SUSY searches at ATLAS

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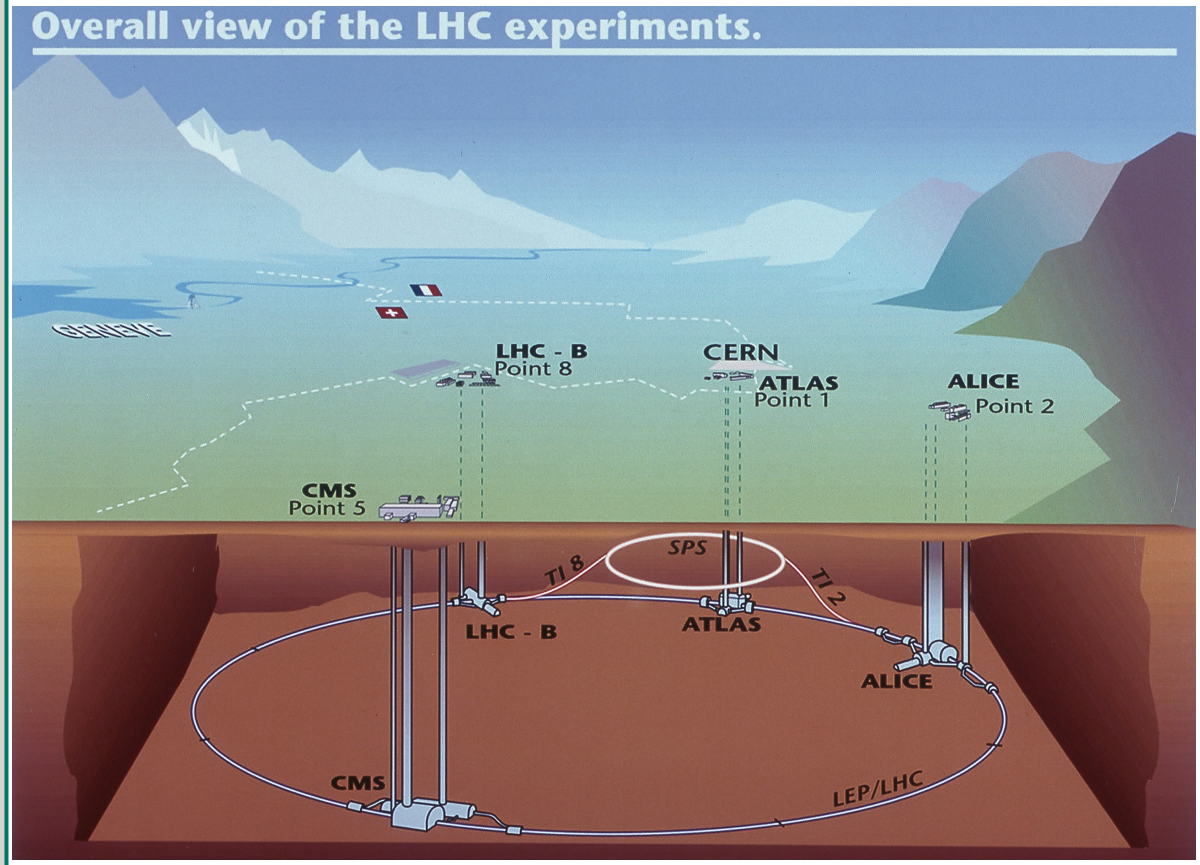
ATLAS collaboration

Large Hadron collider



27 km ring situated underground beneath Geneva,

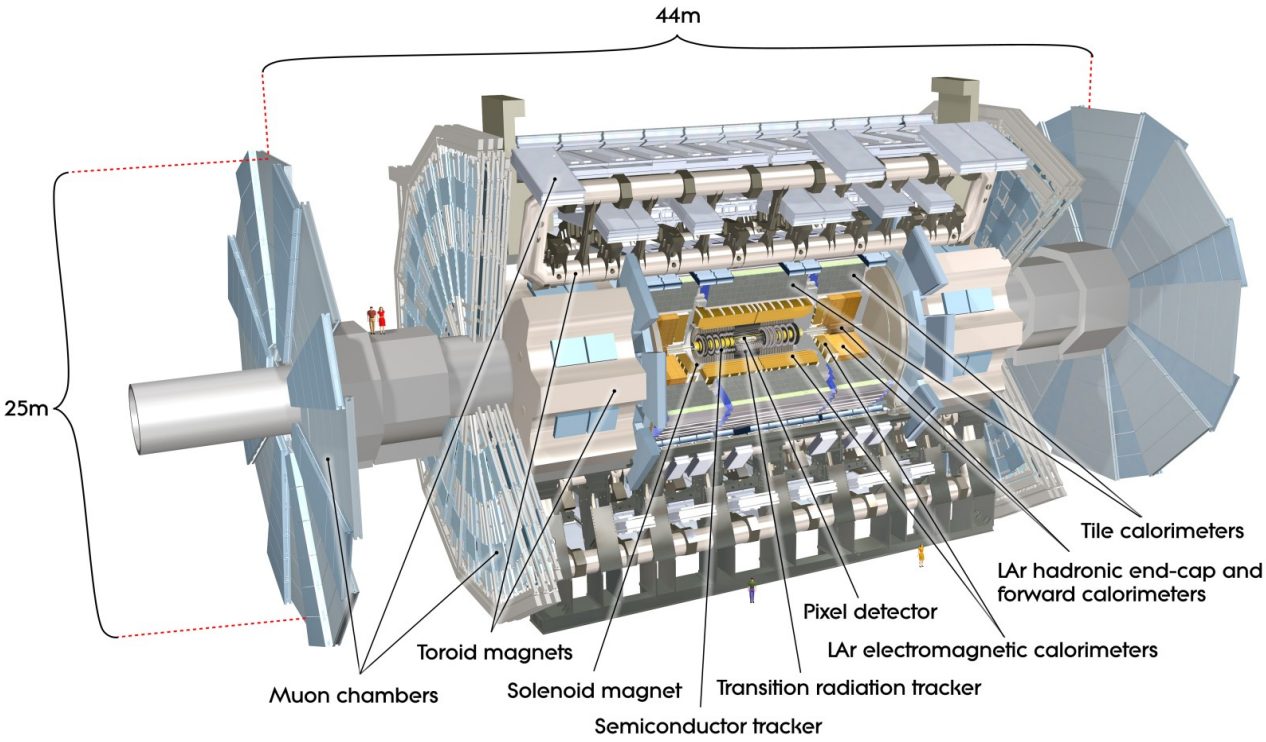
High-energy protons (2*7 TeV) circulated in the ring in two counter-rotating beams,

Four experimental caverns for ATLAS, CMS, ALICE and LHCb.

Physics Program:

Higgs searches, Precise Top Physics, Susy searches, Extra Dimensions ...

The ATLAS Experiment



- 2T solenoid inside calorimeters
- Silicon+TRT tracker + electron ID
- EM cal: Longitudinally segmented Lead-Ar: $\sigma_E/E \sim 10\%/\sqrt{E[GeV]}$ 0.7%
- HAD cal: Fe-scint + Cu-Ar, $\geq 11\lambda_0$ $\sigma_E/E \sim 50\%/\sqrt{E[GeV]}$ 3%
- Air-toroid muon sp.: $\int \sqrt{B}.dl$ = 1 to 7 T.m

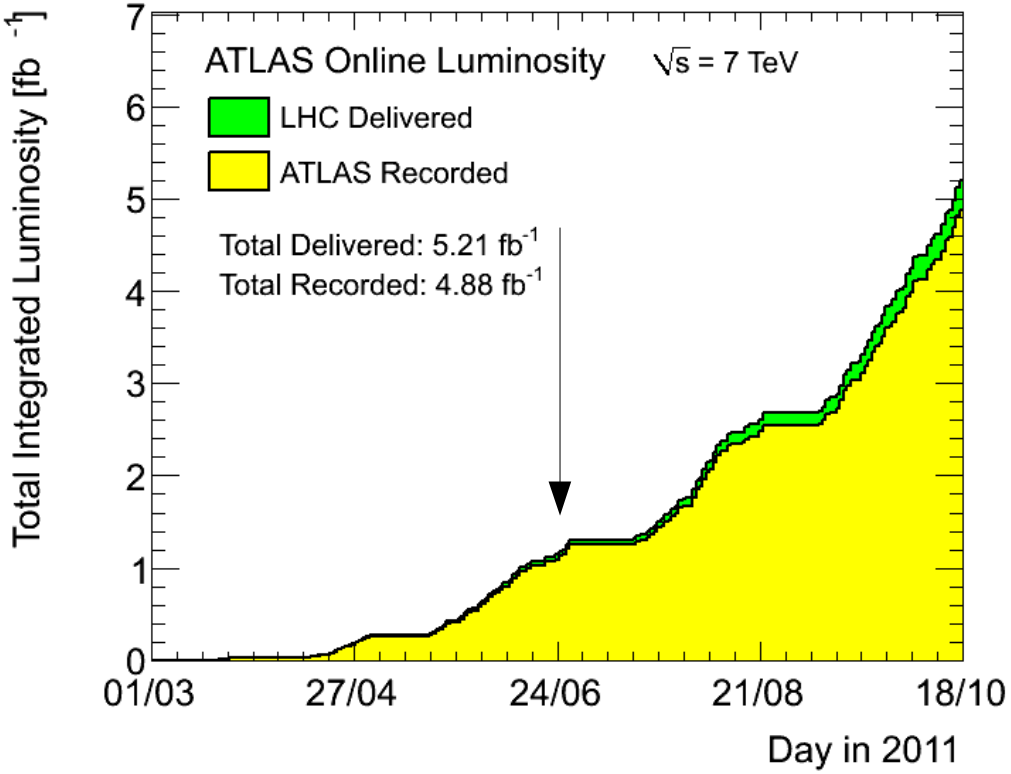
Physics searches relies on:

Good detector acceptance,
Good object reconstruction, identification,
Good energy resolution,
And a lot of data...

Data and Monte Carlo Samples

√s=7 TeV proton-proton data recorded by ATLAS in 2011:

$$\int Ldt = 5021 \pm 185\ pb^{-1}$$



Data used for the plots in these presentation:

Upto: 1 – 2 fb^{-1}

Monte Carlo simulaton:

Aplgen: W, Z+jets,

Herwig: Dibosons,

MC@NLO: single t, $t\bar{t}$.

Beyond Standard Model

- **The Standard Model is in good agreement with all experimental measurement so far but theory has few unanswered questions**
  → Hierarchy: quadratic divergence of the Higgs mass, extremely fine-tuned
  → What is the underlying nature of EWSB?
- **Dark Matter**
  → cannot be explained by SM
- **Neutrinos have mass**
  → where are the right-handed neutrinos?
- **BSM models want to solve the SM limitations.**

Content

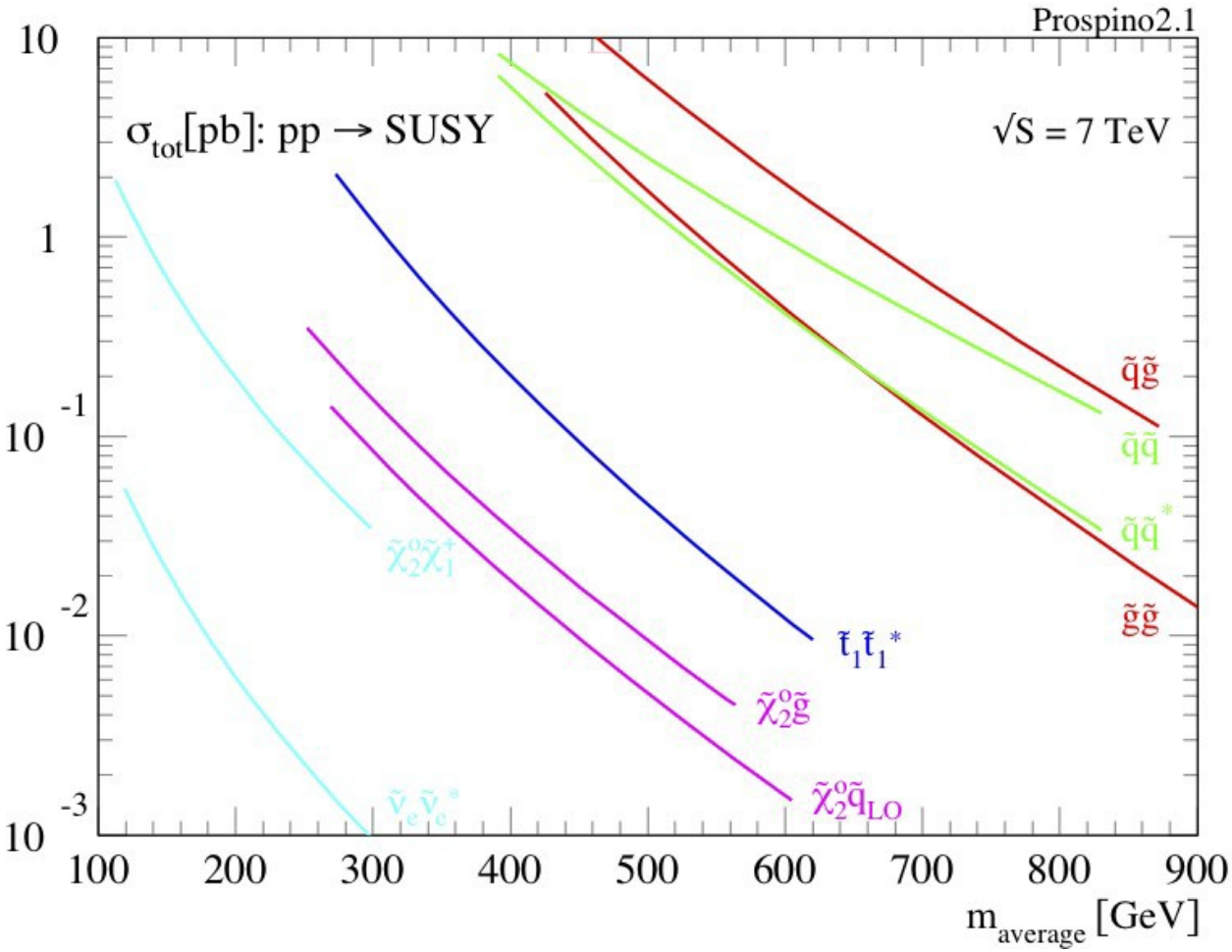
Supersymmetry (with MET),

→ **Jets + MET (results)**

→ **Lepton(s) + MET (in more details)**

→ **3rd generation + MET,**

→ **Photon(s) + MET,**



SUSY phenomenology and search strategies

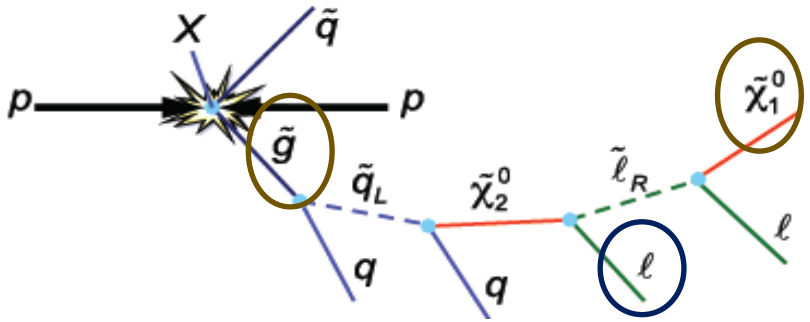
Could solve:

1) The hierarchy problem, protects the Higgs mass from large quantum corrections,
2) the unification of gauge couplings,
3) a dark matter candidate.

In R-parity conserving scenarios, sparticles come in pair, Lightest SuperSymetric Particle (LSP) is stable and escapes undetected,

Signature: High Missing Energy,

Exact decay chain depends on SUSY breaking mechanism and mass hierarchy of sparticles, but visible part consists with SM quarks (high-p_T jets) and leptons.



A SUSY decay chain, where Neutralino is LSP

SUSY models, assume R-parity conservation

MSSM at least 105 new parameters,

-> Constrained MSSM (cMSSM) -> minimal SuperGravity

(mSUGRA) – 5 parameters: m_0, $m_{1/2}$, A_0, tanβ and the sign of μ.

ATLAS - A_0=0 GeV, tanβ =10, μ>0.

Note: benchmark point on plots m_0 = 500 GeV; $m_{1/2}$= 330 GeV;

Simplified models:

decoupled sparticle spectra, particles of no interests considered very massive,

For leptonic final states $\tilde{\chi}^{\pm} \to LSP$ chain, $\tilde{\chi}^{\pm} \to W(*)\tilde{\chi}^0$,

Three free parameters: $m_{\tilde{q}/\tilde{g}}, m_{\tilde{\chi}^0}$, and $x = (m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}^0})/(m_{\tilde{q}/\tilde{g}} - m_{\tilde{\chi}^0})$.

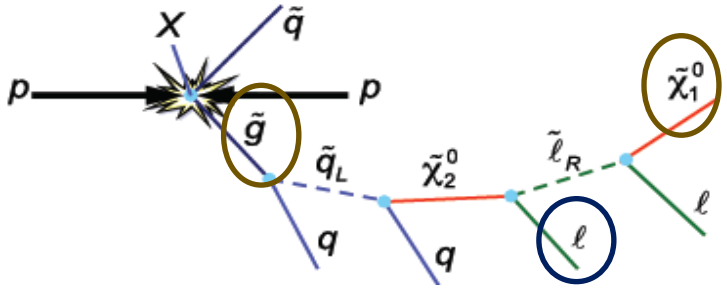
- In squark-chargino-neutralino model: $\tilde{q} \to q'\tilde{\chi}^{\pm} \to q'W(*)\tilde{\chi}^0$,
- In gluion-charginp-neutralino model: $\tilde{g} \to q\bar{q}\tilde{\chi}^{\pm} \to q\bar{q}W(*)\tilde{\chi}^0$,

1-lepton + Jets + Etmiss searches

Easy to trigger, well modeled background contributions

Pre-Selection:

- **Data quality flags,**
- **Single lepton trigger fired,**
- **Good primary vertex,**
- **Cosmic muon veto**
- **==1 muon/electron with p_T>20/25 GeV,**
- **≥ 3/4Jets, p_T requirement on next slide,**
- **$\Delta\phi$ (jet, E_t^{miss}) >0.2 for all jets,**



Transverse mass, m_T

Transverese scalar mass, H_T

"effective" mass, m_{eff}

$$m_T = \sqrt{2 * p_T^l * E_T^{miss} * (1 - \cos(\Delta\Phi(l, E_T^{miss})))},$$

$$H_T = p_T^l + \Sigma_{i=1}^{3} p_T^{jet_i},$$

$$m_{eff} = H_T + E_T^{miss}$$

1-lepton + Jets + Etmiss searches

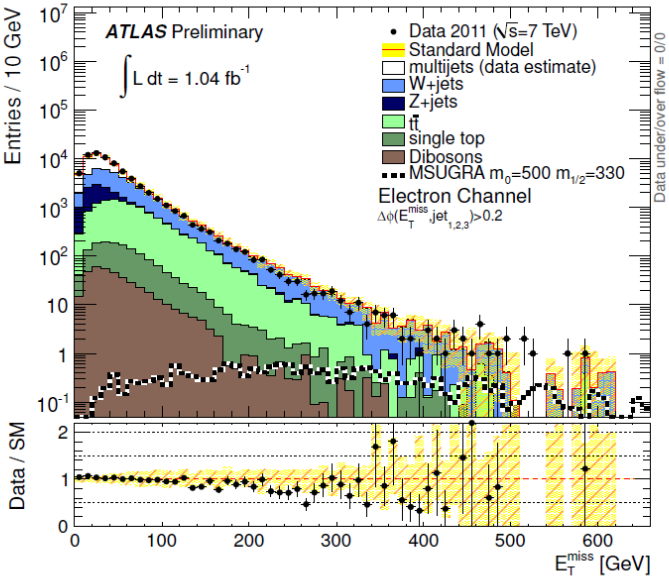
4 Signal Regions: 3 jet loose(3JL), 3 jet tight(3JT), 4 jet loose (4JL), 4 jet tight(4JT).

After pre-selection:

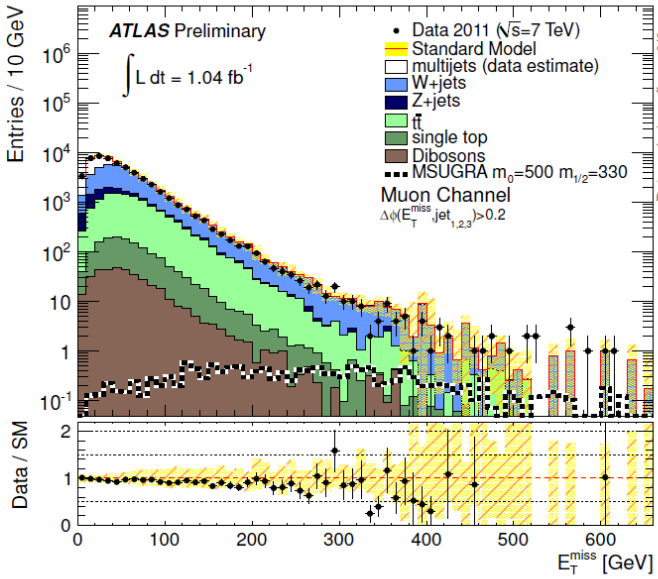
Signal Selection	3JL	3JT	4JL	4JT
Leading jet p_T [GeV]	60	80	60	60
Subsequent jets p_T [GeV]	25	25	25	40
M_T [GeV]	100	100	100	100
E_T^{miss} [GeV]	125	240	140	200
E_T^{miss}/M_{eff}	0.25	0.15	0.30	0.15
M_{eff} [GeV]	500	600	300	500

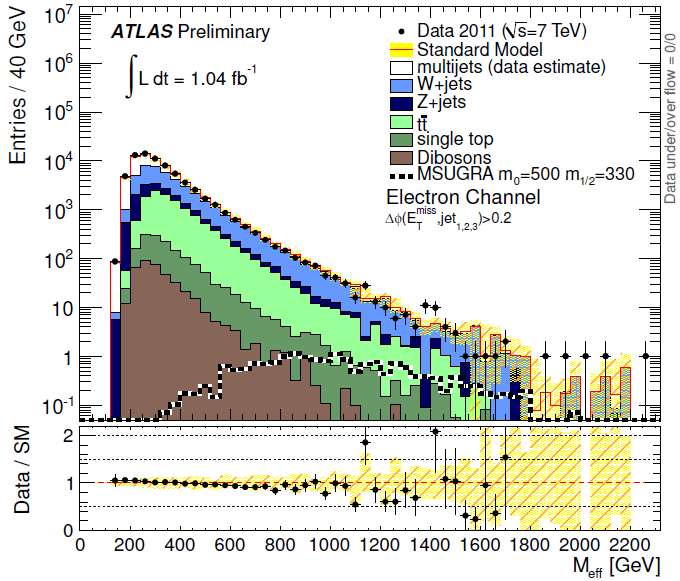
m_{eff} and E_T^{miss} distributions after 3JL pre-selection

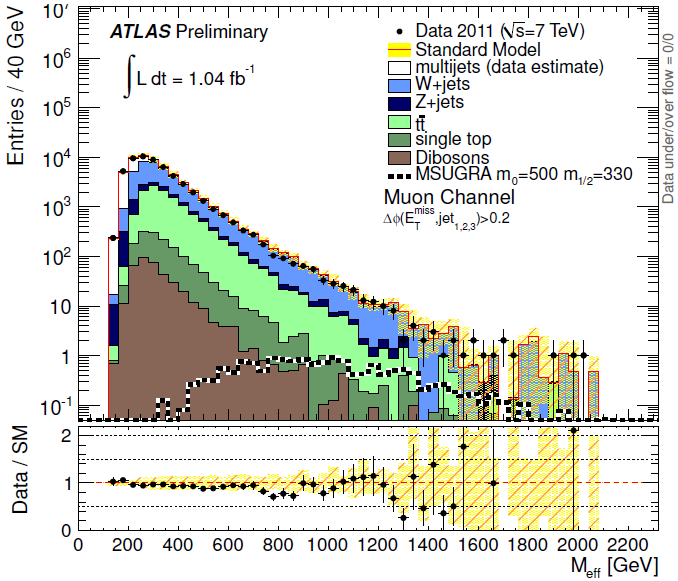
Electron Channel



Muon Channel







Good agreement between Data and SM expectation within uncertainties after 3J pre-selection. **Note: 4J pre-selection on Backup slide.**

Control regions

Main BG in SR: Top and W+jets processes.

W+jets CR:

After pre selection,

m_{eff} > 500/300 GeV for 3J/4J Control Regions,

30 GeV < E_t^{miss} < 80 GeV,

40 GeV < m_T < 80 GeV,

no b-tagged jet among the three hardest jets.

Top CR:

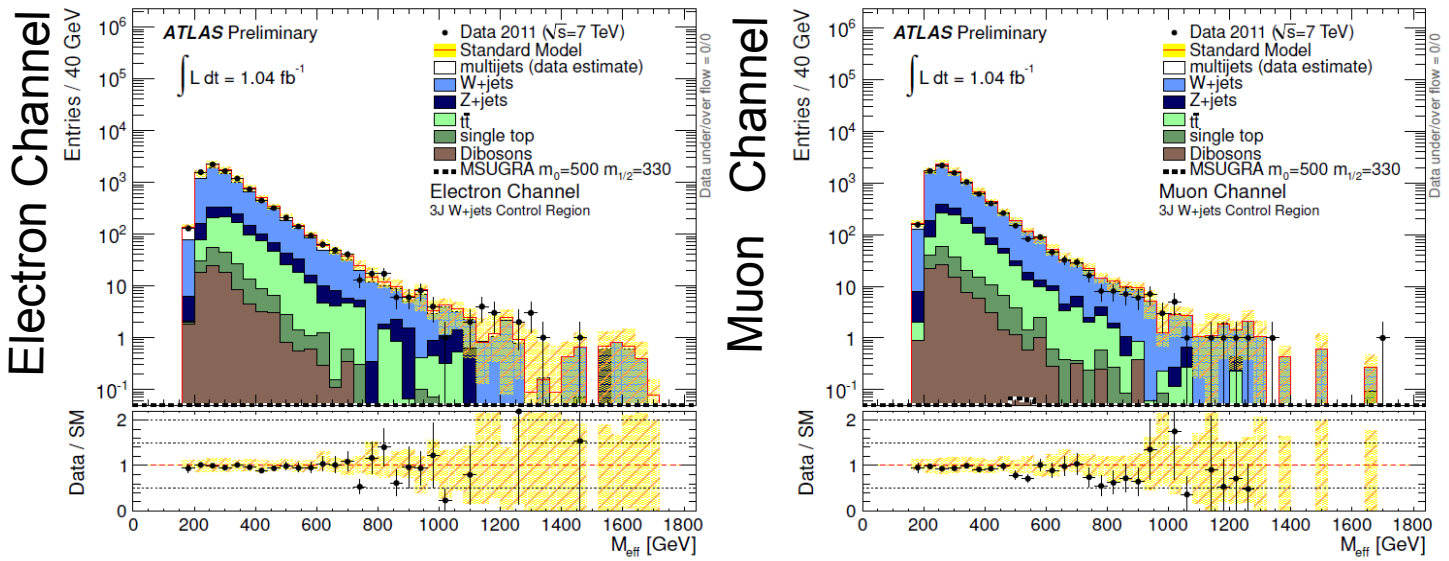
Same as W + jets, but at least one b-tagged jet among the three hardest jets.

QCD CR:

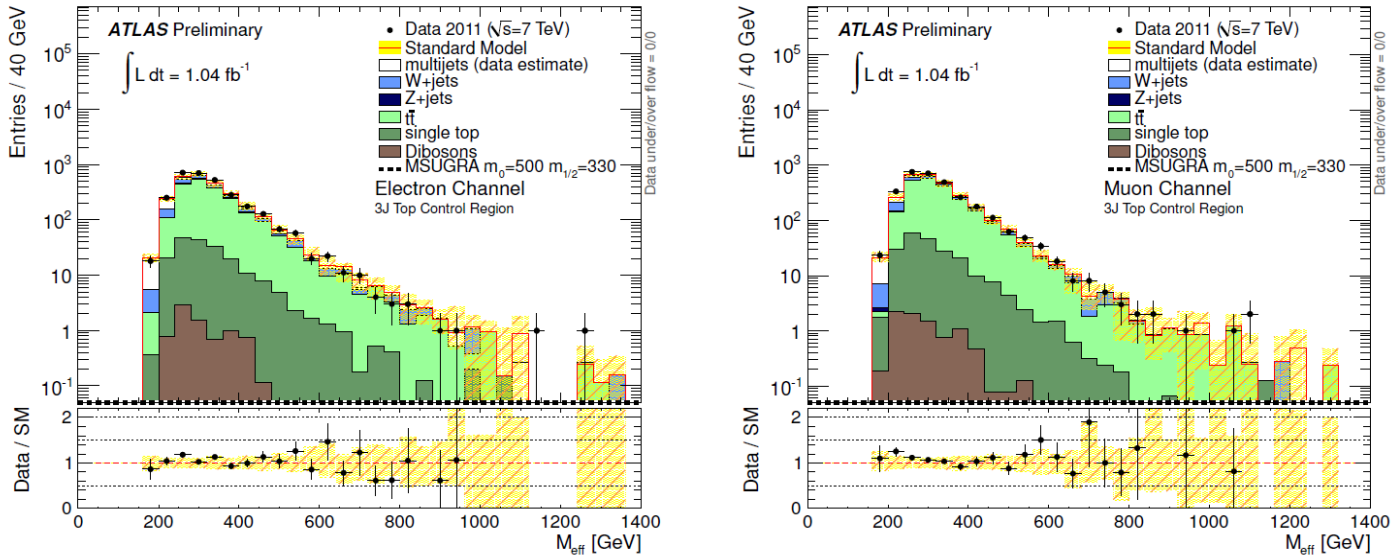
E_T^{miss} < 30 GeV, 1jet with p_T>30/60 GeV in electron/muon channel.

m_{eff} distributions in 3J CRs

W+jets CR



Top CR



Good agreement between Data and SM expectation within uncertainties in Crs.
Note: 4J CRs on Backup slide.

Background (BG) estimation

Data driven QCD estimation with matrix method:

- Loosening lepton ID, dropping isolation criteria,

$$N_{pass} = \varepsilon_{real} N_{real} + \varepsilon_{misid.} N_{misid.}$$

$$N_{fail} = (1-\varepsilon_{real}) N_{real} + (1 - \varepsilon_{misid.}) N_{misid.}$$

N_{pass}/N_{fail} loose events passing/failing the tight selection.

$\varepsilon_{real}/\varepsilon_{misid.}$ is ID/ misID efficiency.

$\varepsilon_{misid.} N_{misid}$ is estimated for every CRs and SRs.

Top and W+ jets contribution in SRs:

Normalization of W and Top BG derived from the CRs,

- Assumed MC shapes,
- Transfer factors $C_{CR->SR} = N^{SR}_{MC}/N^{CR}_{MC}$, for each BG and each CR,
- Extrapolate to SR: $N^{SR}_{predicted} = N^{CR}_{data} * C_{CR->SR}$,
- Simultaneous likelihood fit of the different CRs to account for cross contamination.

The procedure validation (MC shape assumption) in 28 additional CRs,

- low m_T and high E_t^{miss} ,
- low E_T^{miss} and high m_T.

Good agreement were observed between predicted and observed event counts in every validation CRs.

Systematic Uncertainties

The systematic uncertainties on BG estimation:

- Jet energy scale (JES) and jet energy resolution (JER) measured from 2010 data + pile up effects 2011,
- MC modeling uncertainties affecting transfer factors,
- MC statistics of Top and W processes,
- Lepton energy/momentum scale and resolution,
- Lepton ID/ misID,
- Heavy flavor tagging uncertainties .

Total uncertainty in 3J Loose SR:

- Electron channel ±8.4% (stat.) ±30.2% (syst.),
- Muon channel ±7.6% (stat.) ±19.3% (syst.).

Note: Break down of all systematic in all SRs on Backup slide.

Signal systematic uncertainties, calculated for each signal hypothesis:

- Factorization, normalization scale variations,
- Variations in α_s and PDF uncertainties (STEQ6),
  - Total theory ~ 20-30%.
- MC statistics ~15%,
- Lepton trigger and ID (1-4%),
- JES, JER ~(1-10%),
- Pile-up ~(1-10%),
- Luminosity 3.7%.

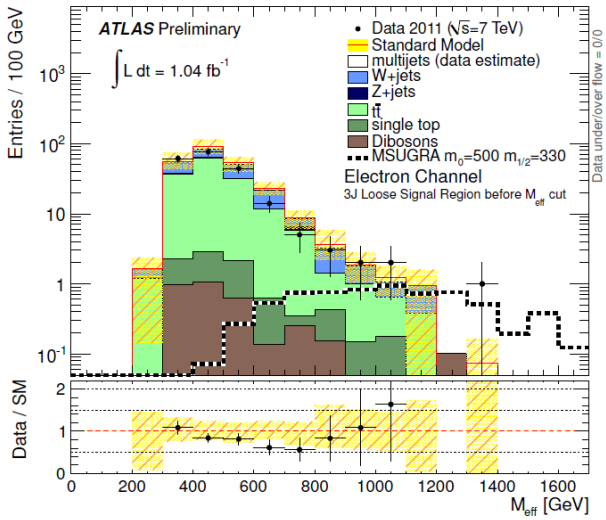
m_{eff} distributions in 3J Signal regions

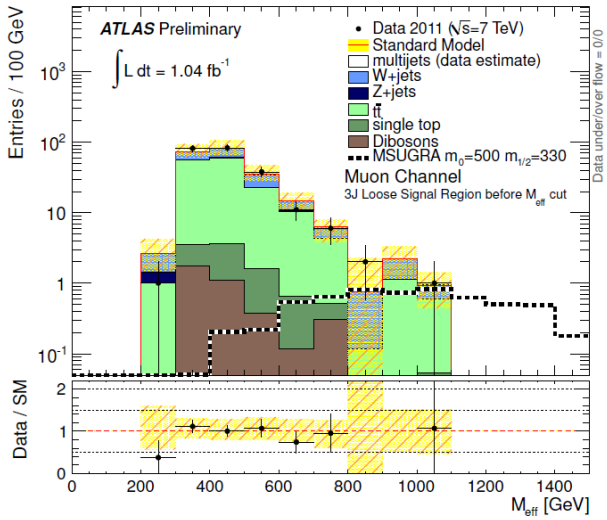
3J Loose

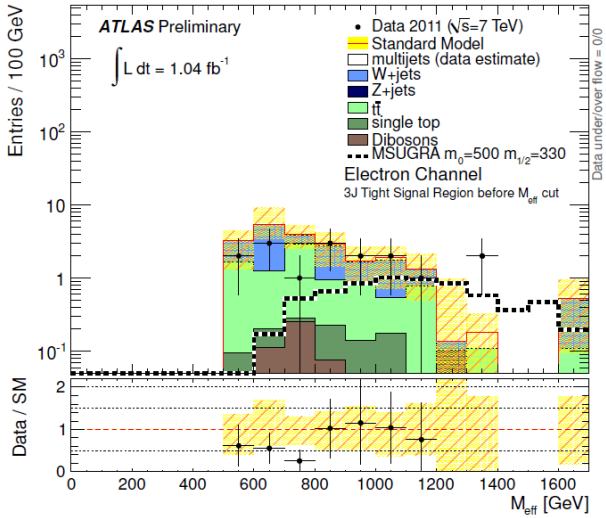
3J Tight

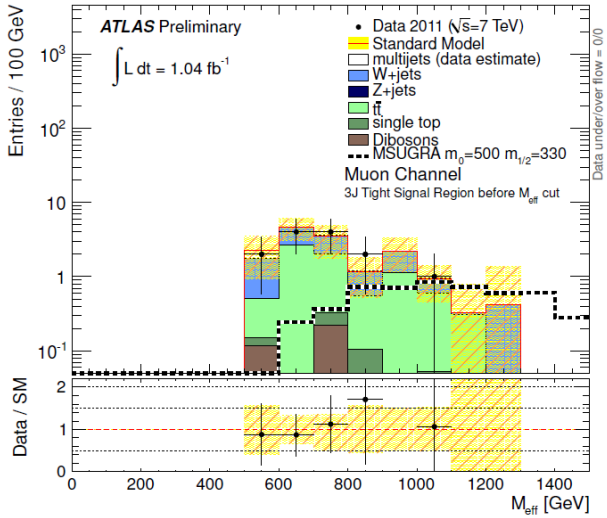
Electron Channel

Muon Channel









- Plots are produced before m_{eff} cut.
- Good agreement between Data and SM expectation within uncertainties,
- No excess observed.

Note: 4J Signal regions on Backup slide.

Results

Combined fit to the number of events in the Signal and Control regions,

$$L(n|s,b,\theta) = P_s \, x \, P_w \, x \, P_T \, x \, C_{syst},$$

n - observed events, s - signal counts to be tested, b - background counts,
θ- systematic uncertainties, treated as nuisance parameters with a Gaussian pdf.
P functions are Poisson probability distributions for event counts in SR, and in Top and W CRs.

Two fits performed:

- Discovery fit, signal events in SR left free, no signal contamination in CR,
- Exclusion fit, signal events fix to the expected values in SR and CRs,

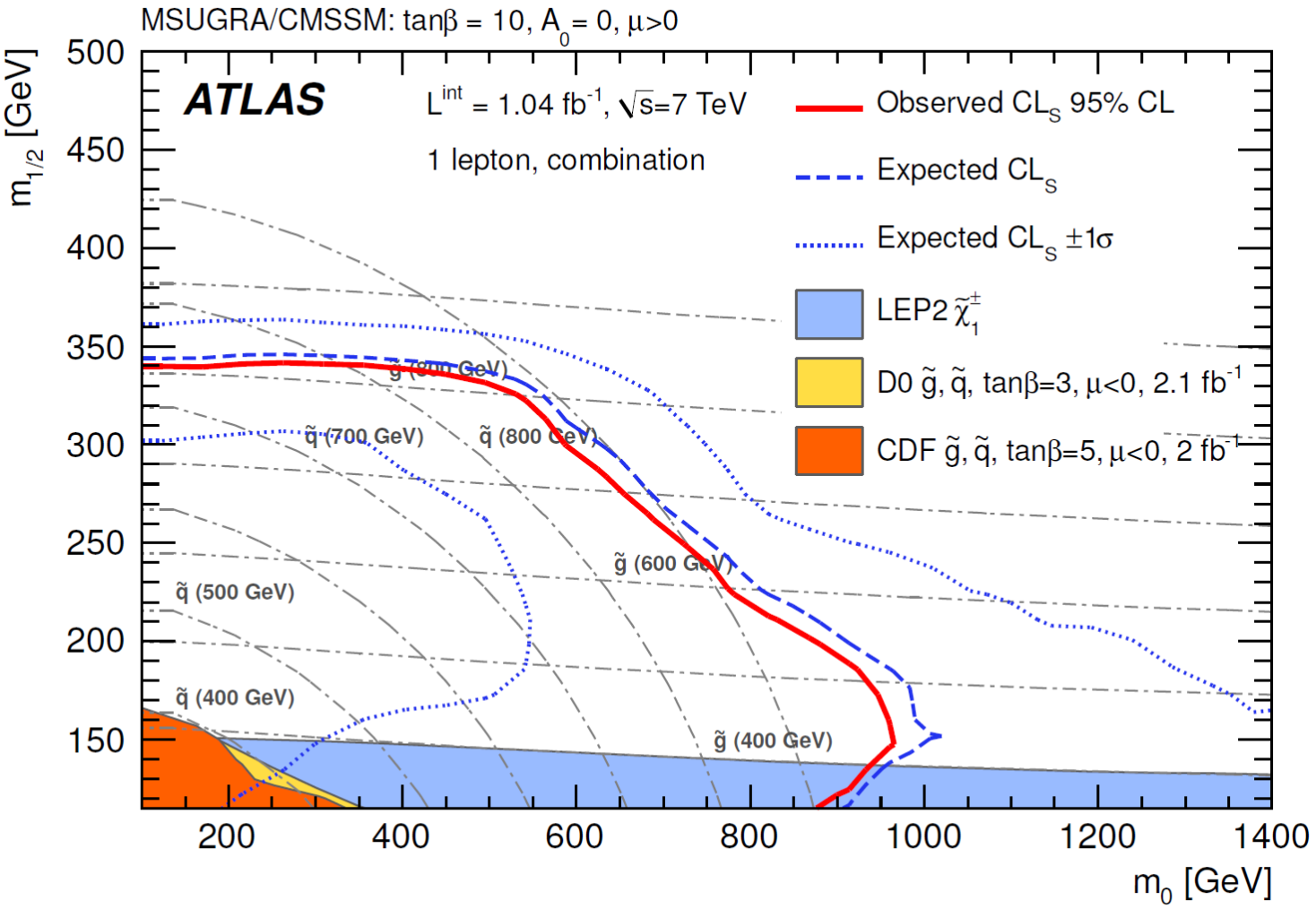
Model independent upper limits

- Derived from the discovery fit
- Profile likelihood ratio technics
- CL_s method.

Electron channel	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B	$p(s=0)$
3JL	50	52	63^{+23}_{-11}	0.21	0.79
3JT	14	14.3	$16.5^{+6.7}_{-3.0}$	0.30	0.71
4JL	33	34	38^{+15}_{-7}	0.35	0.65
4JT	10	10.6	$9.5^{+4.3}_{-1.6}$	0.61	0.42
Muon channel	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B	$p(s=0)$
3JL	36	38	41^{+16}_{-7}	0.39	0.60
3JT	10	9.9	$11.4^{+4.5}_{-2.0}$	0.31	0.70
4JL	31	32	34^{+14}_{-7}	0.42	0.58
4JT	9	8.9	$8.0^{+3.0}_{-1.6}$	0.63	0.39

95% CL upper limits on the visible cross-section (εσobs), on the observed/expected (Sobs/Sexp) number of signal events. The CLB, the confidence level for the BG hypothesis and discovery fit p-value (p(s=0)).
Note: Fit results for all Control and Signal Regions on Backup slide.

Interpretation: MSUGRA/CMSSM

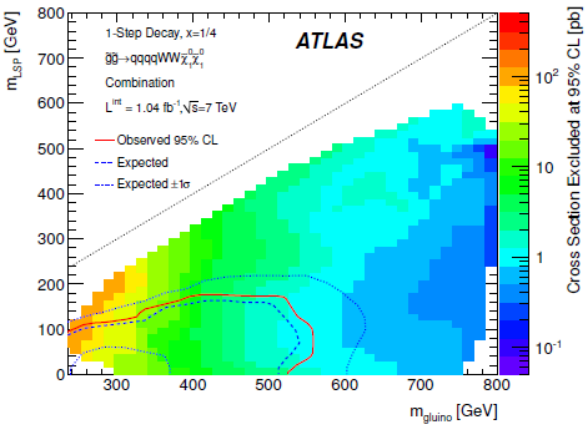


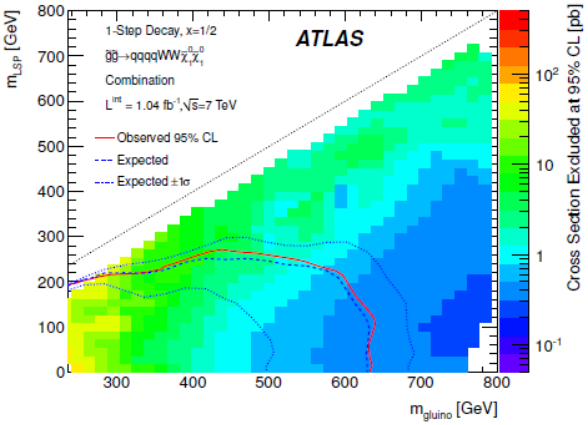
observed and expected 95% CL exclusion limits in the combined electron and muon channels shown in m_0 and $m_{1/2}$ plane, for the MSUGRA/CMSSM model, where A_0=0 GeV, tanβ =10, μ>0.

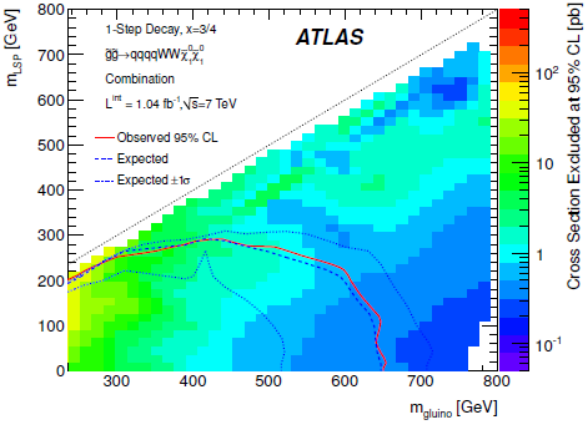
New Limit: Mgluino = Msquark > 875 GeV.

Simplified Models

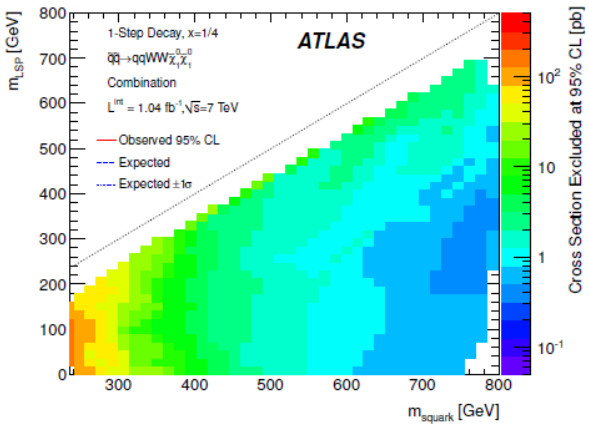
gluino Model

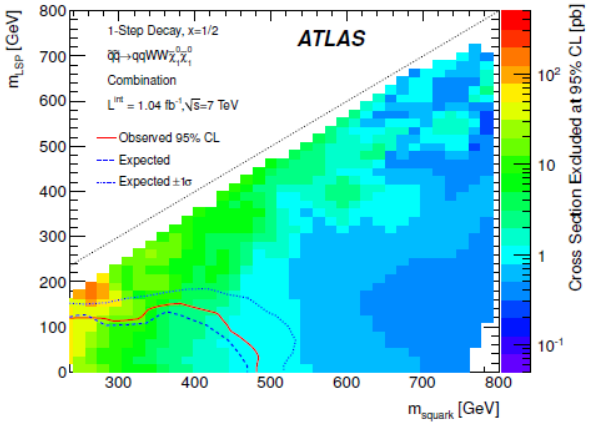


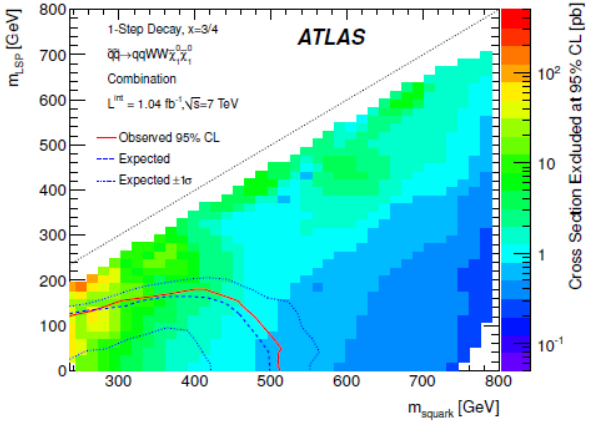




squark Model







Results are presented in the m_{heavy}-m_{LSP} plane:

- Color coding: Cross section limit,
- Full line: Observed exclusion limit assuming 100% br. fraction to assumed decay modes,
- Dashed line: Expected exclusion limit.

3 fixed values of x considered to effectively scan the range:

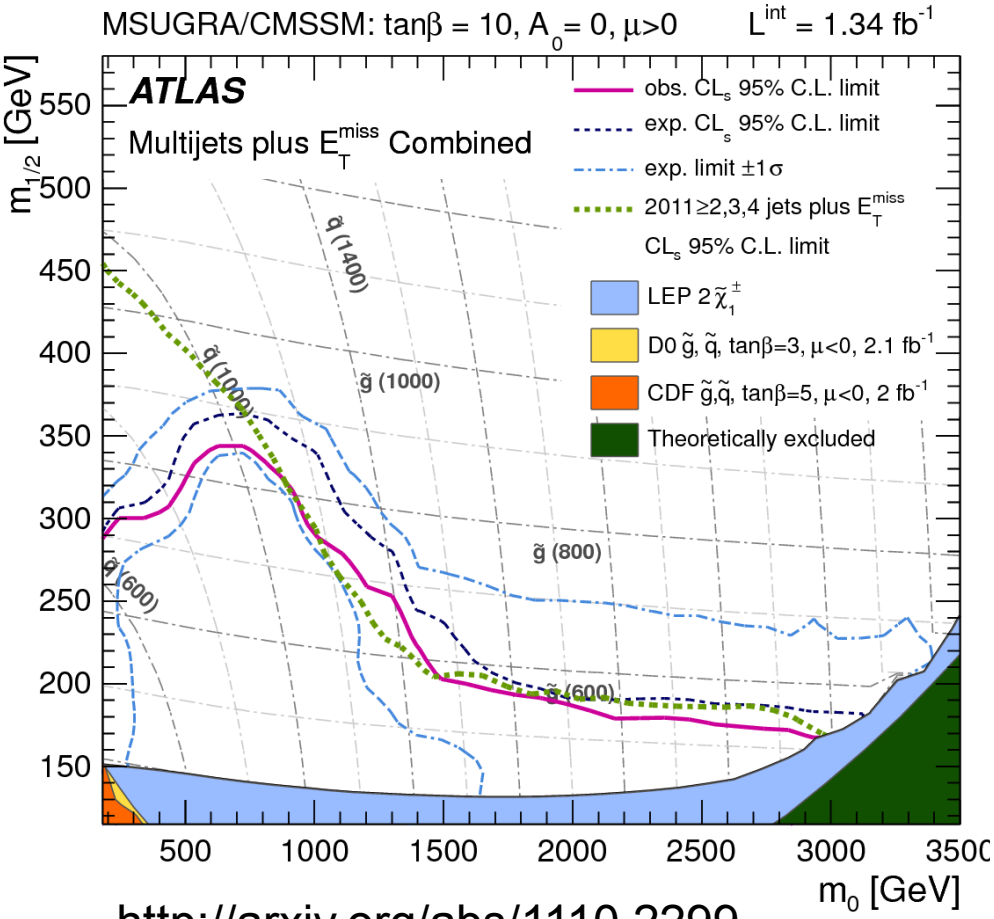
$$x = \left(m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}^{0}}\right) / \left(m_{\tilde{q}/\tilde{g}} - m_{\tilde{\chi}^{0}}\right).$$

- Top row 1/4, lightest $\tilde{\chi}^{\pm}$,
- Middle row 1/2,
- Bottom row 3/4,heaviest $\tilde{\chi}^{\pm}$,

Gluon model has better reach in m_{heavy}-m_{LSP} plane, due to SR with 4-jet selection.

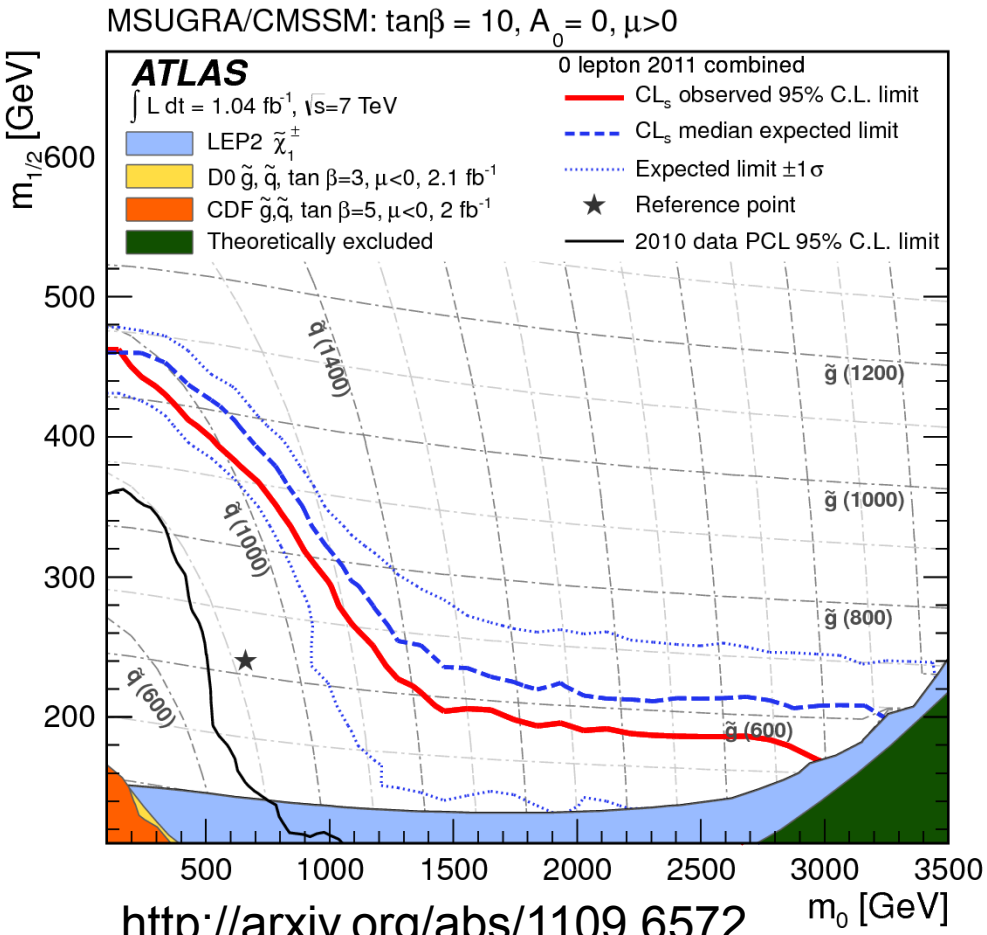
More SUSY results, jets plus missing energy

Large number of jets (upto 8 or more) + missing energy in final state

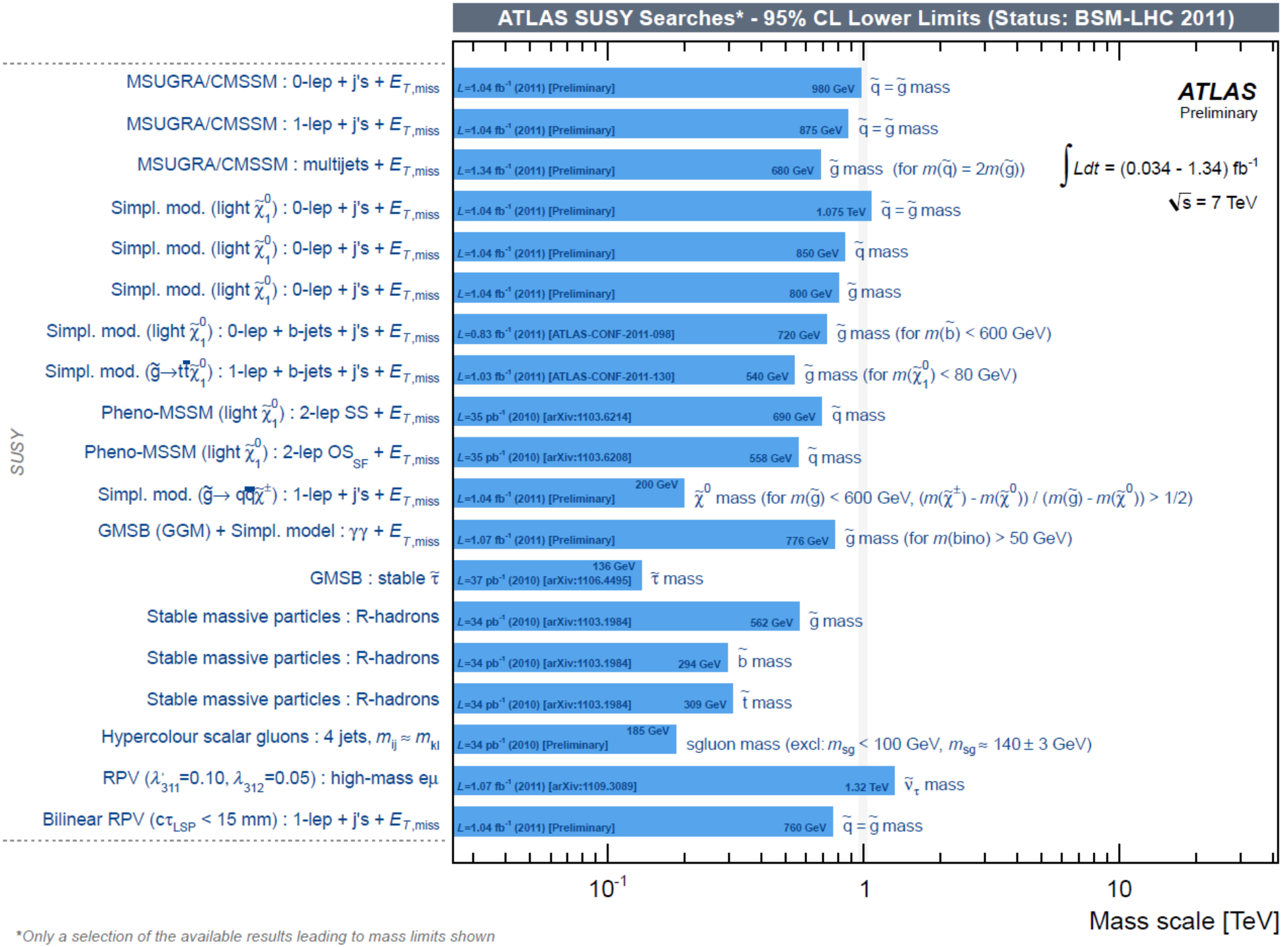


http://arxiv.org/abs/1110.2299

Low number of jets (upto 4 or more) + missing energy in final state



http://arxiv.org/abs/1109.6572

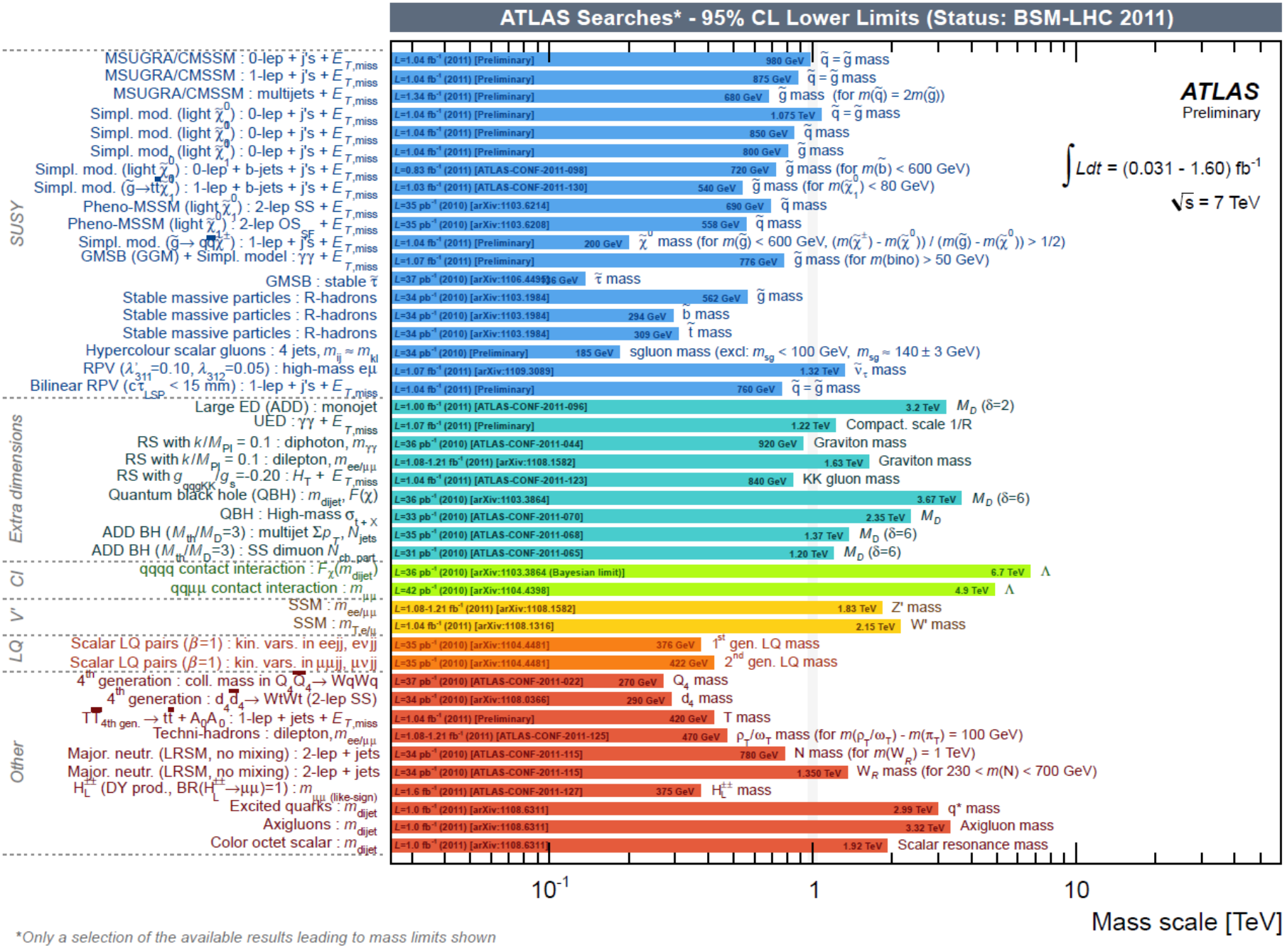


*Only a selection of the available results leading to mass limits shown

Conclusion

- Presented selected SUSY searches,
- Dominant SM Backgrounds are estimated from the data,
- No new physics found with 1.04fb^{-1} ATLAS data,
- Improved model independent upper limits on new physics,
- Limits within the MSUGRA/CMSSM and Simplified models were derived.
- There are more specific searches:
  - higher lepton multiplicity (>2,3,4) → lower branching ratio/cross-section but complementary
  - 3rd generation, direct production requires more data,
  - Photon(s)+MET: GMSB models, no public results yet.

Non-SUSY searches results



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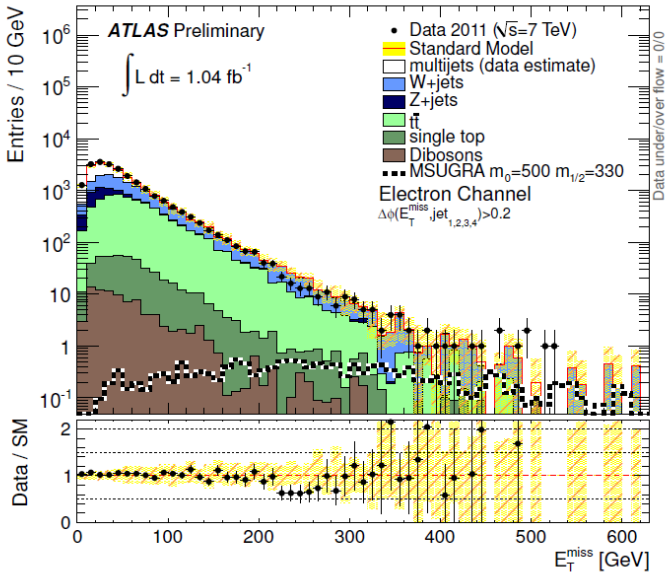
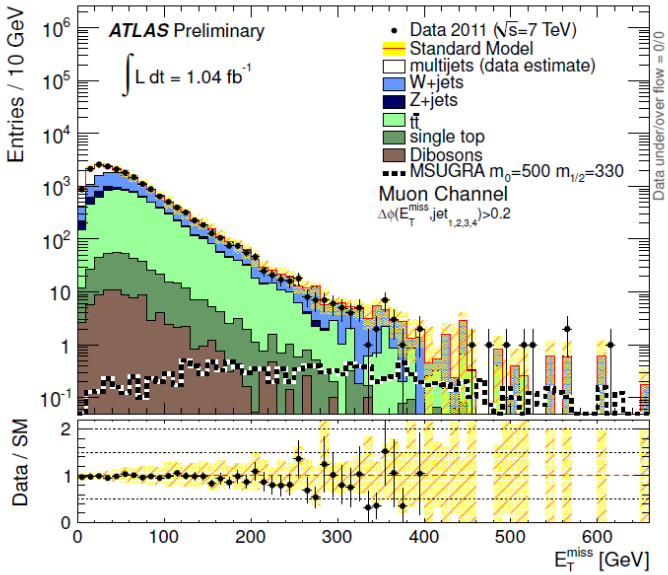
Backup slides

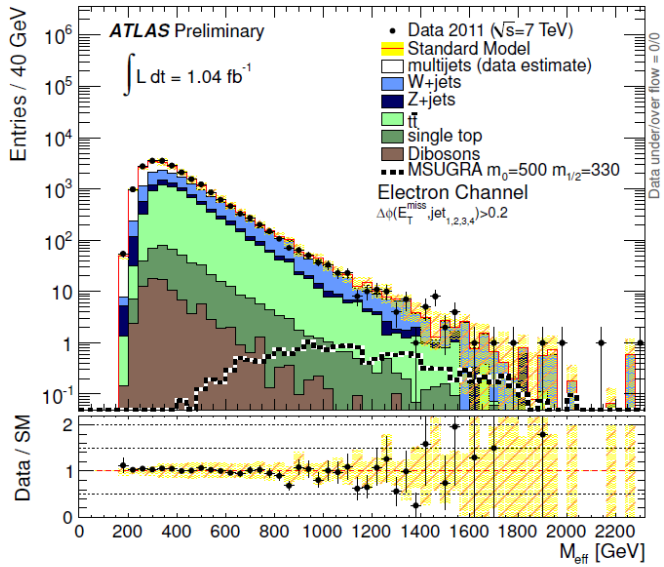
m_{eff} and E_T^{miss} distributions after 4J pre-selection

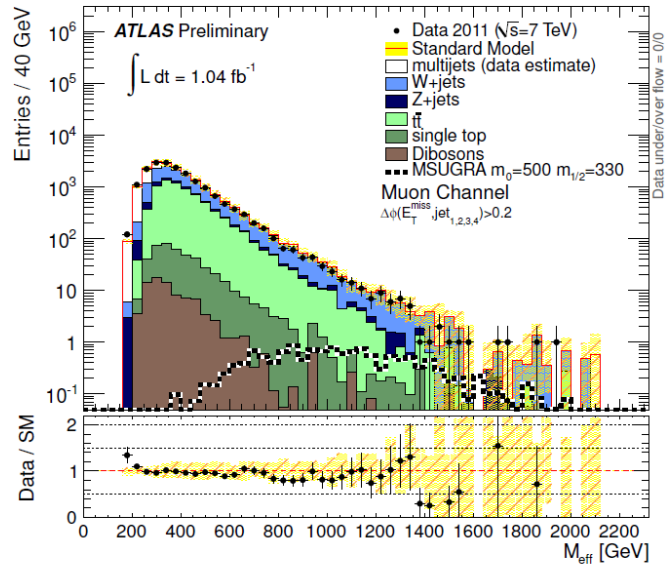
Electron Channel



Muon Channel







Good agreement between Data and SM expectation within uncertainties after 4J pre-selection.

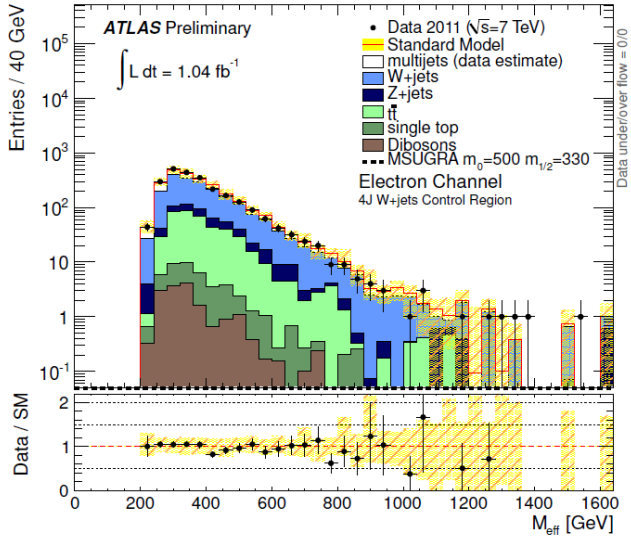
m_{eff} distributions in 4J CRs

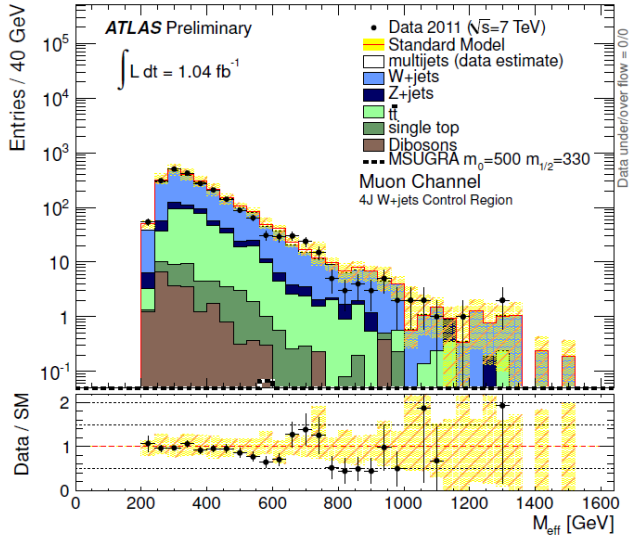
W+jets CR

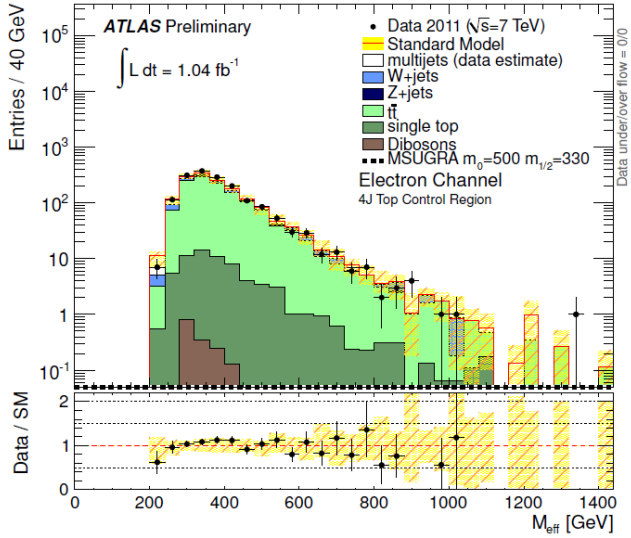
Top CR

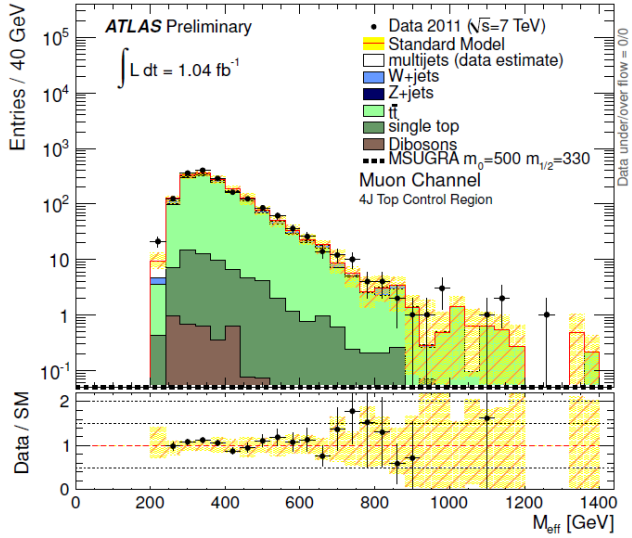
Electron Channel

Muon Channel









Good agreement between Data and SM expectation within uncertainties after 4J pre-selection.

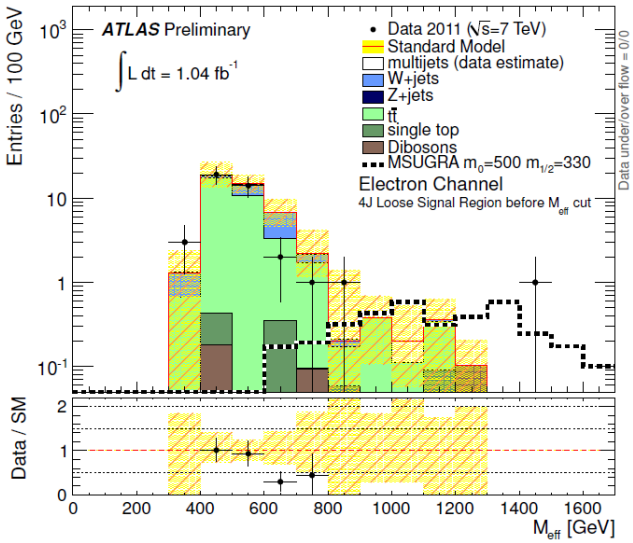
Breakdown of BG systematic uncertainties

Electron channel	3JL	3JT	4JL	4JT
Total statistical ($\sqrt{N_{\text{obs}}}$)	±8.4	±3.7	±6.4	±3.0
Total background systematic	±30.2	±7.4	±17.9	±3.7
Jet/$E_{\text{T}}^{\text{miss}}$ energy resolution	±5.9	±0.5	±4.2	±0.8
Jet/$E_{\text{T}}^{\text{miss}}$ energy scale	±18.6	±4.1	±13.6	±2.4
Lepton energy resolution	±0.5	±0.3	±0.1	±0.3
Lepton energy scale	±1.1	±0.3	±0.4	±0.5
b-tagging	±1.2	±0.2	±0.7	±0.1
MC stat. top	±5.8	±2.0	±3.8	±1.4
MC stat. W	±4.4	±2.3	±2.2	±1.3
Lepton misidentification rate	±1.4	±0.1	±0.2	< 0.1
Real lepton rate	±1.5	±0.3	±0.8	±0.1
Theory top	±15.9	±2.1	±9.8	±1.2
Theory W	±19.0	±5.6	±5.1	±1.9
Pile-up	±5.1	±1.0	±2.5	±0.4
Muon channel	3JL	3JT	4JL	4JT
Total statistical ($\sqrt{N_{\text{obs}}}$)	±7.6	±3.3	±7.1	±2.7
Total background systematic	±19.3	±4.3	±15.8	±2.7
Jet/$E_{\text{T}}^{\text{miss}}$ energy resolution	±9.0	±1.1	±0.9	±0.5
Jet/$E_{\text{T}}^{\text{miss}}$ energy scale	±7.0	±0.2	±9.1	±1.6
Lepton energy resolution	< 0.1	< 0.1	< 0.1	< 0.1
Lepton energy scale	±0.8	±0.3	±1.4	±0.5
b-tagging	±1.0	±0.2	±0.9	±0.1
MC stat. top	±5.4	±2.1	±4.0	±1.4
MC stat. W	±2.5	±1.4	±2.6	±0.7
Lepton misidentification rate	< 0.1	< 0.1	< 0.1	< 0.1
Real lepton rate	±0.5	±0.1	±0.4	< 0.1
Theory top	±12.9	±2.4	±10.0	±1.2
Theory W	±8.8	±2.7	±7.3	±0.7
Pile-up	±3.5	±0.8	±2.7	±0.3

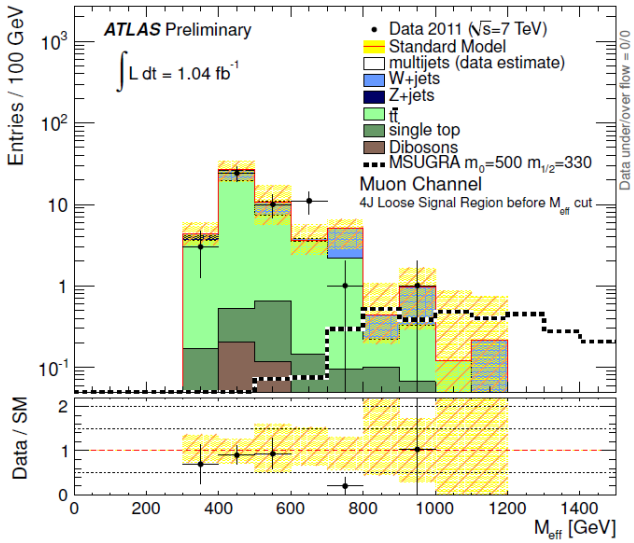
m_{eff} distributions in 4J Signal regions

4J Loose

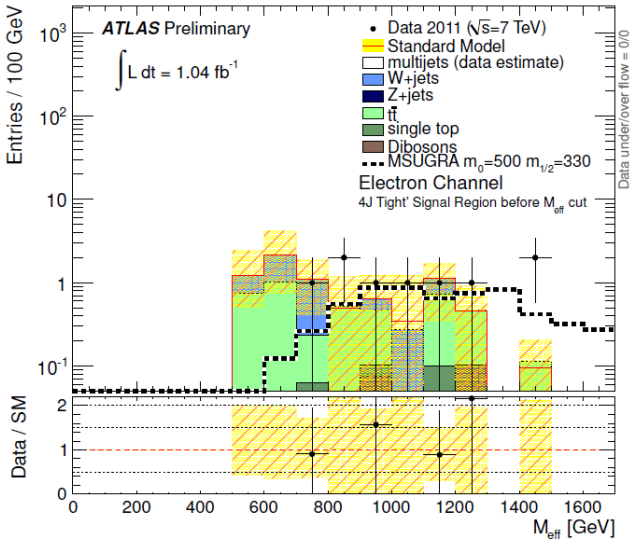
Electron Channel

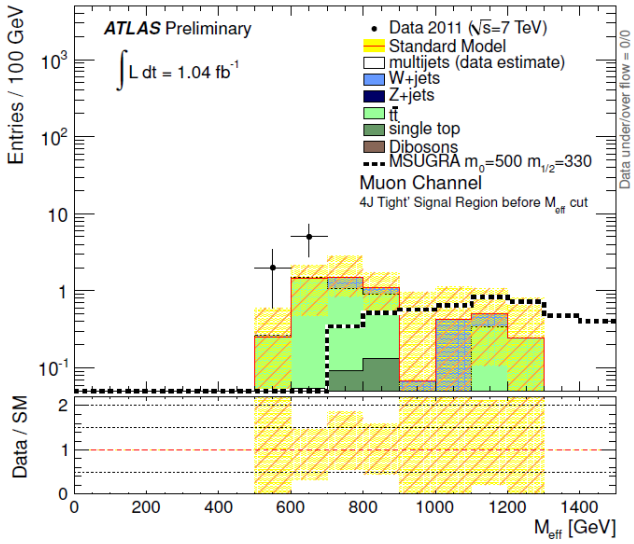


Muon Channel



4J Tight





- Plots are produced before m_{eff} cut.
- Good agreement between Data and SM expectation within uncertainties,
- No excess observed.

Fit results in Signal and Control Regions

Electron channel	3JL Signal region	3JT Signal region	Top region	W region
Observed events	71	14	162	565
Fitted top events	56 ± 20 (51)	7.6 ± 3.0 (6.8)	125 ± 16 (112)	64 ± 8 (58)
Fitted W/Z events	35 ± 20 (34)	10.5 ± 6.5 (10.1)	30.1 ± 9.1 (29.3)	425 ± 36 (413)
Fitted QCD events	$6.0^{+2.3}_{-1.4}$	$0.46^{+0.37}_{-0.22}$	7.2 ± 2.6	76 ± 24
Fitted sum of background events	97 ± 30	18.5 ± 7.4	162 ± 13	565 ± 24

Muon channel	3JL Signal region	3JT Signal region	Top region	W region
Observed events	58	11	166	413
Fitted top events	47 ± 16 (38)	8.9 ± 3.2 (7.3)	142 ± 14 (115)	70 ± 7 (57)
Fitted W/Z events	16.6 ± 9.4 (20.1)	5.0 ± 3.2 (6.1)	19.0 ± 4.8 (23.2)	322 ± 23 (393)
Fitted QCD events	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$	5.4 ± 2.2	21.6 ± 5.7
Fitted sum of background events	64 ± 19	13.9 ± 4.3	166 ± 13	413 ± 20

3J SRs and CRs

Electron channel	4JL Signal region	4JT Signal region	Top region	W region
Observed events	41	9	1382	1872
Fitted top events	38 ± 15 (34)	4.5 ± 2.6 (4.1)	1258 ± 44 (1138)	391 ± 14 (354)
Fitted W/Z events	9.5 ± 7.5 (9.2)	3.5 ± 2.2 (3.4)	88 ± 21 (86)	1242 ± 89 (1202)
Fitted QCD events	$0.90^{+0.54}_{-0.37}$	$0.00^{+0.02}_{-0.00}$	35 ± 13	239 ± 78
Fitted sum of background events	48 ± 18	8.0 ± 3.7	1382 ± 37	1872 ± 43

Muon channel	4JL Signal region	4JT Signal region	Top region	W region
Observed events	50	7	1448	1623
Fitted top events	39 ± 13 (36)	4.7 ± 2.2 (4.3)	1319 ± 45 (1231)	382 ± 13 (357)
Fitted W/Z events	14.1 ± 8.5 (14.2)	1.4 ± 1.1 (1.4)	91 ± 19 (92)	1169 ± 46 (1185)
Fitted QCD events	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$	38 ± 10	71 ± 16
Fitted sum of background events	53 ± 16	6.0 ± 2.7	1448 ± 38	1623 ± 40

4J SRs and CRs

The results are obtained using the "discovery fit". Nominal MC expectations (normalised to MC cross-sections) are given between parentheses for comparison.