Search for SUSY with lepton(s), jets and missing energy

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SUSY at the LHC

particle	spin	superpartner	spin
quarks	1/2	squarks	0
leptons	1/2	sleptons	0
gauge bosons	1	gauginos	1/2
Higgs bosons	0	higgsinos	1/2
graviton	2	gravitino	3/2

◉SUSY provides one of the popular frameworks for physics beyond SM.

◉Classical signatures of search for SUSY at LHC based on minimal SUSY model (MSSM)

◉It produces superpartner for each SM particles with a half-integer spin difference (sparticles)

◉ A new parity under which the SM fileds are even and their superpartners are odd, $R_p = (-1)^{2s+3(B-L)}$

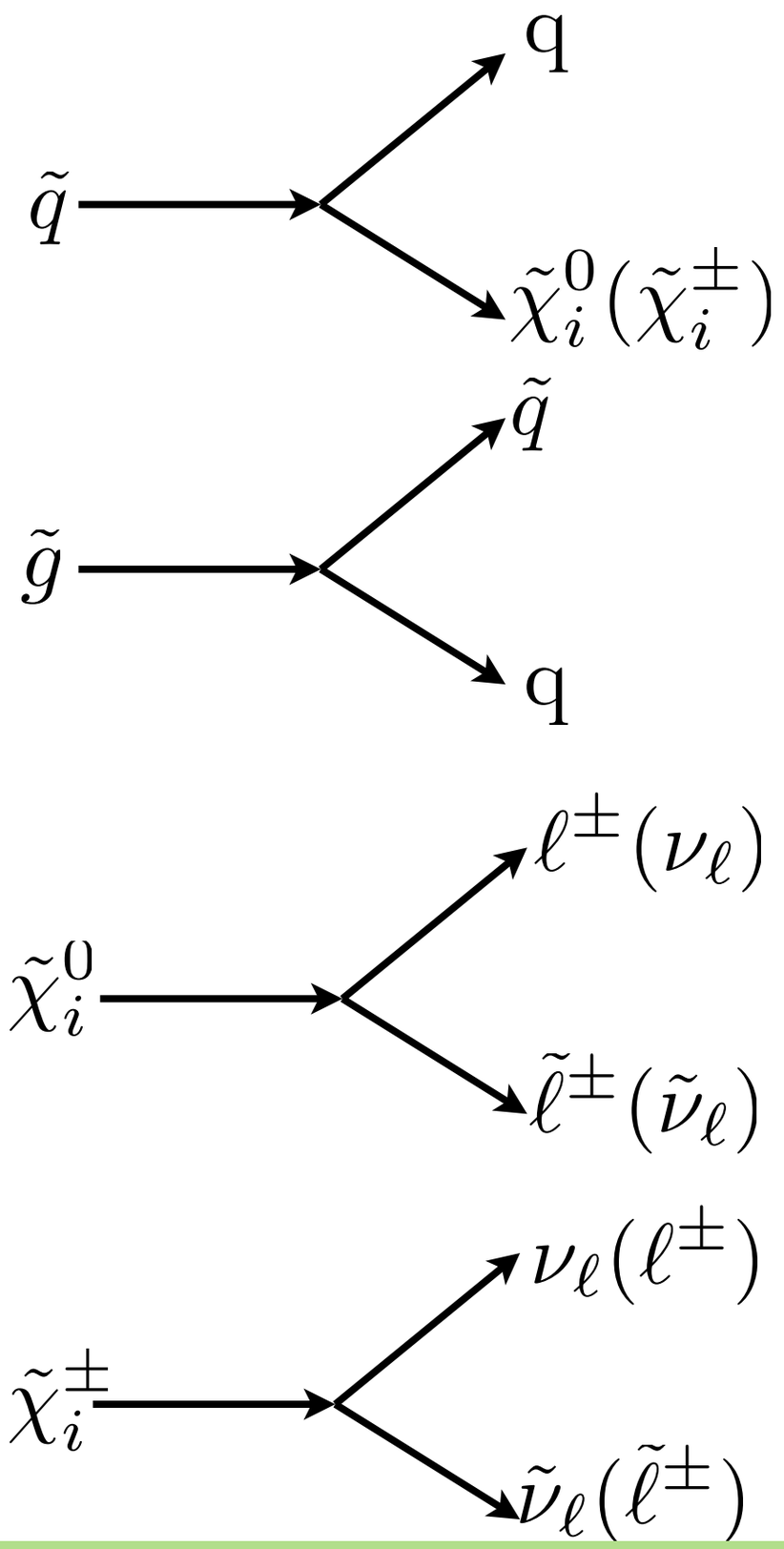
◉Conservation of B and L leads to conservation of R_p (RPC):
- sparticles produced in pairs
- decay cascades in order to produce other sparticles and SM particles
- the lightest SUSY particle (LSP) is stable and goes undetected **(DM candidate)**

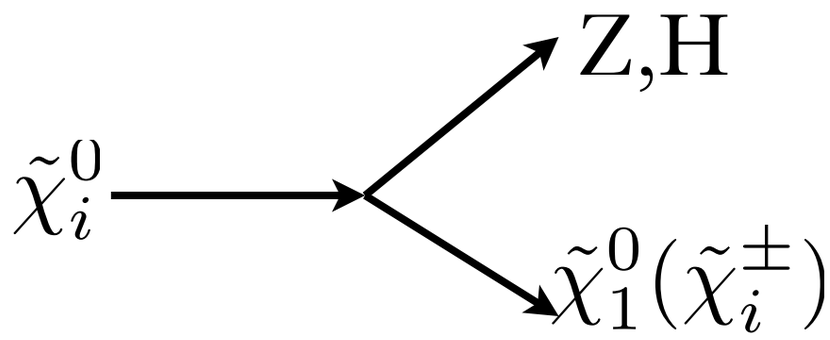
◉SUSY is not a perfect symmetry ⇒ SUSY-breaking ("softly") at a higher mass scale

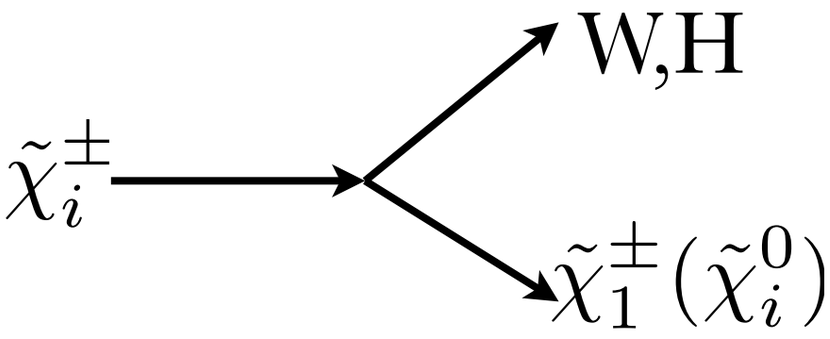
◉Introduces more than 100 parameters ⇒ economize to a handful of parameters, test models

◉Different models ⇒ Different mass hierarchies ⇒ Different decay chains

SUSY searches by signature







❖Leptonic signatures :

- ◉ 1-lepton, jets, missing energy
- ◉ Dileptons, jets, missing energy
  - ◉ same-sign dileptons
  - ◉ opposite-sign dileptons
- ◉ multileptons

❖Lightest Supersymmetric Particle (LSP) is a WIMP and it is produced abundantly (DM candidate)

1-lepton, jets and missing energy

- Require an isolated and high-pT lepton in the event
  - Reduces the QCD multijet background significantly

- Give extra handle like transverse mass, mT
  - Controls SM background such as W+jets and ttbar

- High pT jet and large missing energy requirements
  - Reduces the overall SM background rate even further

- In contrast, SUSY particle decays have a larger branching fraction to produce this final state
  - Enhance the signal by cutting on the M_{eff} and Etmiss/M_{eff}

1-lepton, jets and missing energy [Background estimations]

❖**QCD multijet :**

◉Select events with a looser selection of leptons in a QCD multijet dominated region (ctrl sample)

◉Calculate the pass/fail ratio of the lepton that satisfy the signal lepton selection

❖**W+jets :**

◉Define a 2D region depending on transverse mass (mT) and Etmiss

◉Select events that has no b-tagged jets in order to separate it from the ttbar+jets events

❖**ttbar+jets :**

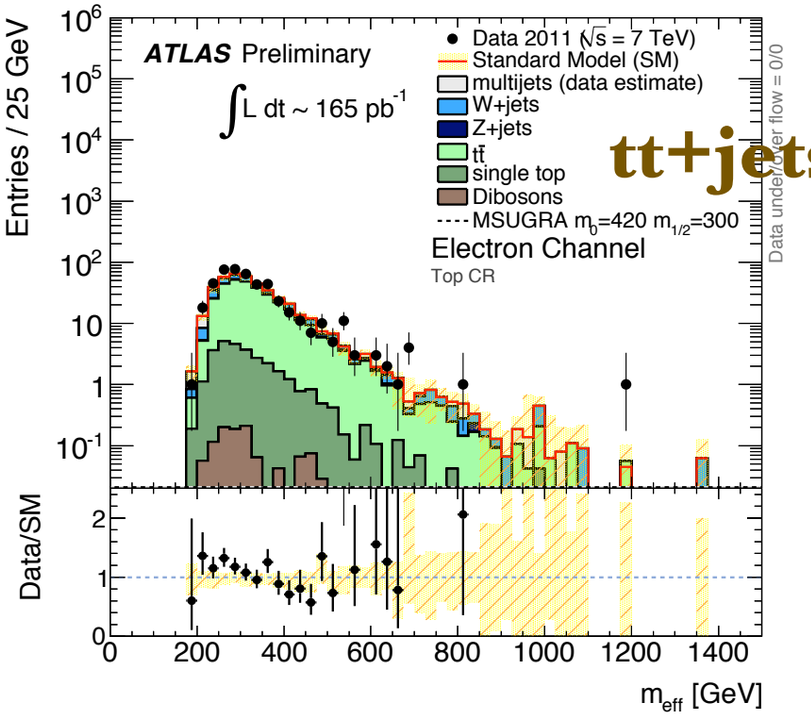
◉Similar 2D region depending on mT and Etmiss

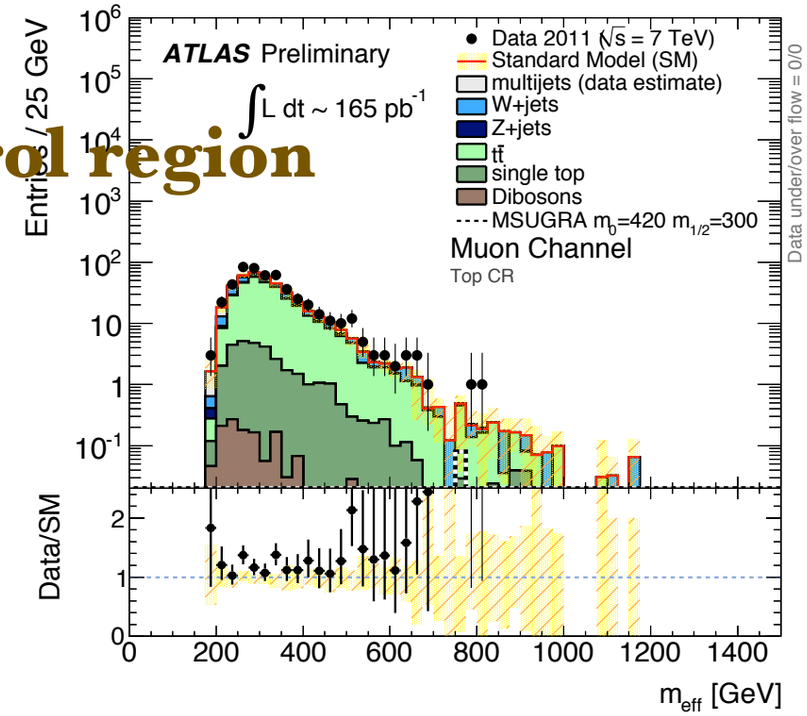
◉Select events that has at least one b-tagged jet among the first three jets (leading ones in pT)

1-lepton, jets and missing energy (Control Regions)

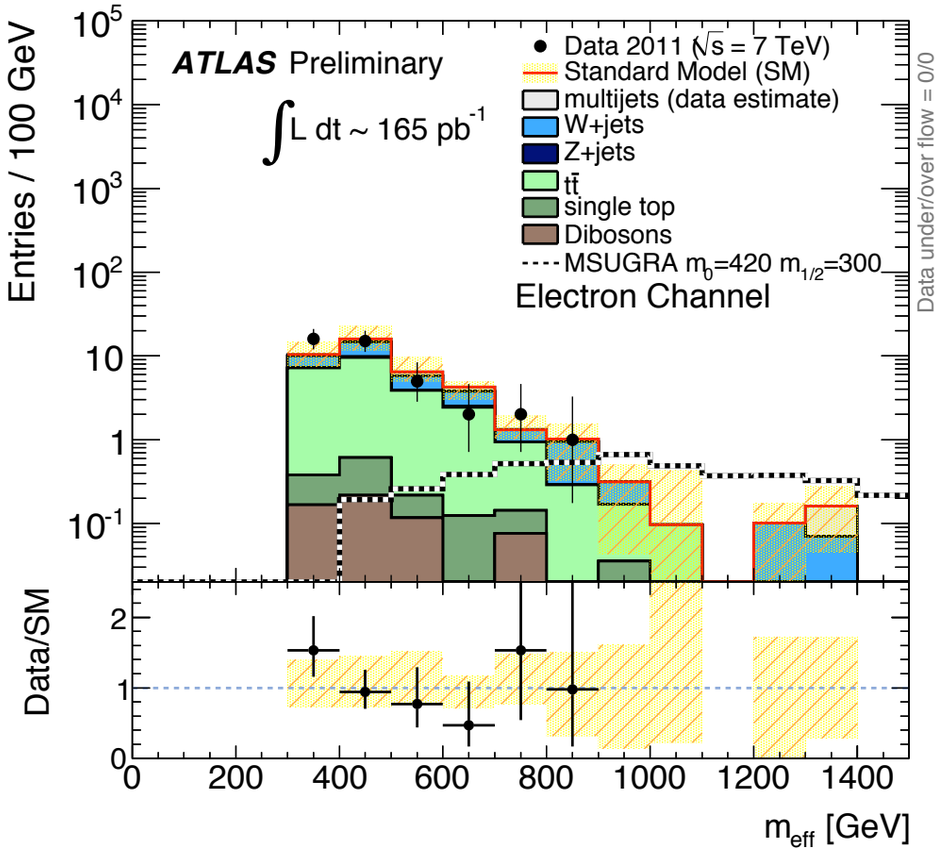
W+jets control region

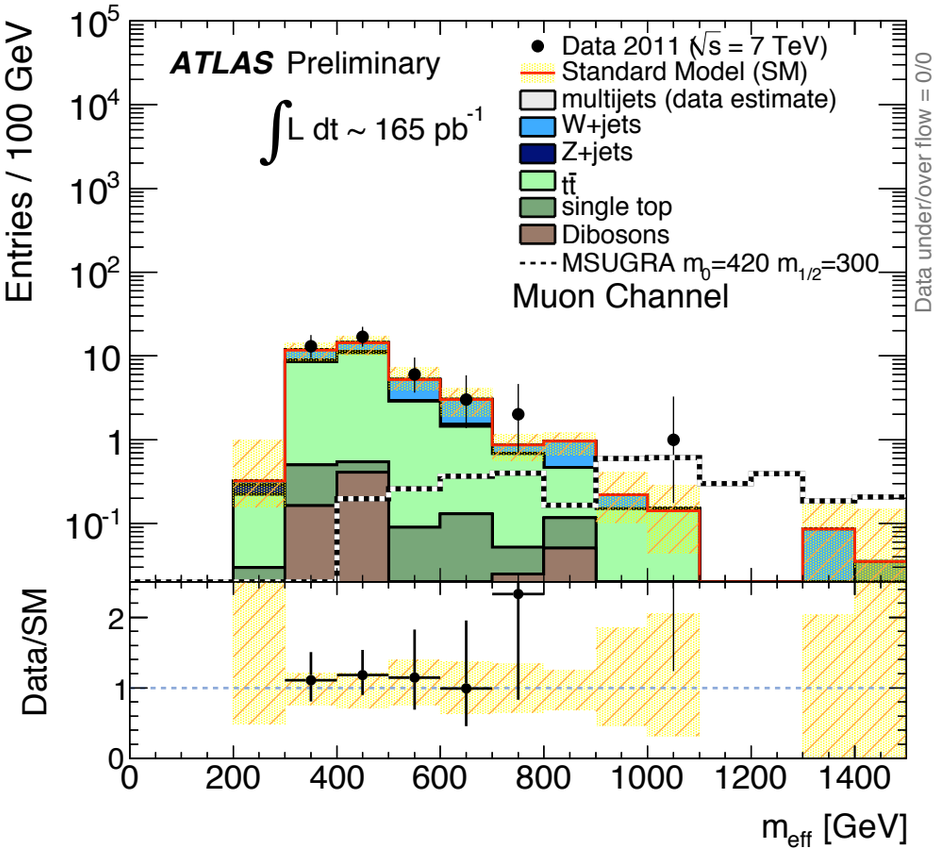
tt+jets control region





1-lepton, jets and missing energy (Signal Region)





❖Signal Selection :

- ◉Exactly one isolated lepton (e,mu) with pT > 20 GeV
- ◉Three high pT jets (60, 25, 25) GeV
- ◉Transverse mass, mT > 100 GeV
- ◉Etmiss > 125 GeV and Etmiss/M_{eff} > 0.25

1-lepton, jets and missing energy (Results and Interpretation)

- Signal region includes an additional cut on $M_{eff} > 500$ GeV
- A global likelihood fit is performed in each of the control region simultaneously in order to obtain the SM background in signal region

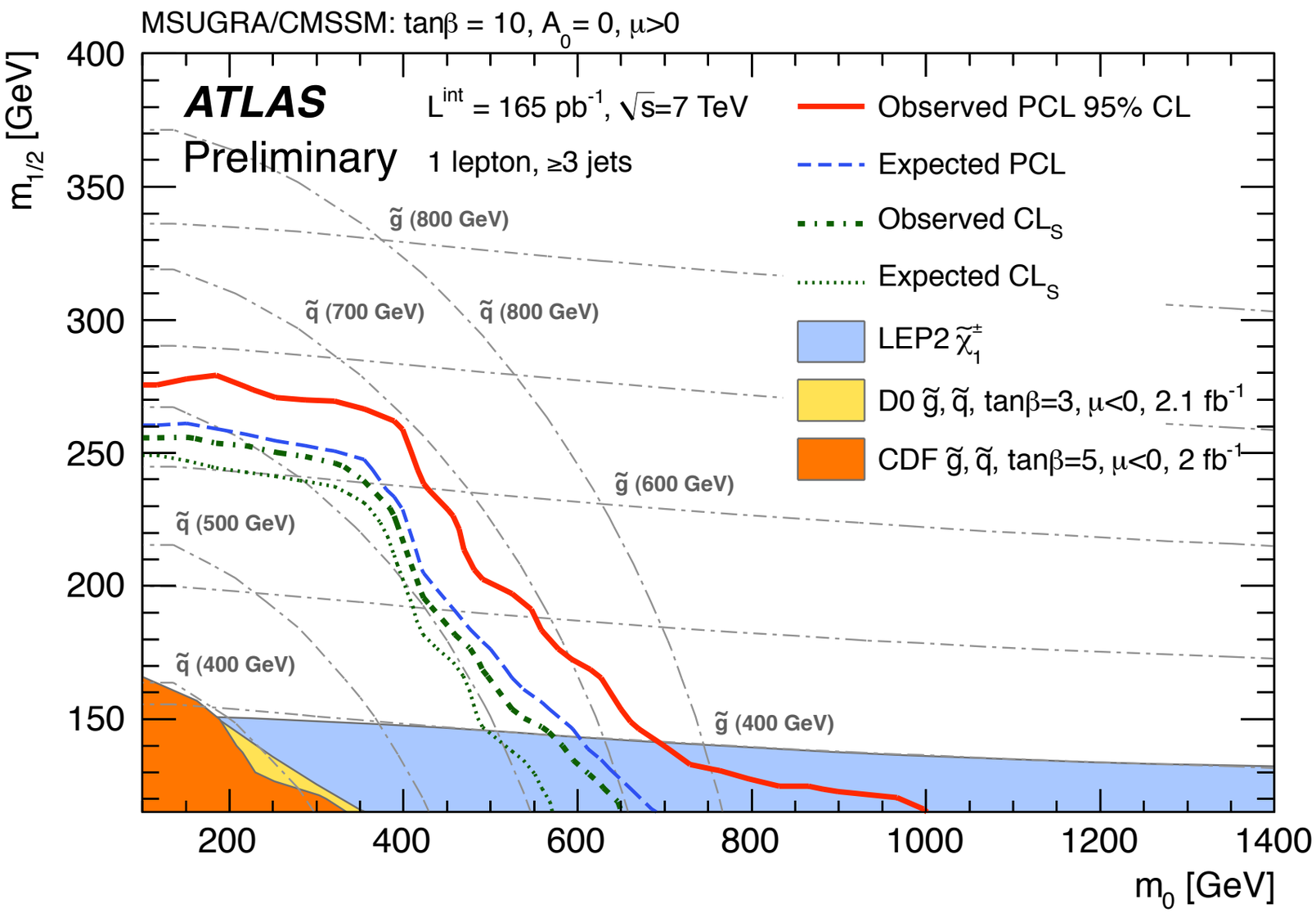
Electron channel	Signal region	Top region	W region
Observed events	10	465	1719
Fitted top events	8.7 ± 3.6 (7.7)	373 ± 28 (329)	223 ± 17 (196)
Fitted W/Z events	4.6 ± 2.8 (4.9)	64 ± 16 (69)	1206 ± 91 (1283)
Fitted QCD events	$1.12^{+0.70}_{-0.40}$	27.7 ± 8.5	290 ± 81
Fitted sum of background events	14.5 ± 5.2	465 ± 22	1719 ± 41

Muon channel	Signal region	Top region	W region
Observed events	12	504	1650
Fitted top events	7.2 ± 2.7 (5.7)	416 ± 29 (327)	247 ± 17 (195)
Fitted W/Z events	5.0 ± 2.6 (5.0)	66 ± 16 (66)	1335 ± 48 (1336)
Fitted QCD events	$0.00^{+0.50}_{-0.00}$	22.8 ± 6.1	68 ± 16
Fitted sum of background events	12.2 ± 3.8	504 ± 22	1650 ± 41

Data and SM background expectation agrees

No sign of SUSY

1-lepton, jets and missing energy (Exclusion Limits)



❖**For equal squark and gluino mass, ATLAS excludes,**

◉**m(g) ~ 600 GeV for tanβ=10, A0=0, μ>0 @ 165 pb^{-1}** [ATLAS-CONF-2011-090]

2-leptons and missing energy

- Requires two isolated and high-pT leptons in the event
  - Complementary approach to the 1-lepton analysis (much smaller contribution from the SM background sources)

- Gives a handle to use the charge of the two leptons
- Three separate analysis are performed

- Same-Sign dileptons :
  - Requires the charge of the two leptons to be same
  - Scarce production through SM processes, clean signature

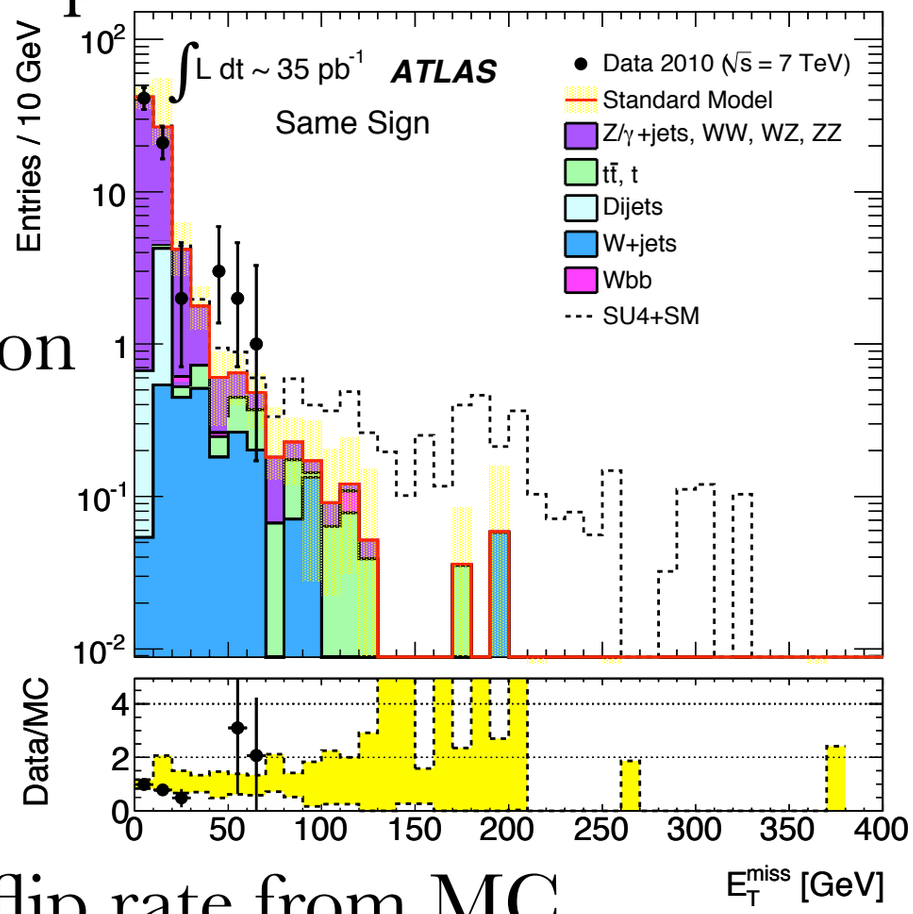
- Opposite-Sign dileptons :
  - Much higher rate for SUSY events that produces leptons from $\tilde{\chi}_2^0$ decay

- Flavor subtraction (exclusive OS-Same-Flavor leptons) :
  - Exclusively look into Same Flavor leptons with opposite charge
  - Exploit the fact that most of the dominant SM backgrounds are flavor symmetric

2-leptons and missing energy (same-sign analysis)

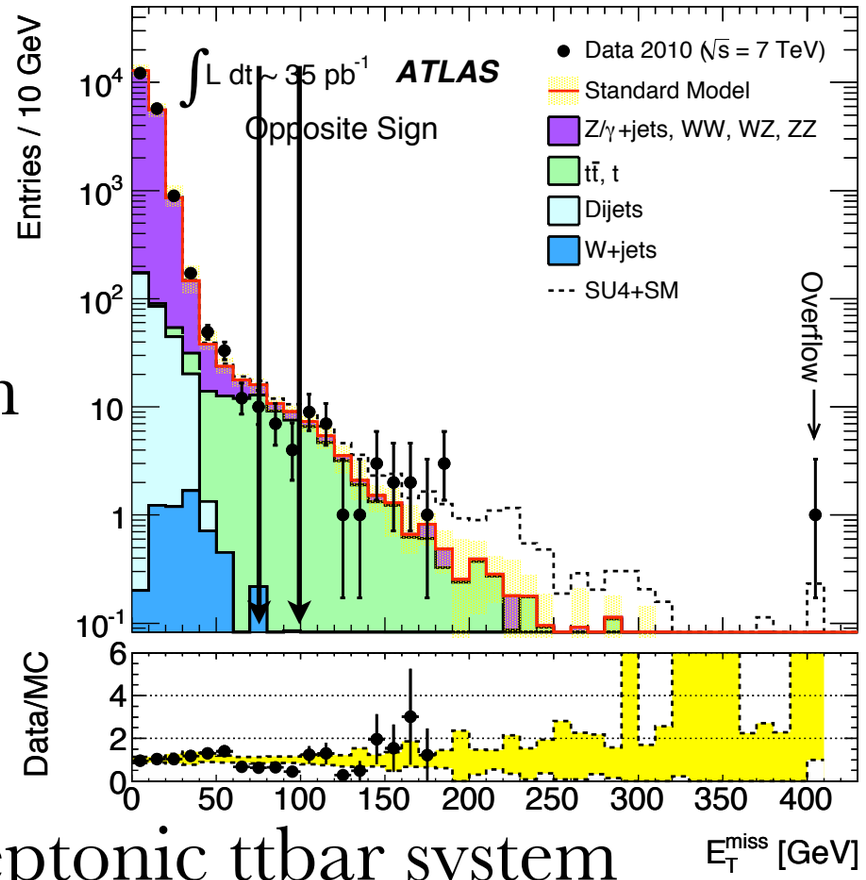
- SM background source :
  - Mostly an event contains at least one lepton from a fake source (e.g, heavy-flavor decay, jet fakes an electron)
  - Z(ee) events contribute through charge flip

- Fake-leptons (data-driven estimate) :
  - Get the pass-fail ratio of a loose lepton to pass a tight(signal) lepton selection
  - Estimates contribution from bb, QCD multijets, W+jets, tt(lvqq), single-top in the signal region



- Charge flip :
  - Use Z control region to get the charge flip rate from MC
  - Closure test comparing data and MC numbers in the control region
  - Estimates contribution from Z(ee), tt(lvlv) process into the signal region

2-leptons and missing energy (opposite-sign analysis)



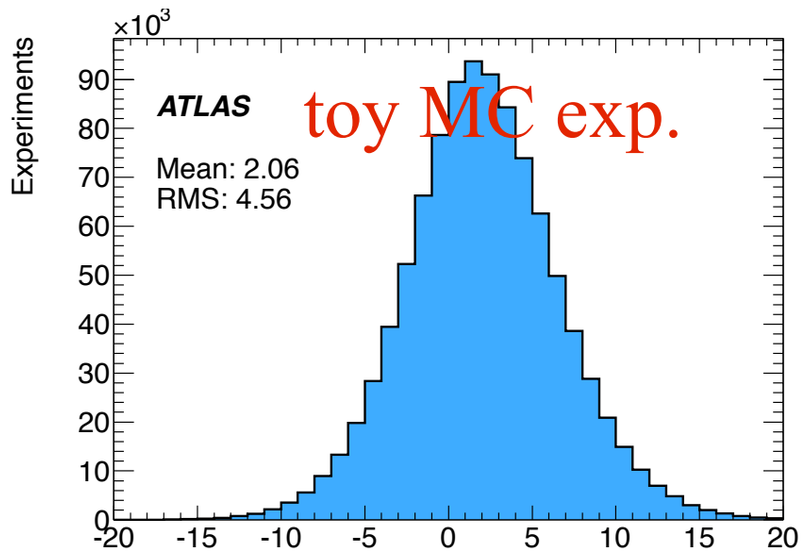
❖**ttbar + jets background estimation:**

- ◉Dominant background in the signal region
- ◉Exploit the kinematics of tt(lvlv) system
- ◉Use cotransverse mass, mCT to tag the ttbar events
- ◉mCT uses the constraints from the (j,j), (l,l) and (lj,lj) combinations in the fully leptonic ttbar system

$$m_{\mathrm{CT}}^2(v_1, v_2) = \left[E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)\right]^2 - \left[\mathbf{p_T}(v_1) - \mathbf{p_T}(v_2)\right]^2$$

- ◉Use Etmiss to transfer from control region to the signal region

2-leptons and missing energy (flavor subtraction analysis)

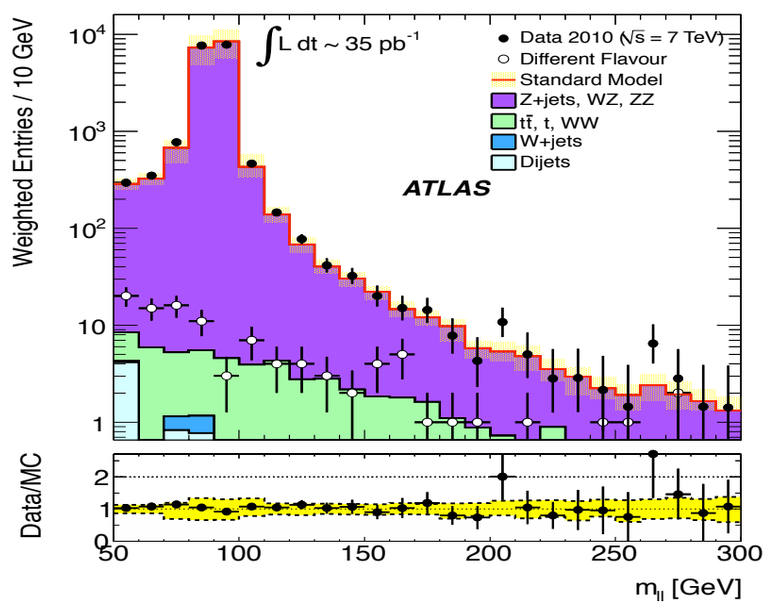


◉Look exclusively an excess of events with same flavor and opposite charge leptons

◉Subtract off the SM background with different flavor leptons after the efficiency correction

S

$$\mathcal{S} = \frac{N(e^{\pm}e^{\mp})}{\beta(1-(1-\tau_e)^2)} - \frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_\mu)} + \frac{\beta N(\mu^{\pm}\mu^{\mp})}{(1-(1-\tau_\mu)^2)}$$



◉Flavor symmetric SM events will cancel out to zero

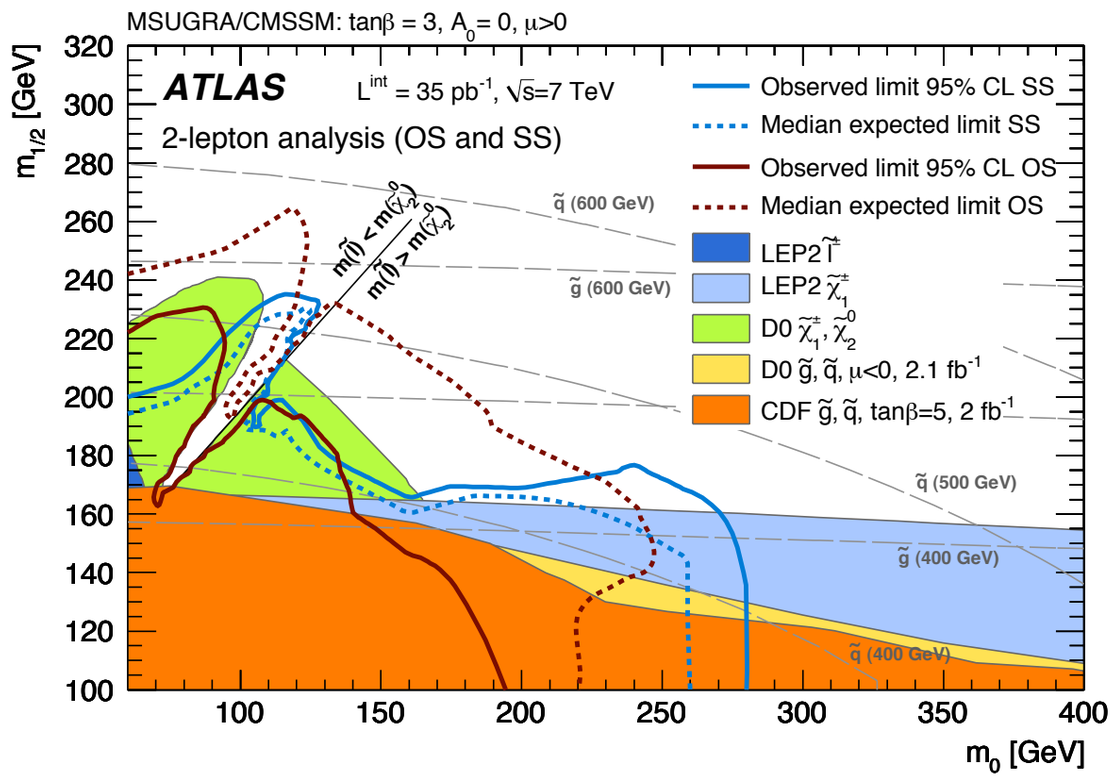
◉Z+jets events are suppressed by requiring large Etmiss in the event

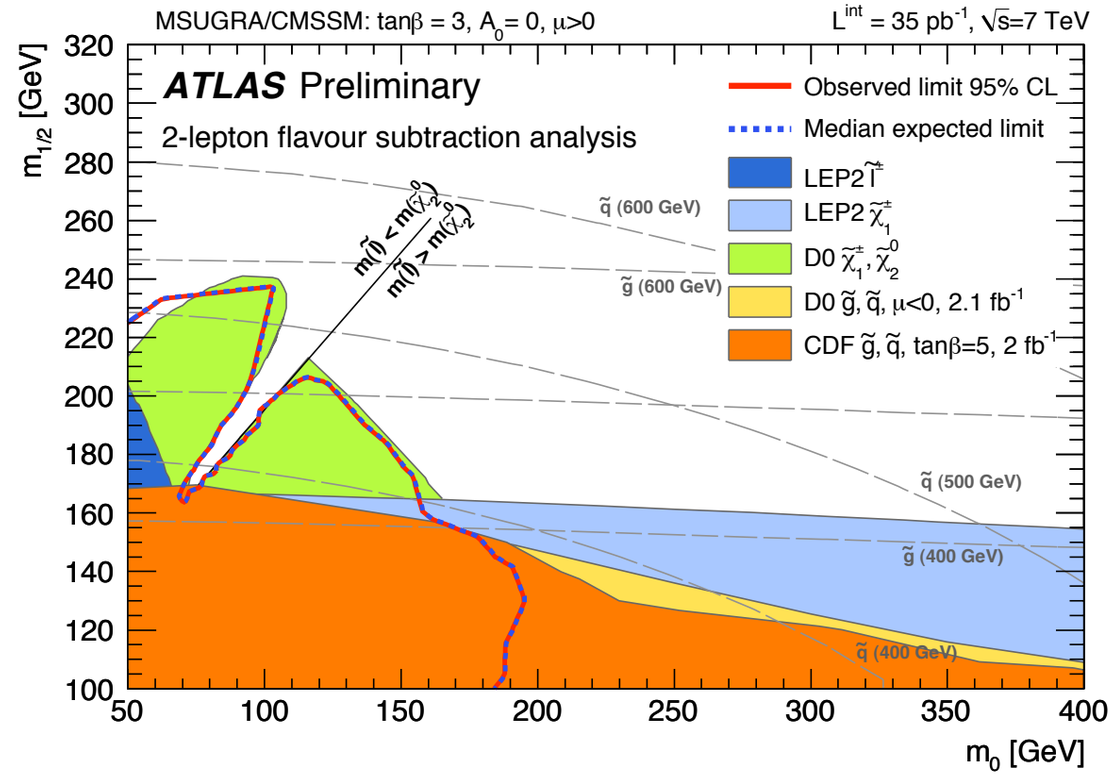
Process	$\mathcal{S}_b$
Z/γ^*+jets	0.86 ± 0.33 (stat.) ± 0.74 (sys.)
Dibosons	0.51 ± 0.04 (stat.) ± 0.12 (sys.)
$t\bar{t}$	0.34 ± 0.61 (stat.) ± 0.13 (sys.)
Single top	-0.10 ± 0.23 (stat.) ± 0.08 (sys.)
Fakes	0.46 ± 0.31 (stat.) ± 0.10 (sys.)
SM total	2.06 ± 0.79 (stat.) ± 0.78 (sys.)

2-leptons and missing energy (Signal Region)

Same Sign, $E_T^{miss} > 100$ GeV			
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Data	0	0	0
Fakes	0.12 ± 0.13	0.030 ± 0.026	0.014 ± 0.010
Di-bosons	0.015 ± 0.005	0.035 ± 0.012	0.021 ± 0.009
Charge-flip	0.019 ± 0.008	0.026 ± 0.011	-
Cosmics	-	$0^{+1.17}_{-0}$	-
Total	0.15 ± 0.13	$0.09^{+1.17}_{-0.03}$	0.04 ± 0.01
Opposite Sign, $E_T^{miss} > 150$ GeV			
	$e^{+}e^{-}$	$e^{\pm}\mu^{+}$	$\mu^{+}\mu^{-}$
Data	1	4	4
$t\bar{t}$	$0.62^{+0.31}_{-0.28}$	$1.24^{+0.62}_{-0.56}$	$1.00^{+0.50}_{-0.45}$
Z+jets	0.19 ± 0.15	0.08 ± 0.08	0.14 ± 0.17
Fakes	-0.02 ± 0.02	-0.05 ± 0.04	-
Single top	0.03 ± 0.05	0.06 ± 0.08	0.10 ± 0.07
Di-bosons	0.09 ± 0.03	0.06 ± 0.03	0.15 ± 0.03
Cosmics	-	-0.2 ± 1.18	-0.43 ± 1.27
Total	$0.92^{+0.42}_{-0.40}$	$1.43^{+1.45}_{-0.59}$	$1.39^{+1.41}_{-0.53}$

	$e^{\pm}e^{\mp}$	$e^{\pm}\mu^{\mp}$	$\mu^{\pm}\mu^{\mp}$
Data	4	13	13
Z/γ^*+jets	0.40±0.46	0.36±0.20	0.91±0.67
Dibosons	0.30±0.11	0.36±0.10	0.61±0.10
$t\bar{t}$	2.50±1.02	6.61±2.68	4.71±1.91
Single top	0.13±0.09	0.76±0.25	0.67±0.33
Fakes	0.31±0.21	-0.15±0.08	0.01±0.01
Total SM	3.64±1.24	8.08±2.78	6.91±2.20





2-leptons and missing energy (signal Interpretation)

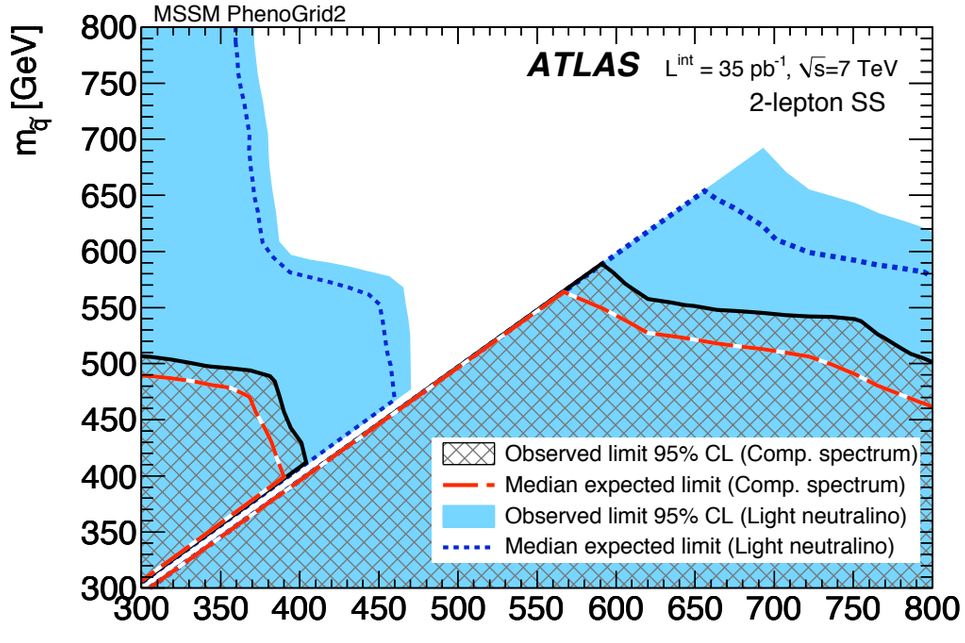
- MSSM 24-parameter framework
  - m_A = 1 TeV, μ= 1.5 x min(mg, mq)
  - tanβ = 4, A_t = μ/tanβ, A_b= μ x tanβ = A_l
  - M(3rd gen.) = 2 TeV
- In $m(\tilde{q})$-$m(\tilde{g})$ plane, two grids are defined

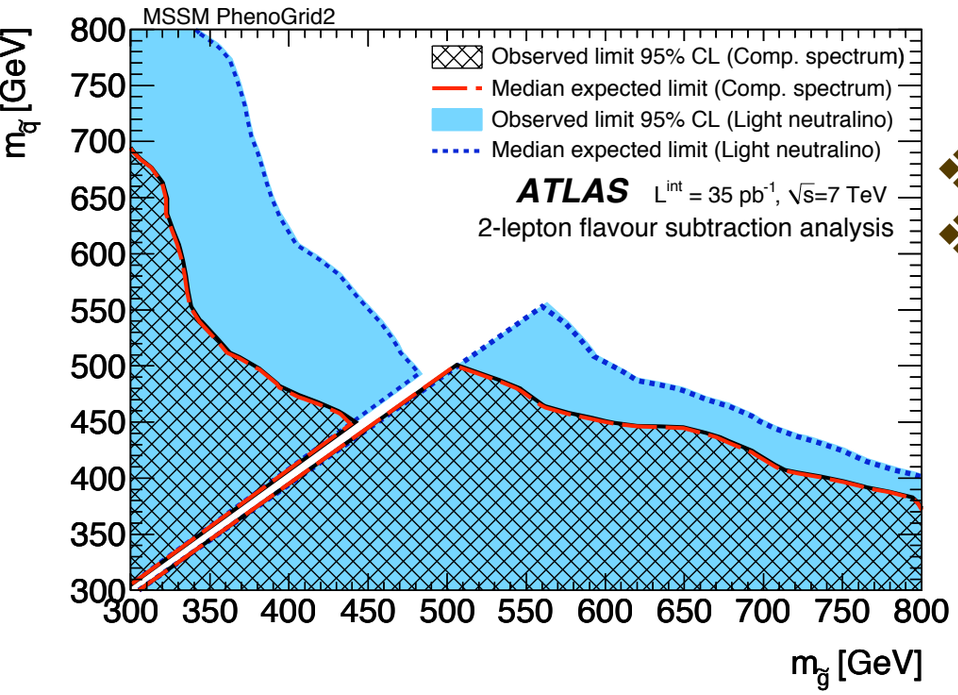
1) Compressed spectrum (CS) :

- $m(\tilde{\chi}_2^0)$ = M - 50 GeV, M = min(mg, mq)
- $m(\tilde{\chi}_1^0)$ = M - 150 GeV, $m(\tilde{\ell})$ = M - 100 GeV

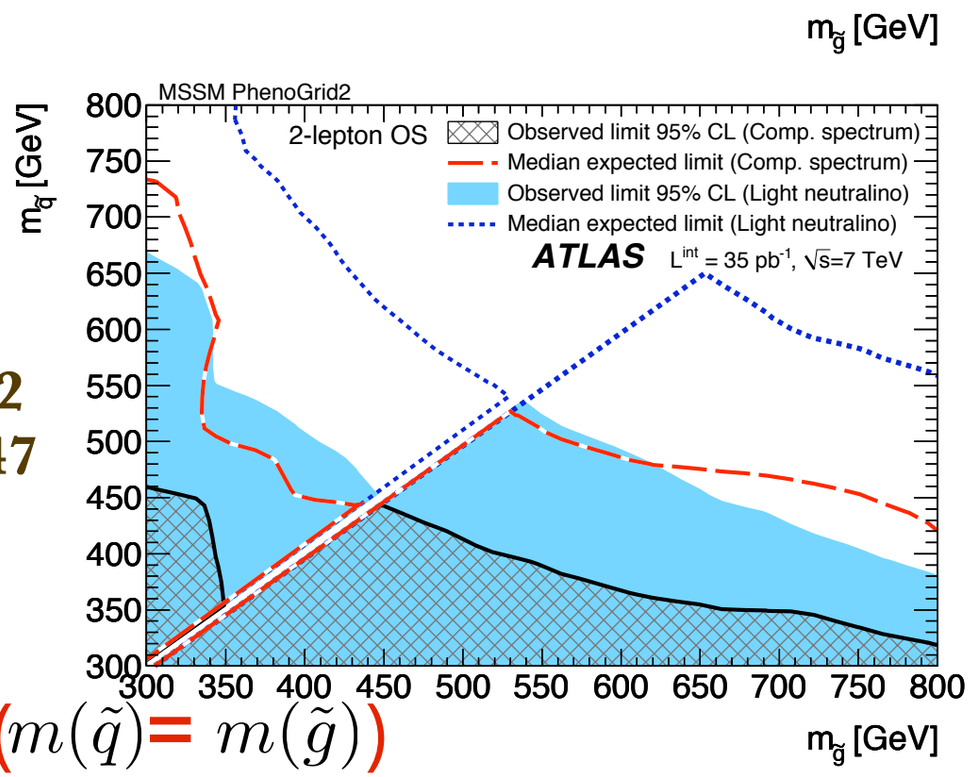
2) Light neutralino (LN):

- $m(\tilde{\chi}_2^0)$ = M - 100 GeV
- $m(\tilde{\chi}_1^0)$ = 100 GeV, $m(\tilde{\ell})$= M/2 GeV





❖ **EPJC 71 (2011) 1682**
❖ **EPJC 71 (2011) 1647**



Exclude mass ($m(\tilde{q})$= $m(\tilde{g})$)
~600 GeV with the CS
~700 GeV with LN scenario

Summary

- ATLAS has studied important signatures to discover Supersymmetry

- High pT and isolated leptons are key ingredients for a SUSY discovery at LHC

- So far, Observed data and the expected SM background have good agreement, so no sign of SUSY in any of the channels discussed

- ATLAS sets limit on the colored sparticles using various signal models

- Using the mSUGRA model and the 1-lepton, jets and missing energy signature, masses up to 600 GeV are excluded

- Using the MSSM-24 parameter grid and the 2-lepton, missing energy signature, masses up to 600 GeV are excluded