting as we reach more of the available mass range.

- No evidence for beyond the Standard Model physics has been found so far.
- Searches are on-going and new limits on many models are set. A summary of these limits is included in the back-up slides.
- More models and phase-space will become accessible in the coming year.
- Many BSM searches will benefit from an increase to higher collision energy.

- Results listed at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Backup

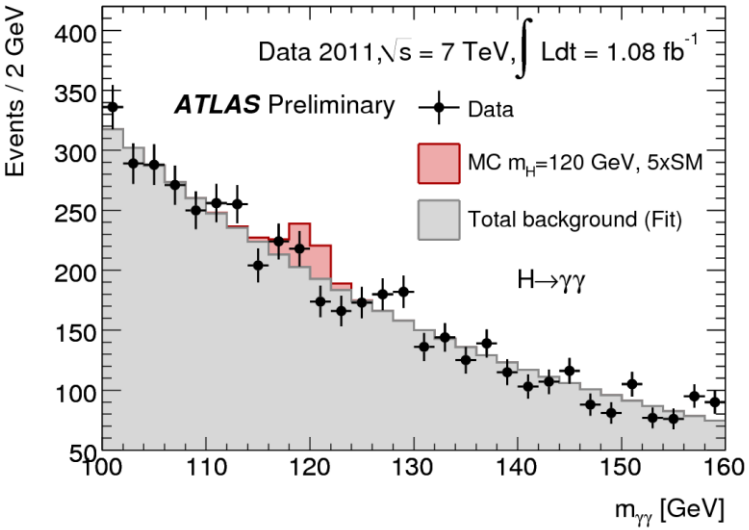
Summary of BSM searches in ATLAS



*Only a selection of the available results leading to mass limits shown

H→γγ

Fit on the $m_{\gamma\gamma}$ spectrum: signal function on an exponential background



Small branching fraction compensated by excellent mass resolution.

Promising for the future

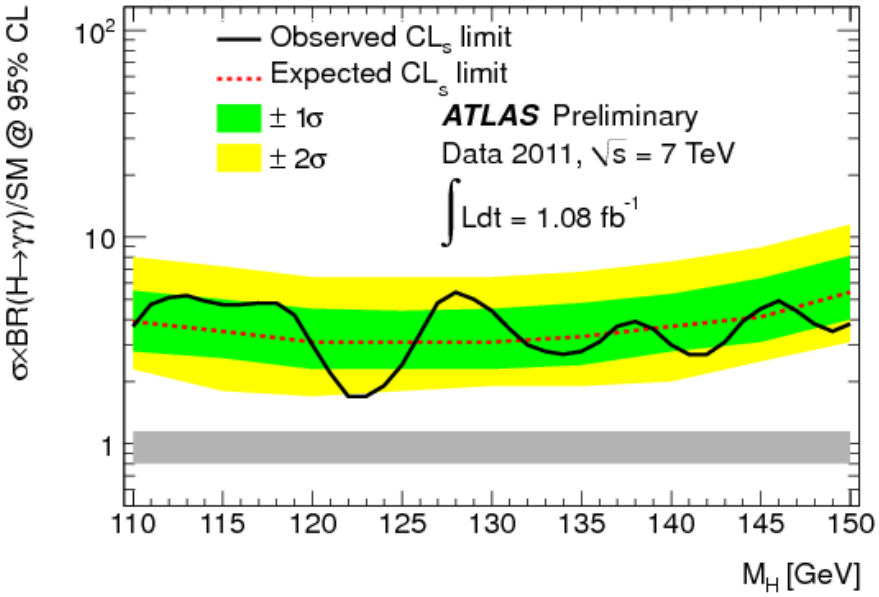
Both converted and unconverted photons are considered

Background: γγ, γ-jet & multi-jet contributions

<u>Results:</u>

Data agree well with background expectation, with no evidence for a signal.

Observed upper limit: (1.7 to 5) x $\sigma_{SM,Higgs}$



WH→lνbb, ZH→llbb

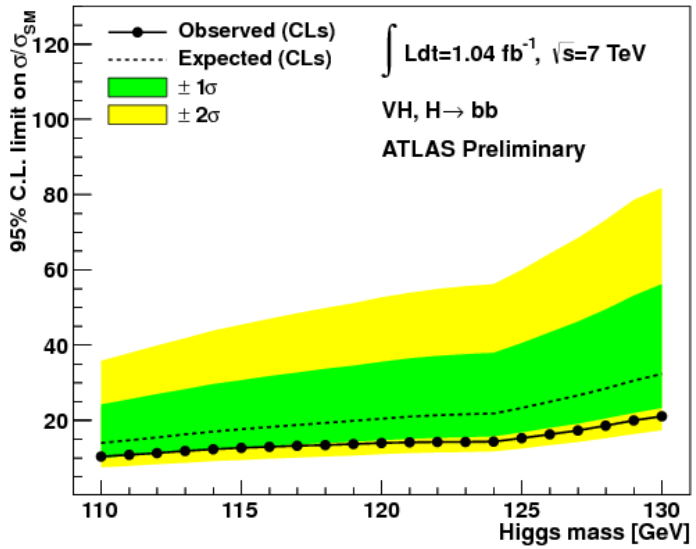
ATLAS-CONF-2011-103

Limits set based on the invariant mass distribution of the two b-jets

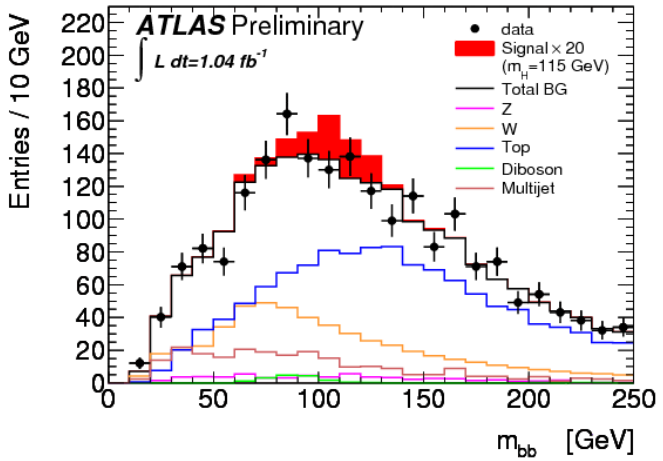
Base selection:

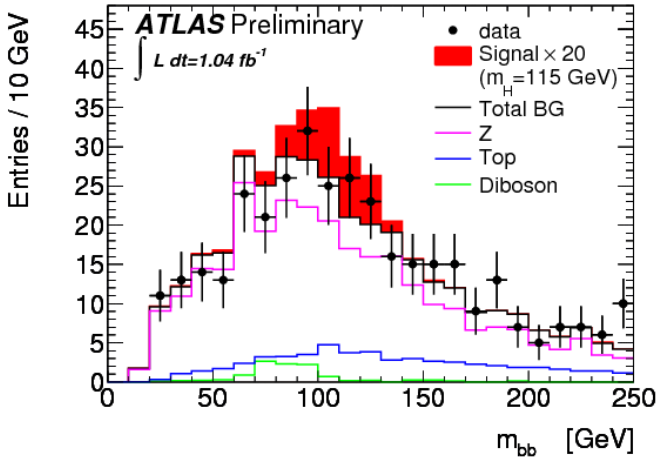
- 2 leptons (ZH) or 1 lepton + E_T^{miss} (WH)
- 2 b-tagged jets

W, Z, top normalisation constrained from m_{bb} sidebands



Observed upper limits: (10 to 20) x $\sigma_{SM,Higgs}$

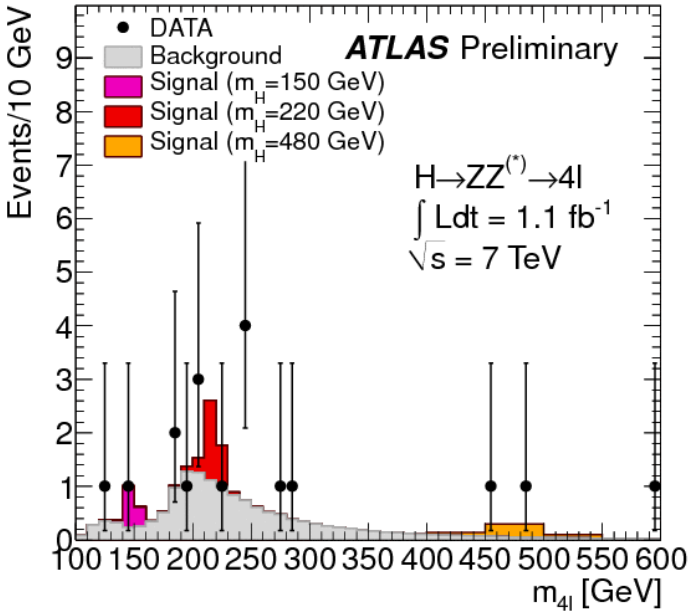




H→ZZ→llll (l=e,μ)

ATLAS-CONF-2011-131

Limits set based on the 4-lepton invariant mass distribution

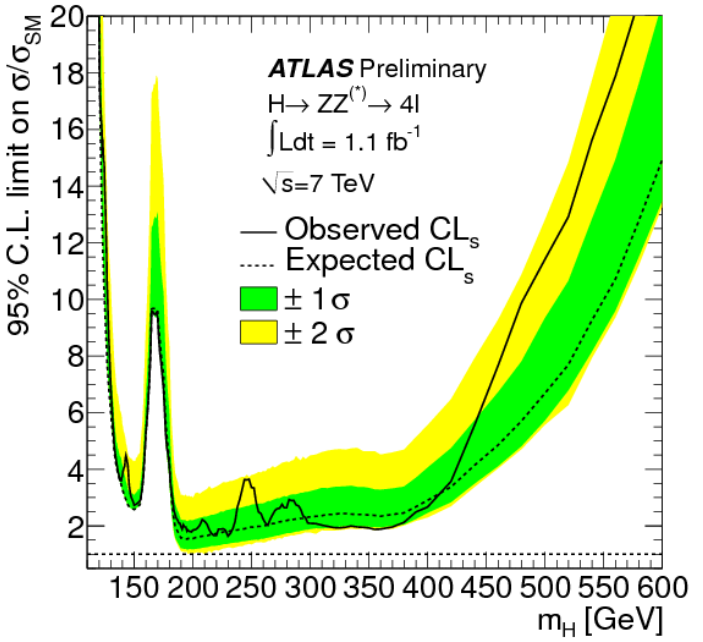


Base selection:

- 2 opposite sign lepton pairs
- at least 1 pair consistent with Z decay

Dominant background: ZZ (taken from theory)

18 candidate events selected: 14.7 expected.



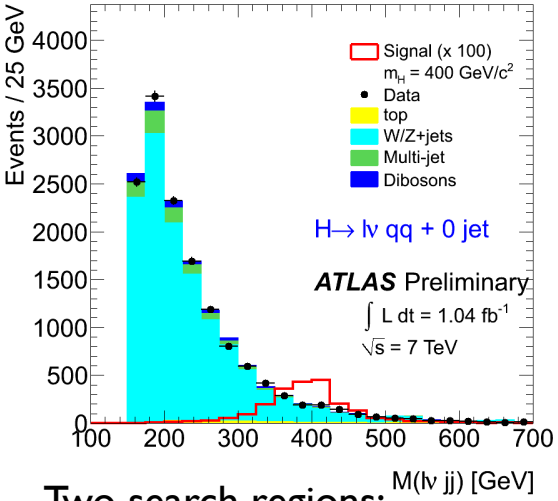
Results:

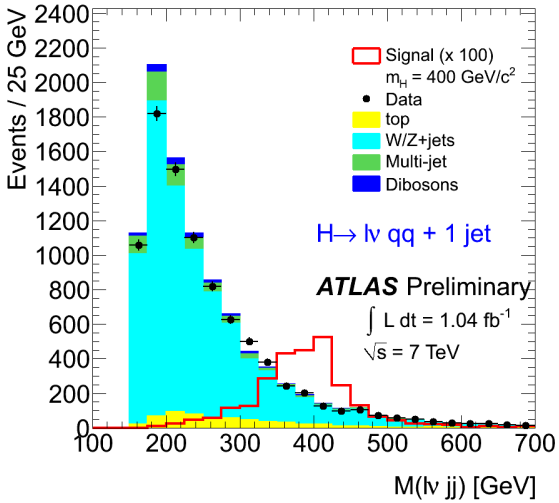
best observed limit 1.8 x $\sigma_{SM,Higgs}$ (m_H = 200 GeV)

some fluctuations, mostly due to individual events
most significant fluctuation: ~2σ at m_H = 246 GeV (4 events)

H→WW→lνqq (l=e,μ) (q=u,d,s,c)

Limits set based on fit of the invariant mass distribution: $m_{l\upsilon jj}$ (using $m_{l\upsilon} = m_W$)



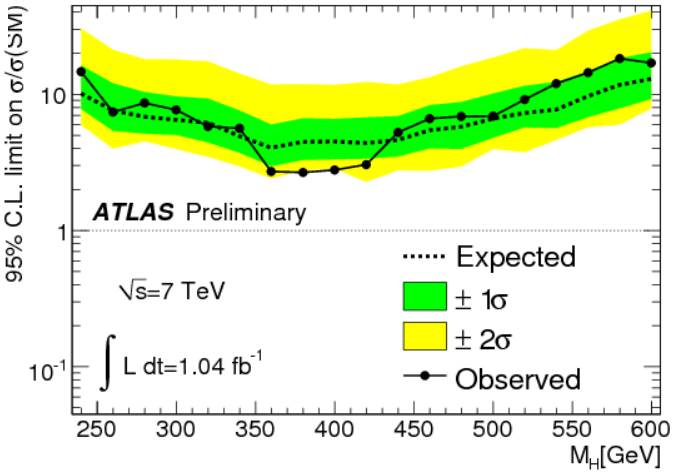


Base selection:
- 1 lepton
- Missing transverse energy
- 2 jets (also 3 jet bin) (b-jet veto)
- Both decays consistent with W

Dominant background: W + jets

Two search regions:
"H+0 jet" sample: 2 jets
"H+1 jet" sample: 3 jets

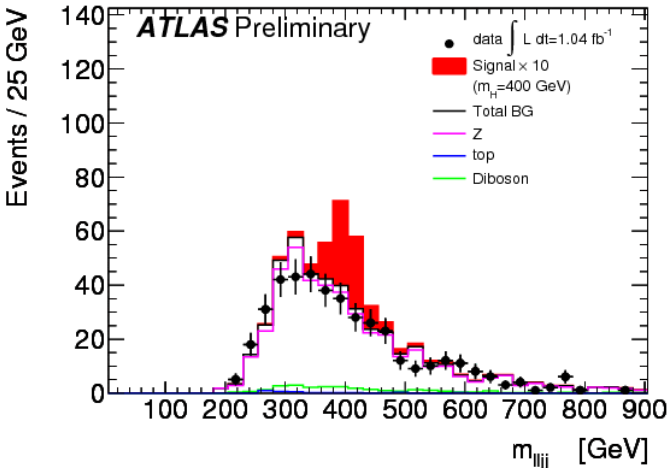
Background modelled with double exponential.
Signal distribution taken from MC simulation.

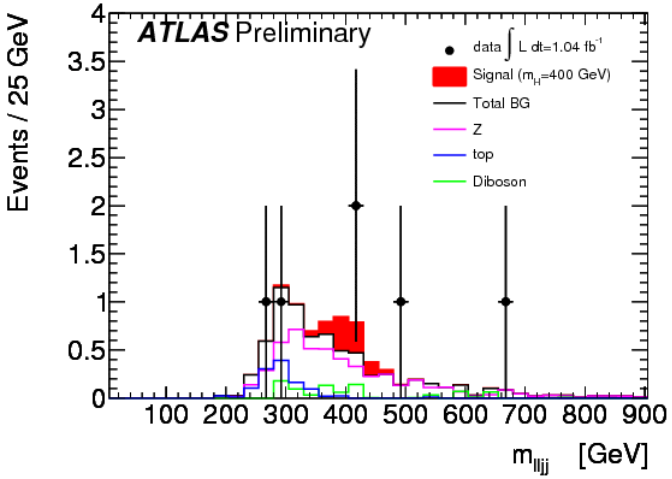


<u>Result:</u>
Best observed exclusion: ~2.5 × σ_{SM} at m_H=400 GeV

H→ZZ→llqq/llbb (l=e,μ) (q=u,d,s,c)

Limits set based on the invariant mass distribution of the 2-lepton+2-jets system

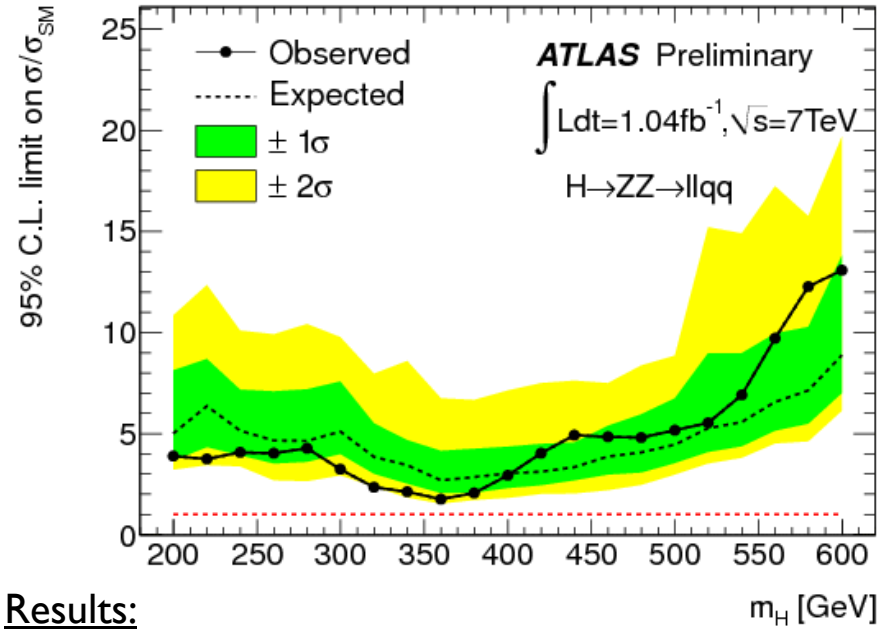




Base selection:

- lepton pairs consistent with Z decay
- jet pair consistent with Z decay

Separate search for b-tagged and untagged jets

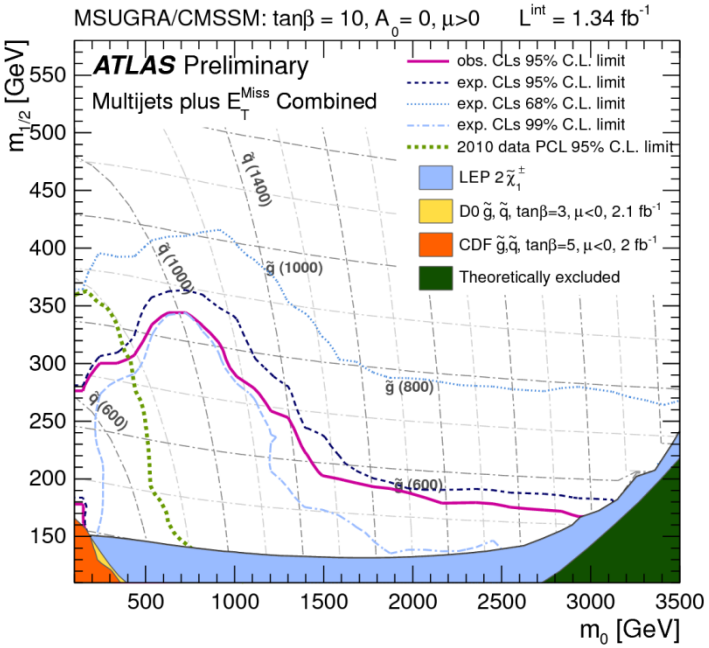


Results:

Best observed limit: $1.8\times\sigma_{SM,Higgs}$ (m_H=360 GeV)

SUSY channel: jets, E_T^{miss} and 0 leptons

High jet multiplicity search:
Increase number of jets to 6, 7 and 8
Result:
MSUGRA (tanβ=10, A_0=0, μ>0):
- Slight increase in limit on $m_{1/2}$ for high m_0
- Gluino masses excluded to ~600 GeV



Analysis with at least 1 b-jet:
Four signal regions:
- ≥ 3 jets
- 1or 2 jets are b-tagged
- m_{eff} (>500 or 700 GeV)

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Sig. Reg.	Data (0.83 fb^{-1})	Top	W/Z	QCD	Total
3JA (1 btag m_{eff} >500 GeV)	361	221^{+82}_{-68}	121 ± 61	15 ± 7	356^{+103}_{-92}
3JB (1 btag m_{eff} >700 GeV)	63	37^{+15}_{-12}	31 ± 19	1.9 ± 0.9	70^{+24}_{-22}
3JC (2 btag m_{eff} >500 GeV)	76	55^{+25}_{-22}	20 ± 12	3.6 ± 1.8	79^{+28}_{-25}
3JD (2 btag m_{eff} >700 GeV)	12	$7.8^{+3.5}_{-2.9}$	5 ± 4	0.5 ± 0.3	$13.0^{+5.6}_{-5.2}$

Result: No excess found, model independent limits on non-SM cross section within acceptance of 288, 61, 78, and 17 fb at 95% confidence.

SUSY channel: di-photons and E_T^{miss}

Base selection:
- 2 photons
- E_T^{miss} > 125 GeV

Irreducible background
- $Z(\rightarrow \nu\bar{\nu}) + \gamma\gamma$
- $W(\rightarrow \ell\nu) + \gamma\gamma$

E_T^{miss} range [GeV]	Data events	Predicted background events			
		Total	QCD	$W/t\bar{t}(\rightarrow e\nu) + X$	Irreducible
0 - 20	20881	-	-	-	-
20 - 50	6304	5968 ± 29	5951 ± 28	13.3 ± 8.1	3.6 ± 0.3
50 - 75	86	87.1 ± 3.3	60.9 ± 2.8	25.2 ± 1.7	1.0 ± 0.2
75 - 100	11	14.7 ± 1.2	6.7 ± 0.9	7.4 ± 0.8	0.52 ± 0.10
100 - 125	6	4.9 ± 0.7	1.6 ± 0.4	3.0 ± 0.5	0.23 ± 0.05
> 125	5	4.1 ± 0.6	0.8 ± 0.3	3.1 ± 0.5	0.15 ± 0.01

Only statistical uncertainties

<u>Result:</u>

Less than 7.1 non-SM events in signal region (including background and selection uncertainties)

In the case of gauge mediate SUSY with:
- Bino-like neutralino
- All SUSY particles have mass ~1.5 TeV except for:
  - gluino,
  - lightest neutralino
  - gravitino

Gluino mass < 800 GeV excluded for neutralino mass > 100 GeV