Searches for SUSY with ATLAS

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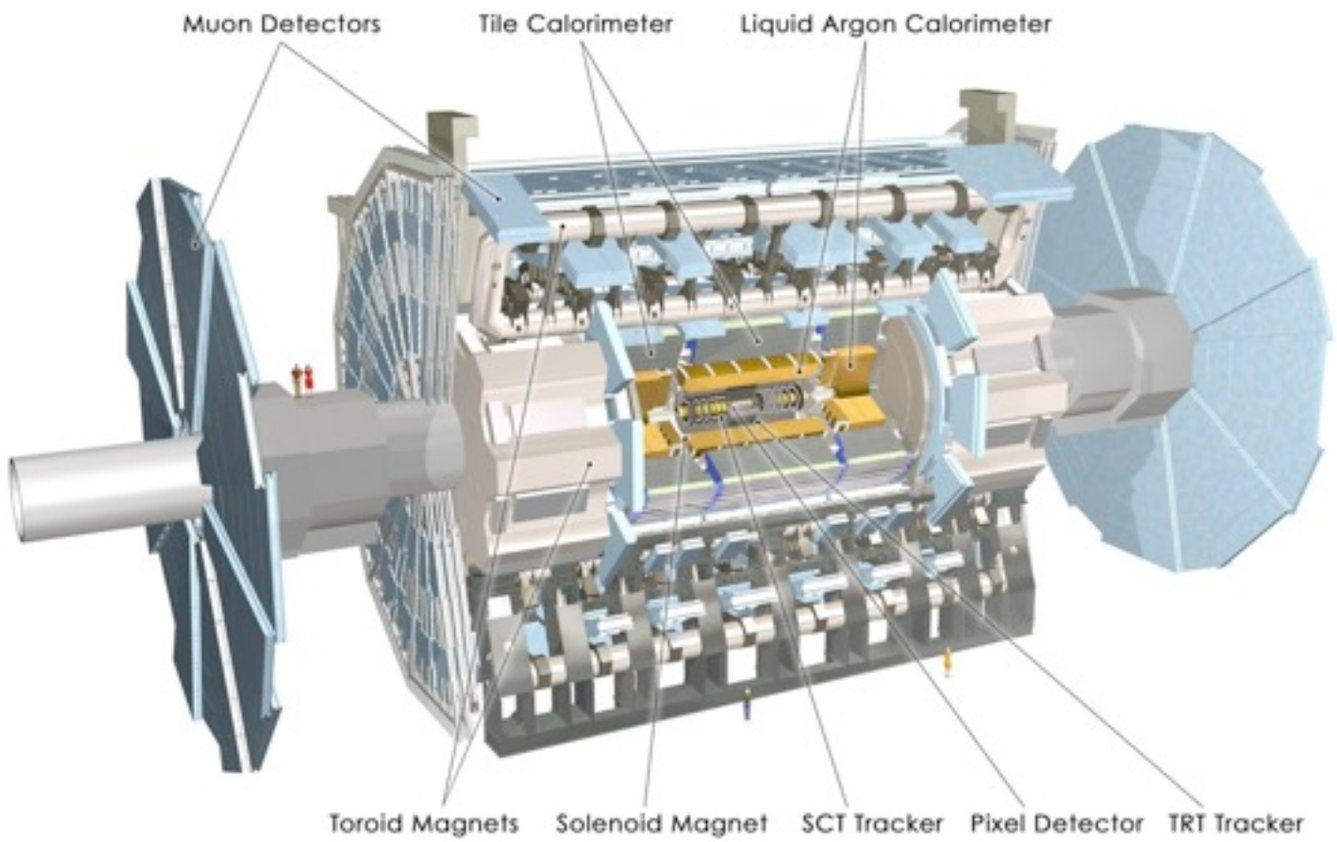
On behalf of the ATLAS Collaboration

The ATLAS detector

- Inner Detector $|\eta|<2.5$
  - Si Pixels, Si Strips, TRT straws
  - Precise tracking and vertexing
  - $\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$
- EM Calorimeter $|\eta|<3.2$
  - Pb-LAr Accordion
  - $\sigma/E \sim 10\%/\sqrt{E}$
- Hadron Calorimeter $|\eta|<5$
  - Fe/scntillator Tiles (central)
    - $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$
  - Cu/W-LAr (fwd)
    - $\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$
- Muon Spectrometer $|\eta|<2.5$
  - Gas-based chamber
  - p_T res <10% up to $E_\mu \sim 1$TeV

- Coverage - almost 4π in solid angle
- B field - 2T



- Integrated luminosity in 2010
  - $\int L = \sim 45\ \mathrm{pb}^{-1}$
  - "Good Run List" cuts $\rightarrow \int L = \sim 35\ \mathrm{pb}^{-1}$
  - Associated systematic uncertainty: 11%
  - ***Known now to 3.4%***

1 lepton + jets + missing p_T

ArXiV:1102.2357 Phys. Rev. Lett. 106, 131802 (2011)

Multilepton + jets + missing E_T

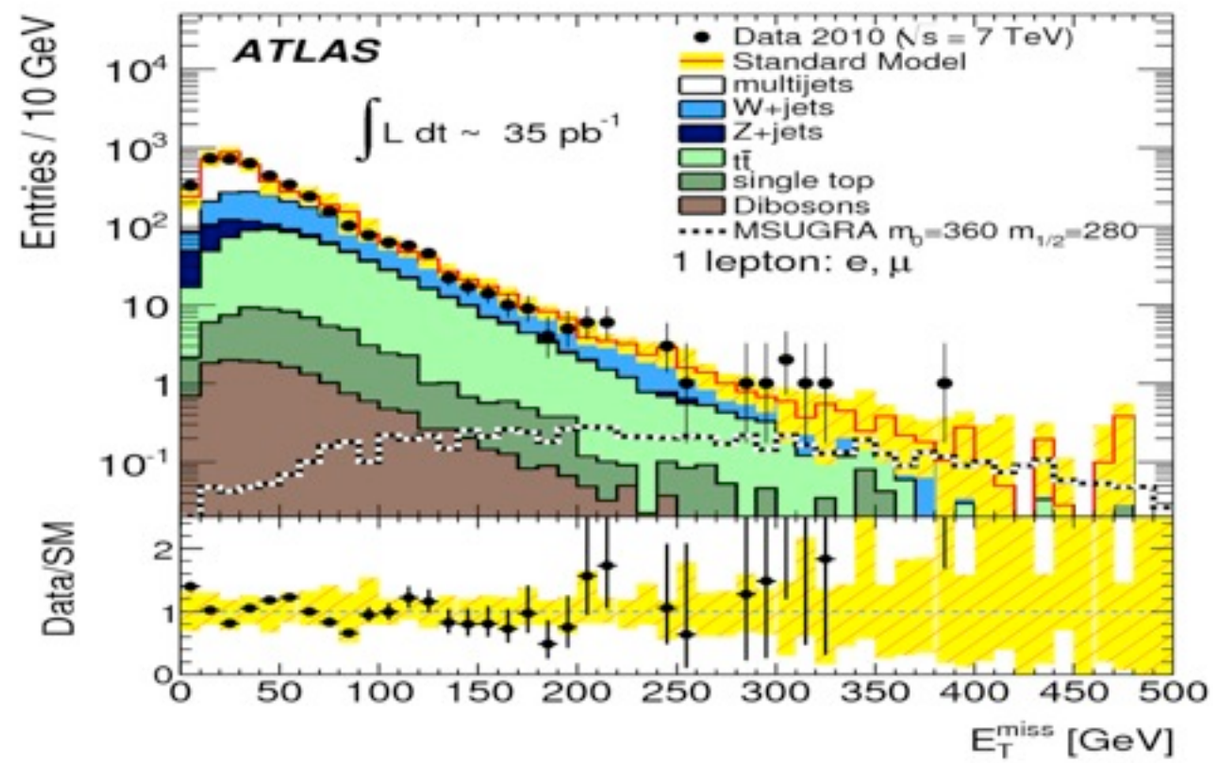
ATL-PHYS-CONF-2011-039 http://cdsweb.cern.ch/record/133856

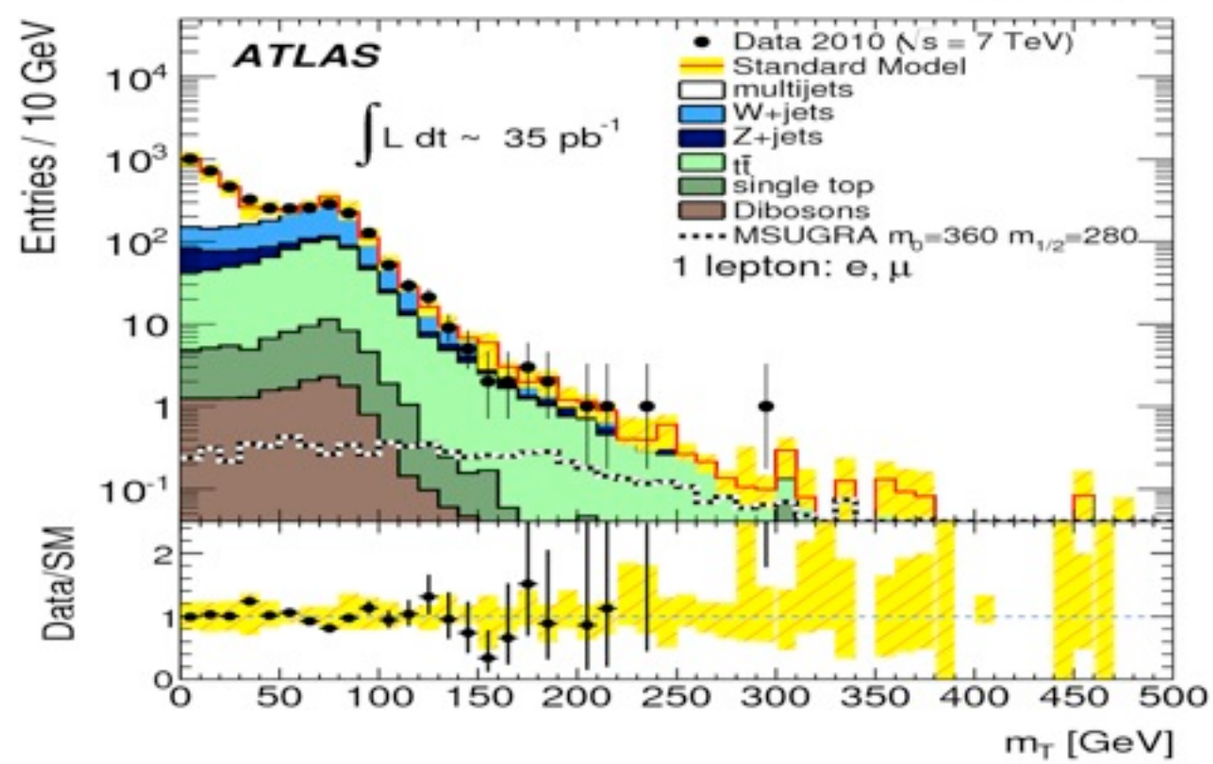
points for comparison are marked with a *line*

1 lepton + jets + missing p_T

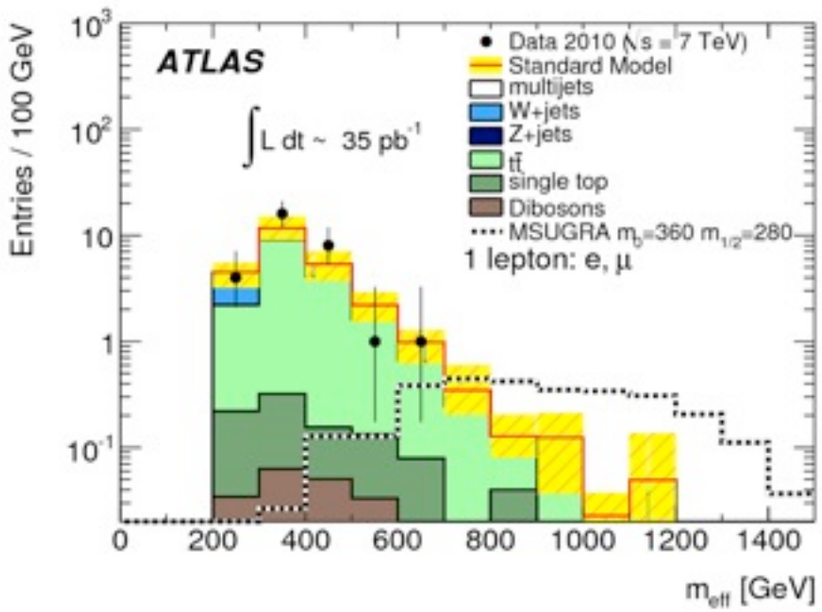
- ***Motivation:*** $\tilde{q}_L \to q\tilde{\chi}^{\pm} \to q\tilde{\chi}^0 l^{\pm}$
  $\tilde{g} \to q\bar{q}'\tilde{\chi}^{\pm} \to q\bar{q}'\tilde{\chi}^0 l^{\pm}$
- ***The signal region:***
  - Exactly 1 isolated e/μ (p_T>20GeV)
  - At least *3 high p_T jets*
    - p_T>60/30/30 GeV
    - $\Delta\phi\left(jet_i, \vec{p}_T^{miss}\right) > 0.2$
  - *High* $E_T^{miss} > 125GeV, 0.25 m_{eff}$
  - $m_T\left(l, \vec{p}_T^{miss}\right) > 100GeV$
  - $m_{eff} = \sum_{i=1}^{3} \left| p_T\left(jet_i\right)\right| > 500GeV$
- ***Background (estimated from)***
  - Top quark pair production (MC in CR)
  - *W + jets* (MC in CR)
  - *QCD* multijet with a jet misidentified as an isolated lepton (Data using loose/tight matrix)

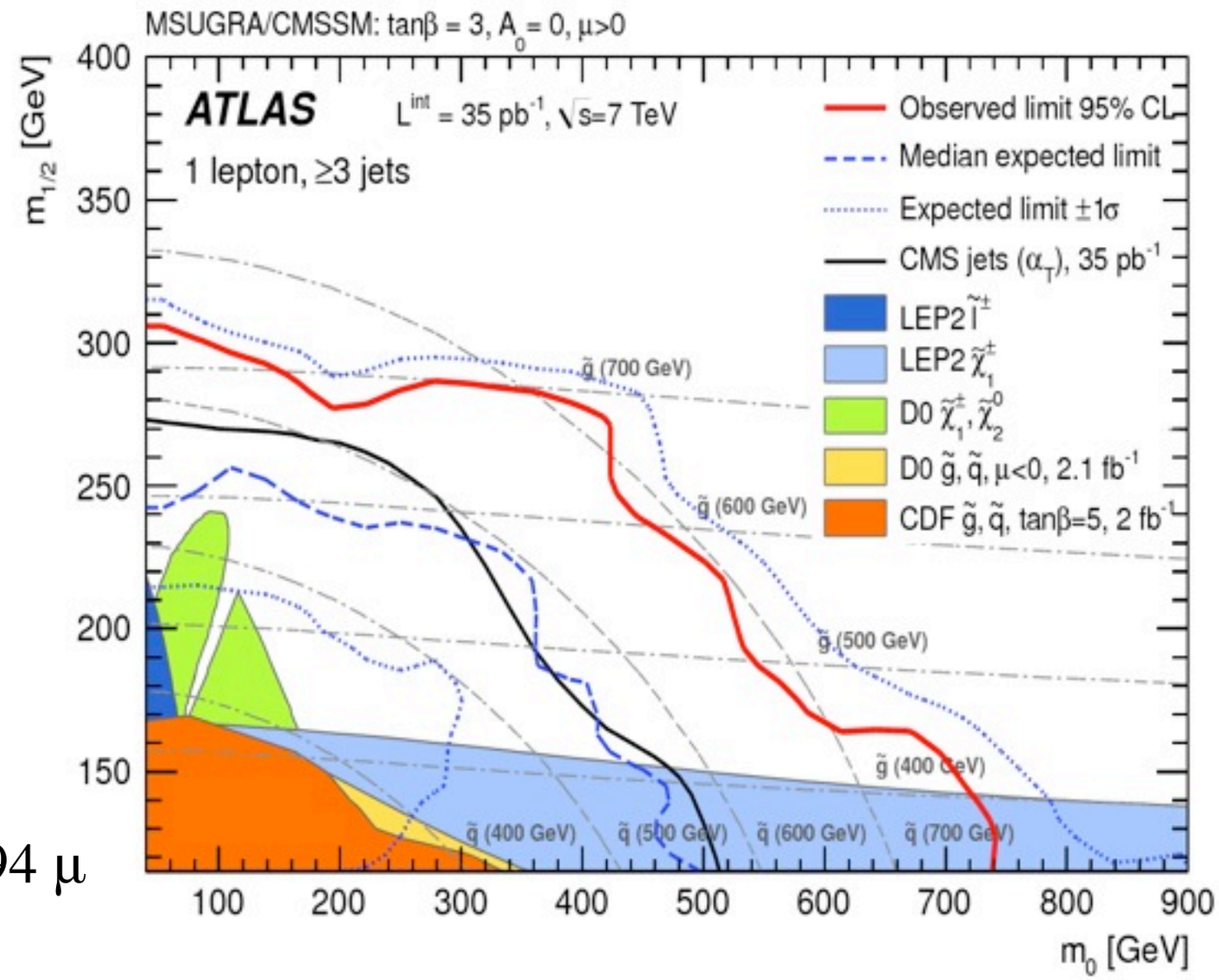
After kinematic cuts





1 lepton + jets + missing p_T - Results



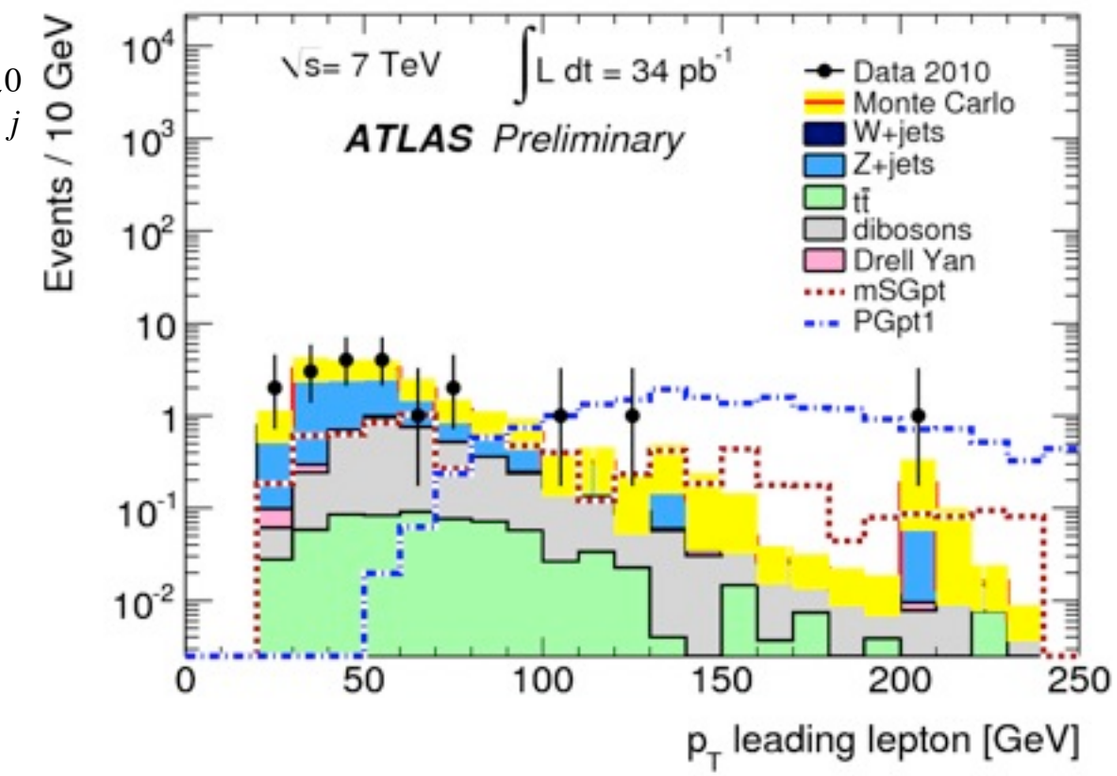


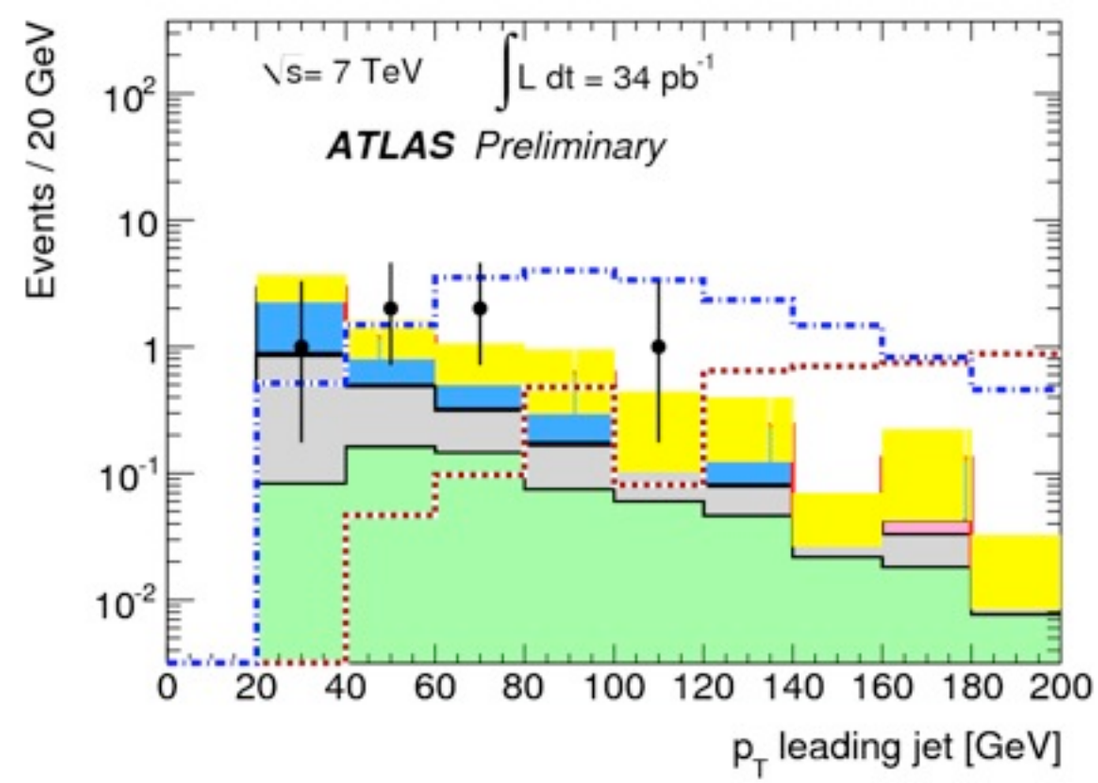
- ***Data in the SR***
  - 1 e and 1 μ
- ***Expected background***
  - 1.81±0.75 e and 2.25±0.94 μ
- ***Limits*** (95% CL)
  - tanβ=3 A_0=0GeV sign(μ)=1

$$m_{\tilde{g}} = m_{\tilde{q}} > 700 GeV$$

Multilepton + jets + missing E_T

- ***Motivation:*** $\tilde{\chi}_i^{\pm} \to l^{\pm}\tilde{\nu}_l / \upsilon\tilde{l}^{\pm} / W^{\pm}\tilde{\chi}_j^0 \to \upsilon l^{\pm}\tilde{\chi}_j^0$
  $\tilde{\chi}_i^0 \to l^{\pm}\tilde{l}^{\pm} / Z\tilde{\chi}_j^0 \to l^+l^-\tilde{\chi}_j^0$
- ***The signal region:***
  - ≥ 3 isolated e/μ, p_T>20/20/20(10)GeV
  - At least <u>*2 jets, p_T*</u>>50GeV
  - <u>*Lower*</u> $E_T^{miss} > 50GeV$
  - Z veto: $m_{Z^0} - 5 < m_{l^+l^-} < m_{Z^0} + 5$
  - SFOS pairs $m_{l^+l^-} > 20GeV$

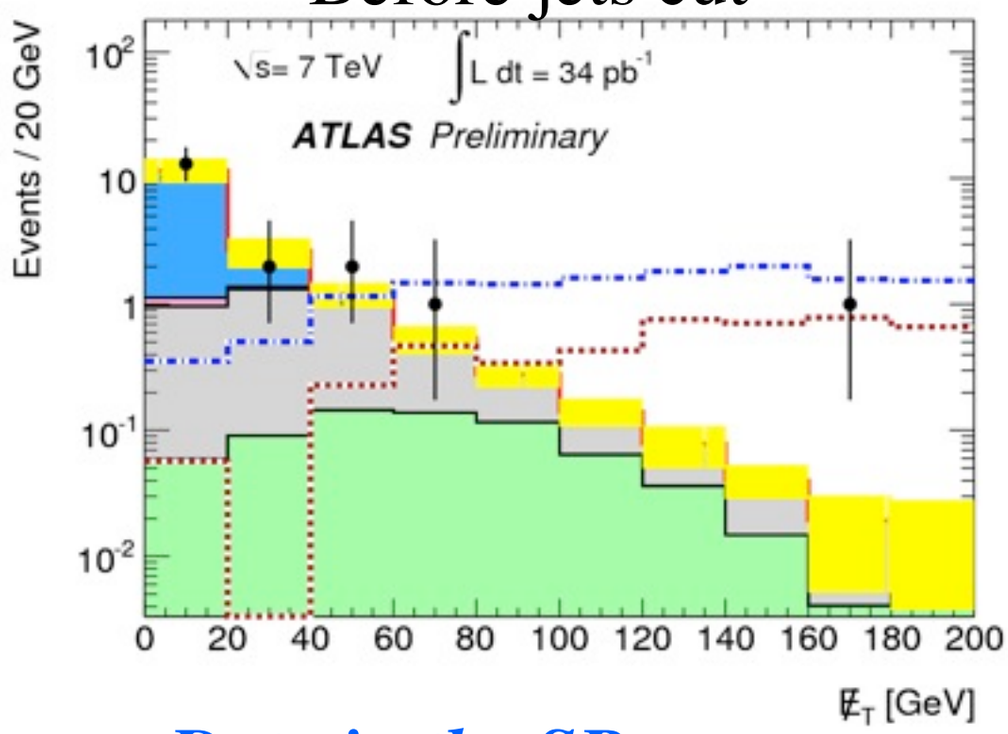


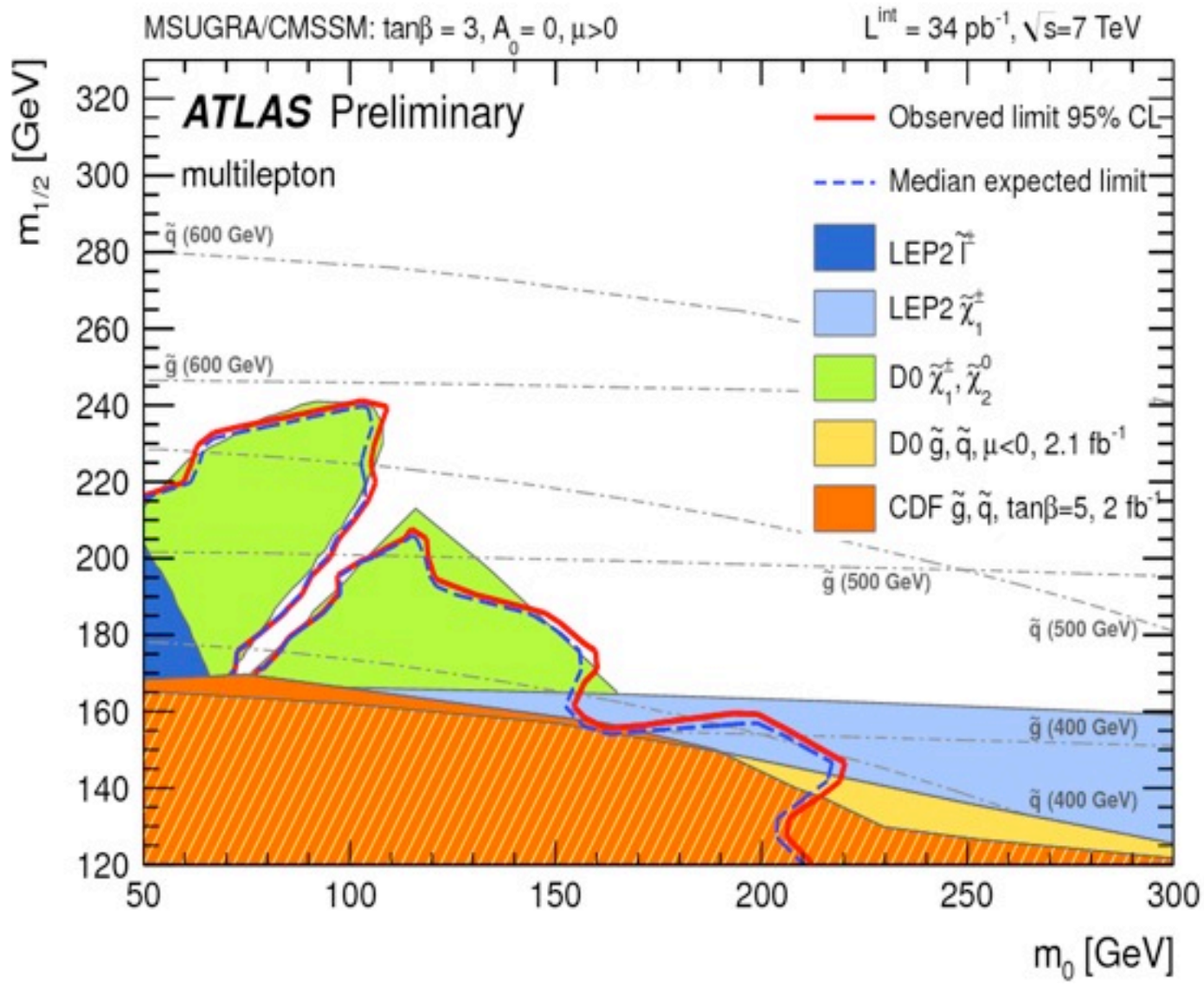


- ***Background*** ***(estimated from)***
  - Top quark pair production (MC)
  - Z + jets (MC)
- W+jets and QCD are no longer major background sources

Multilepton + jets + missing E_T - Results

Before jets cut





- ***Data in the SR***
  - none
- ***Expected background***
  - 0.109±0.023
- ***Limits*** (95% CL)
  - tanβ=3 A_0=0GeV sign(μ)=1

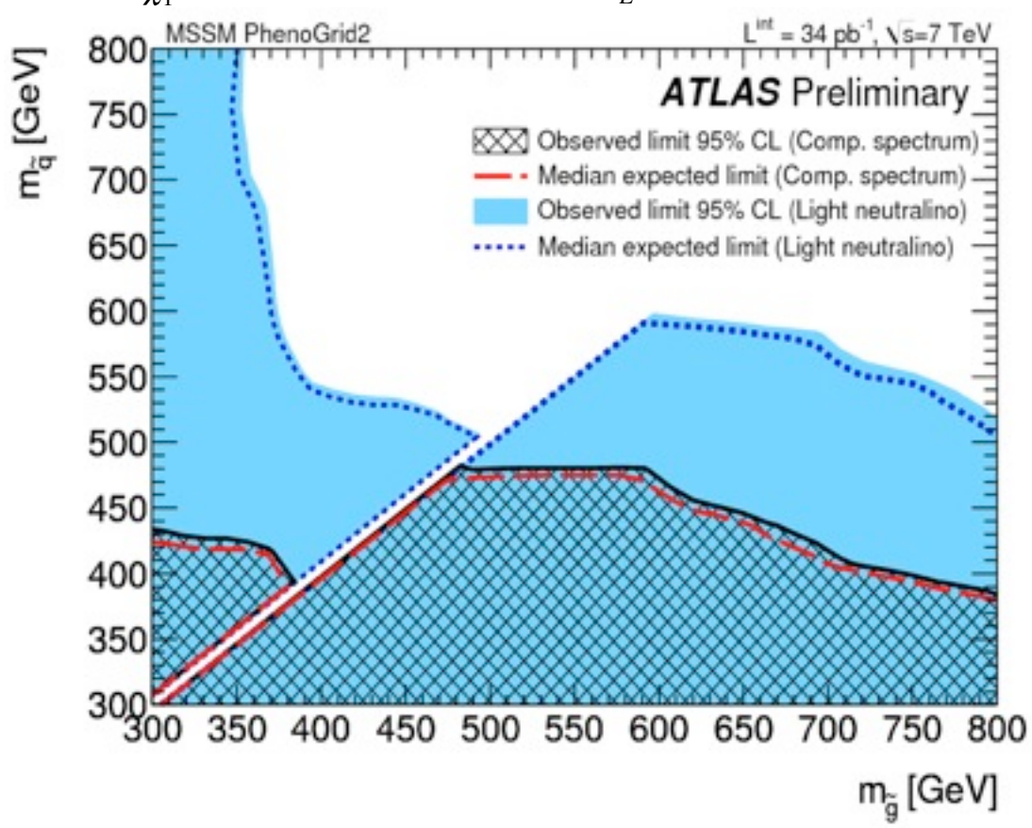
Multilepton + jets + missing E_T - PhenoGrids

- A grid in more general MSSM 24-parameter fw
  - Fixed: $m_A = 1000GeV, \mu = 1.5\min\left(m_{\tilde{g}}, m_{\tilde{q}}\right), \tan\beta = 4, A_t = \mu / \tan\beta, A_b = \mu\tan\beta, m_{\tilde{f}}^{3rd} = 2TeV$
  - Remaining parameters: $m_{\tilde{g}} \times 3, m_{\tilde{q}} = m_{\tilde{l}}$
- "***Compressed spectrum***": soft final state kinematics
- "***Light neutralino***": yield harder final state kinematics

PhenoGrid2

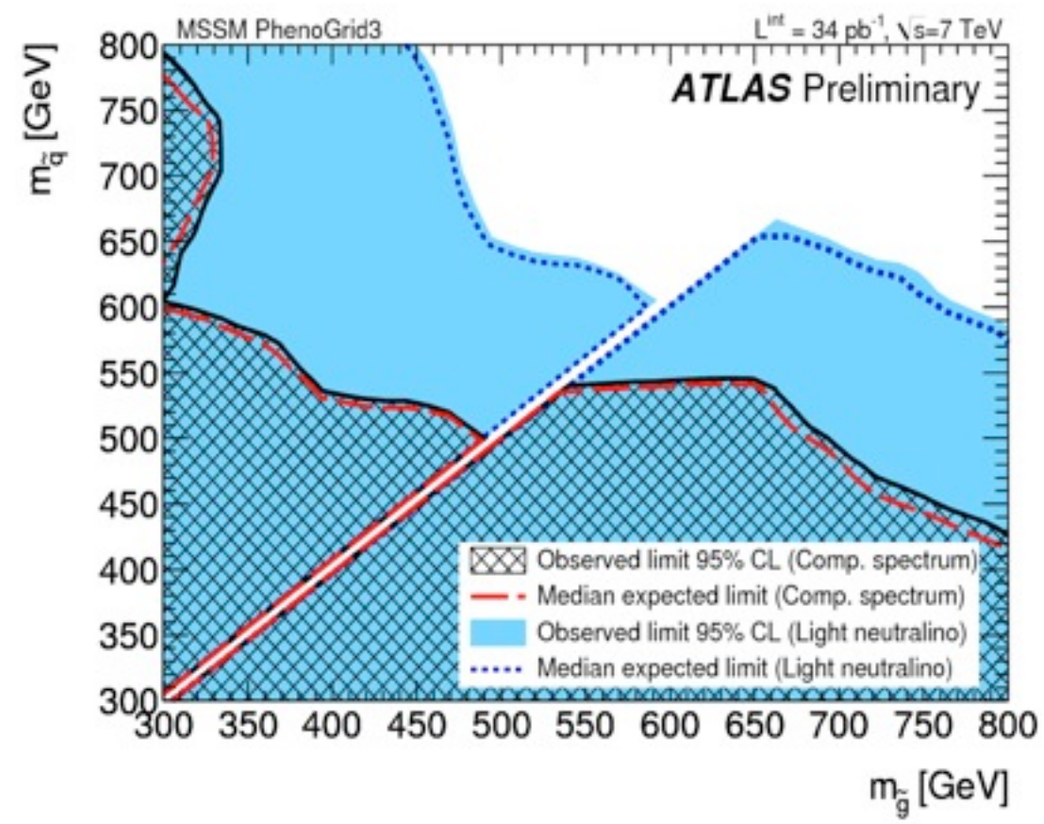
$M = \min\left(m_{\tilde{g}}, m_{\tilde{q}}\right), m_{\tilde{\chi}_2^0} = M - 50GeV,$

$m_{\tilde{\chi}_1^0} = M - 150GeV, m_{\tilde{l}_L} = M - 100GeV$



PhenoGrid3

Right-handed squark and slepton masses are pushed up



2 leptons + missing p_T

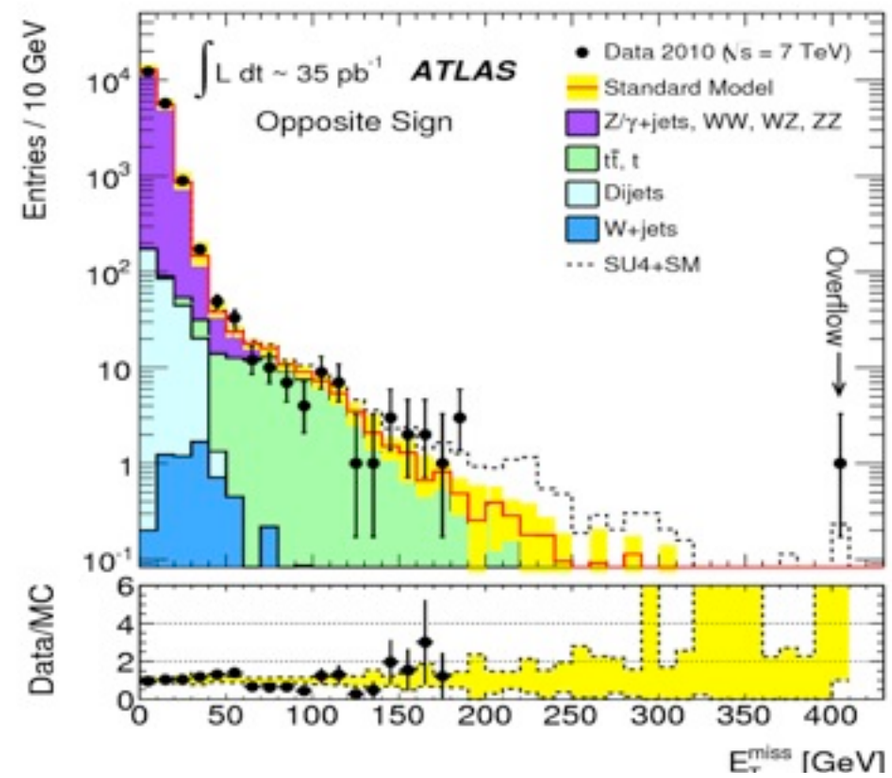
ArXiV:1103.6214 Submitted to EPJCL

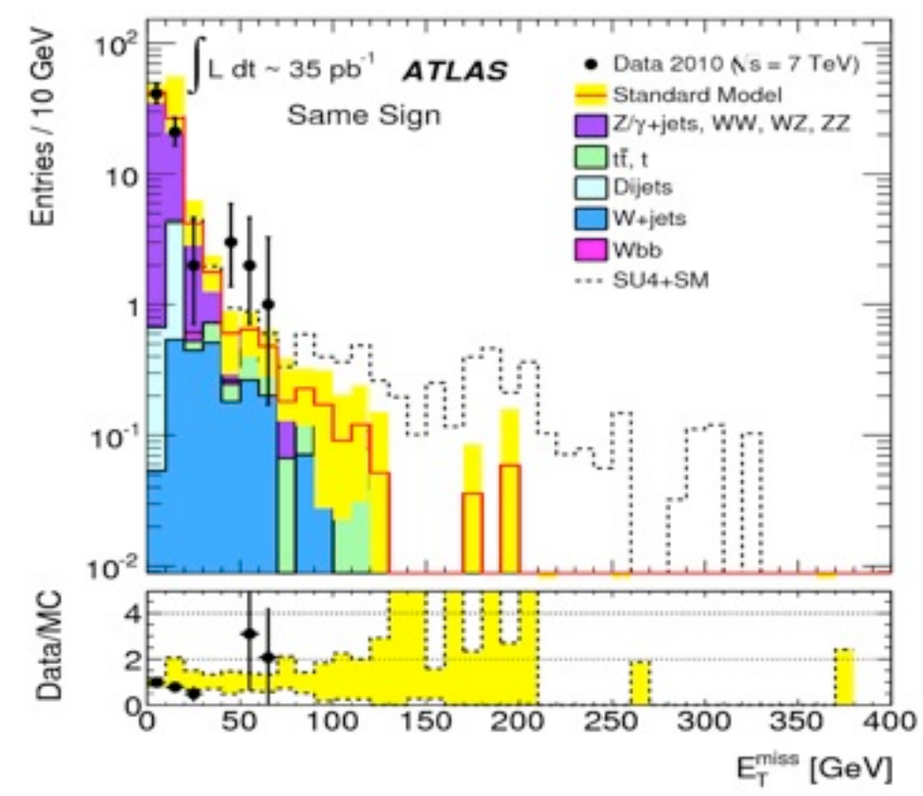
2 same flavour + missing p_T

ArXiV:1103.6208 Submitted to EPJCL

2 leptons + missing p_T

- ***Motivation:*** $\tilde{\chi}_i^{\pm} \to l^{\pm} \nu \tilde{\chi}_j^0 \quad \tilde{\chi}_i^0 \to l^{\pm} l^{\mp} \tilde{\chi}^0$
- ***2 signal regions:***
  - Exactly 2 isolated e/μ with p_T>20GeV
  - $m_{ll} > 5GeV$
- **Opposite sign :**
  - $E_T^{miss} > 150GeV$
- **Same sign :**
  - $E_T^{miss} > 100GeV$
- ***Background*** *(estimated)*:
- **Opposite sign:**
  - $t\bar{t}$ (MC in 'top-tagged' CR)
  - *Fake* non isolated leptons (data loose/tight matrix)
  - Z+jets (ee/μμ: CR/SR factor from MC. eμ: MC)
  - Di-boson (MC)
  - Single t (MC)
- **Same sign:**
  - *Fake* non isolated lepton in $t\bar{t}$, t, W+jets and QCD jet production (data loose/tight matrix)
  - Di-boson (MC)
  - e charge mis-identification in events (MC and validated with data)





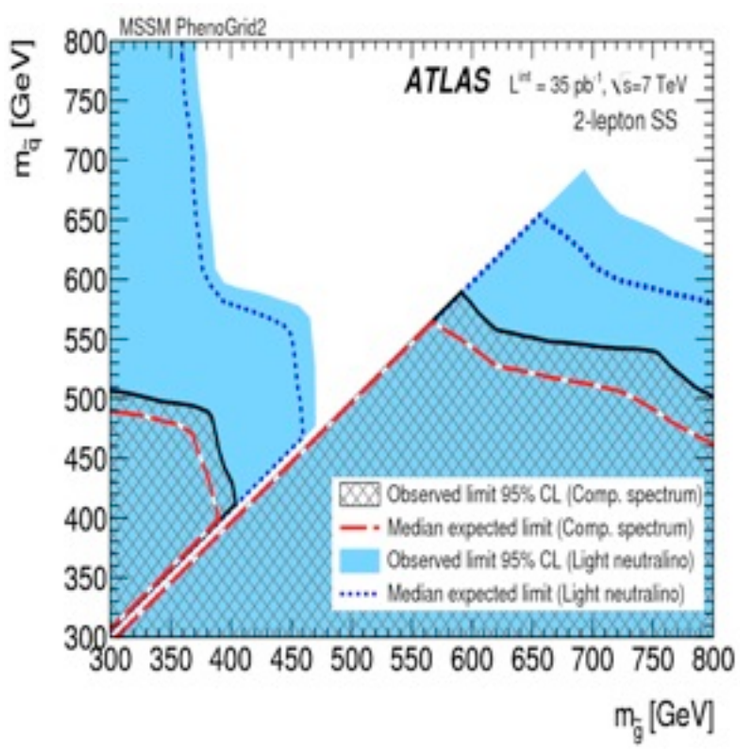
2 leptons + missing p_T - Results

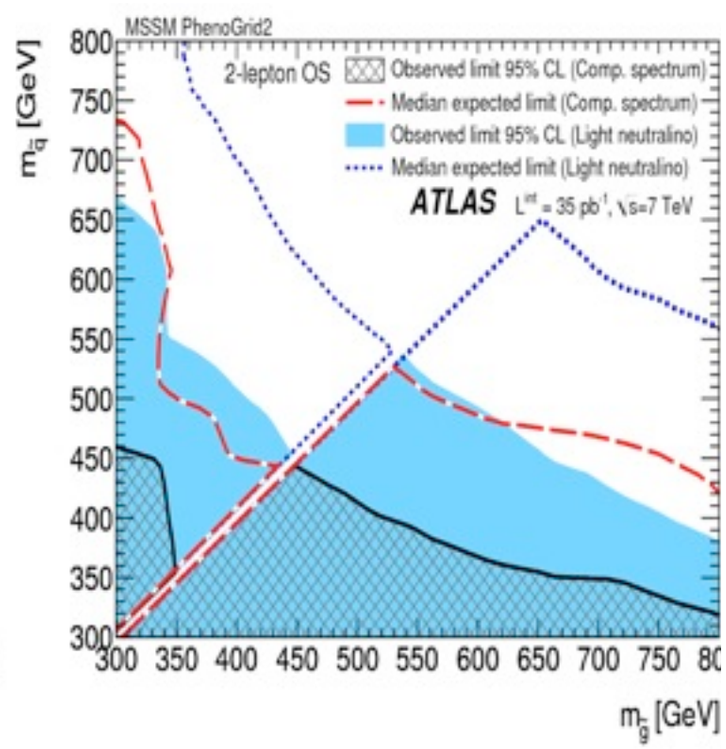
- ***Data*** and ***Background*** in SR:

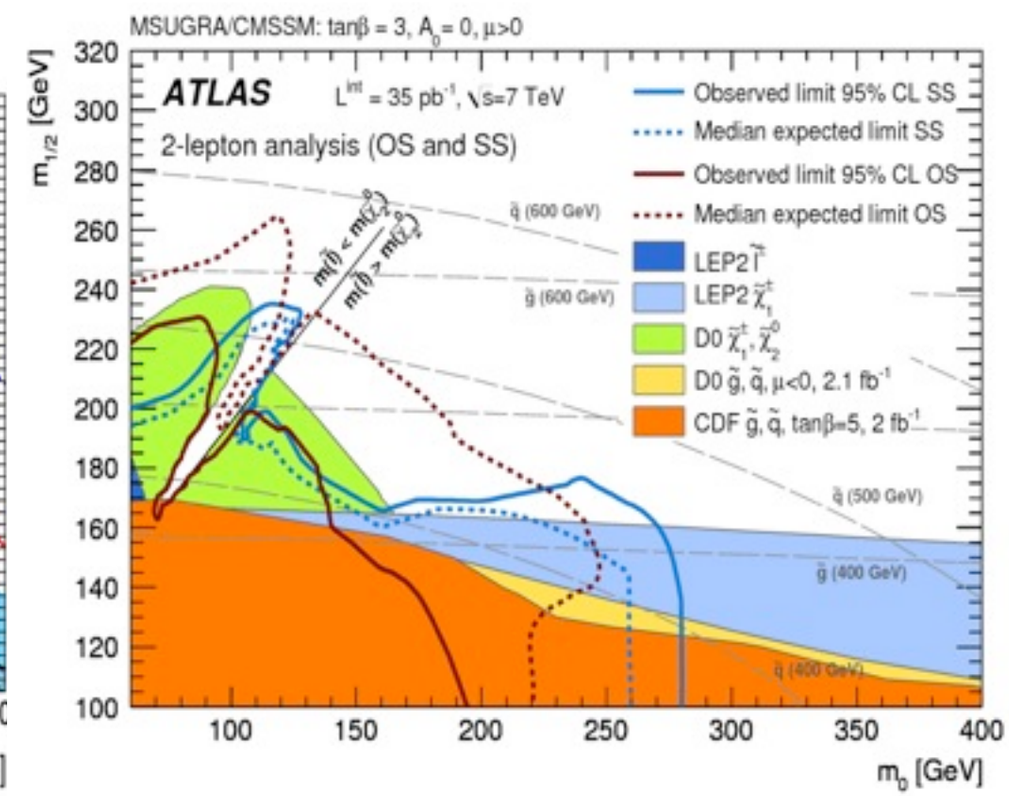
Same Sign, $E_T^{miss} > 100$ GeV			
	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
Data	0	0	0
Total	0.15 ± 0.13	$0.09^{+1.32}_{-0.03}$	0.04 ± 0.01
Opposite Sign, $E_T^{miss} > 150$ GeV			
	$e^+ e^-$	$e^\pm \mu^\mp$	$\mu^+ \mu^-$
Data	1	4	4
Total	$0.92^{+0.42}_{-0.40}$	$1.43^{+1.57}_{-0.59}$	$1.39^{+1.53}_{-0.53}$

- ***X-sec Limits:***
- Opposite sign:
  - ee: σ<0.09 pb
  - μμ: σ<0.21 pb
  - eμ: σ<0.22 pb
- Same sign: σ<0.07 pb
- ***mSUGRA/CMSSM:***
  - $\tan\beta=3$ $A_0=0$GeV sign(μ)=1

PhenoGrid2







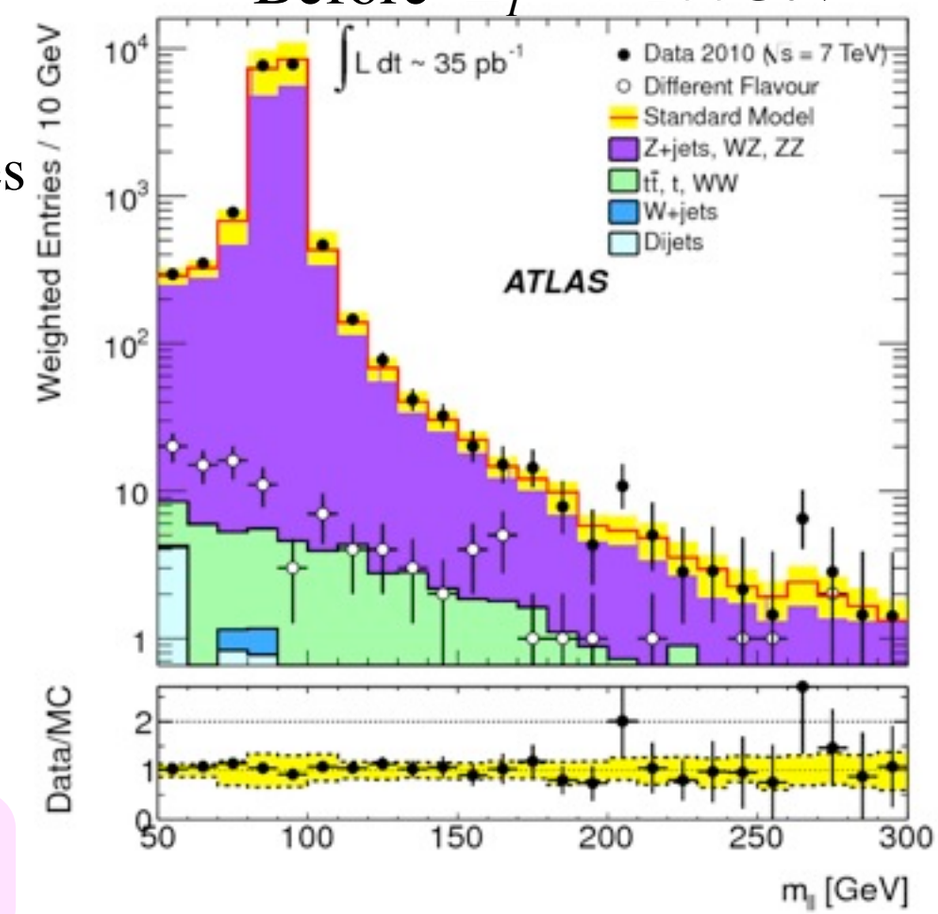
2 same flavour leptons + missing p_T

- ***Motivation:*** $\tilde{\chi}_2^0 \to \tilde{l}l^\pm \to \tilde{\chi}_1^0 l^+ l^-$ $\quad \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-$
- Endpoint in m_{ll} allows measuring sparticle masses
- 'Flavour subtraction' procedure reduces sys. uncertainties
- Reduces background
- ***Signal regions:***
  - Exactly 2 isolated e/μ; p_T>20GeV; $m_{ll} > 5GeV$
  - $E_T^{miss} > 100GeV$ → reject Z+jets
- ***Flavour subtraction:***
  - Measures the excess of same flavour events over different flavour events

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

  - τ- trigger efficiencies (estimated from data)
  - β- (e eff/μ eff)×acceptance (estimated from data)
- ***Background*** ***(estimated from)***
  - Z/γ* boson production (MC in CR)
  - $t\bar{t}$ and events with fake leptons (MC in 'top tagged' CR)

Before $E_T^{miss} > 100GeV$



2 same flavour leptons + missing p_T - Results

- ***Data*** and ***Background*** in SR:

	$e^{\pm}e^{\mp}$	$e^{\pm}\mu^{\mp}$	$\mu^{\pm}\mu^{\mp}$
Data	4	13	13
Total SM	3.64±1.24	8.08±2.78	6.91±2.20

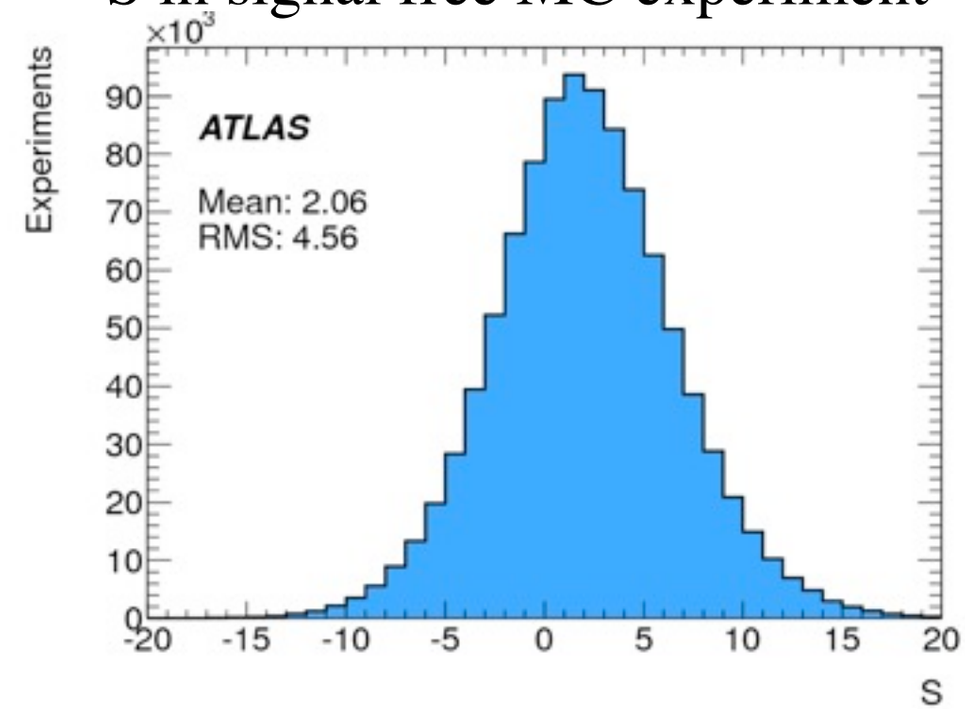
$$s_{obs} = 1.98 \pm 0.15(\beta) \pm 0.02(\tau_e) \pm 0.06(\tau_\mu)$$

$$\overline{s}_b = 2.06 \pm 0.79(stat.) \pm 0.78(sys.)$$

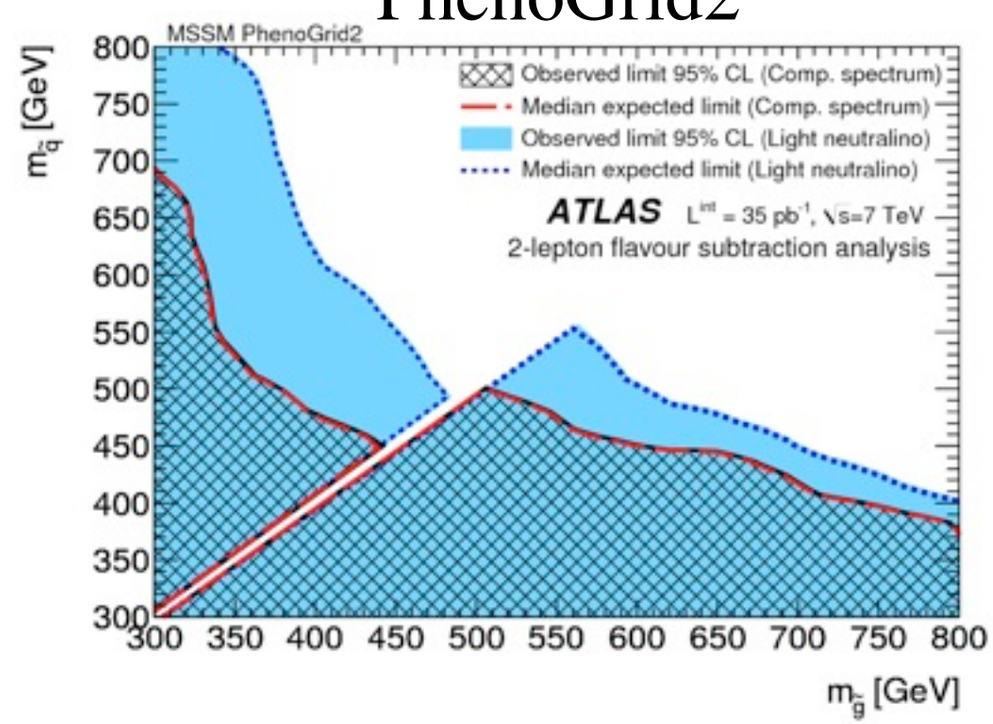
- $t\bar{t}$ contribution to s_b cancels

- ***Limit of S:***
- ***Assumption 1:*** $\overline{s}_s < 8.8$
  - ee and μμ with the same branching fraction
  - eμ with 0 branching fraction
- ***Assumption 2:*** $\overline{s}_s < 12.6$
  - ee and μμ with the same branching fraction
  - eμ with 1/2 branching fraction

S in signal free MC experiment



PhenoGrid2



Missing p_T + jets

ArXiV:1102.5290 Submitted to PLB

Missing E_T + b-jets

ArXiV:1103.4344 Submitted to PLB

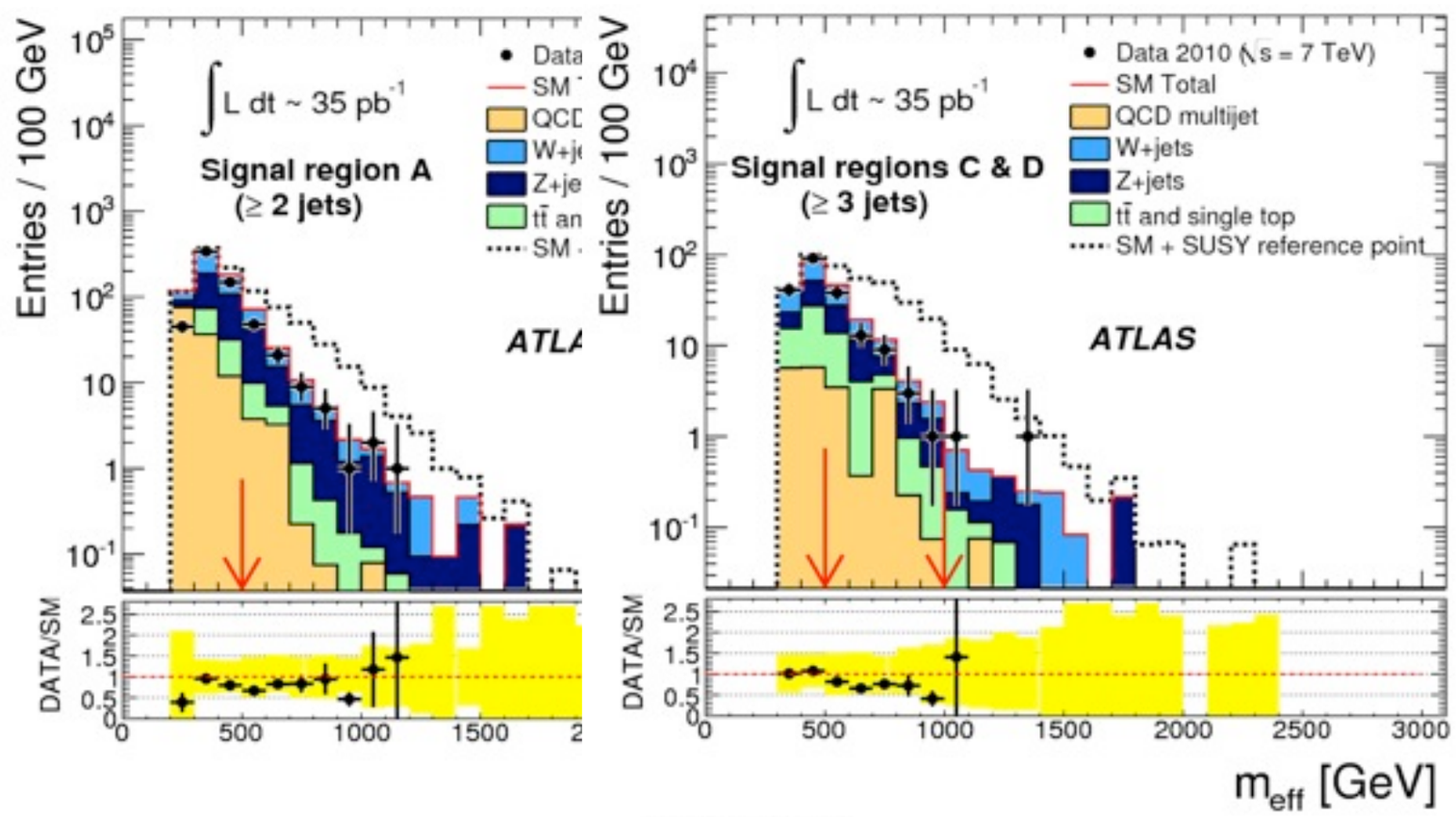
Missing p_T + jets

- ***Motivation:*** $\tilde{q} \to q\tilde{\chi}_1^0$
  $\tilde{g} \to qq\tilde{\chi}_1^0$
- ***The signal region:***
  - No isolated e/μ
  - SR A: light $\tilde{q}\tilde{q}$
  - SR B: heavy $\tilde{q}\tilde{q}$
  - SR C: $\tilde{g}\tilde{g}$
  - SR D: $\tilde{g}\tilde{q}$
- ***Background*** ***(estimated from)***
  - $t\bar{t} \to b\bar{b}\tau\nu qq$ (MC* in CR)
  - single t (MC* in CR)
  - W + jets, Z+jets (MC* in CR)
  - QCD multijet (MC in CR - ΔΦ<0.4 - and data)
  - Irreducible $Z \to \nu\bar{\nu}$

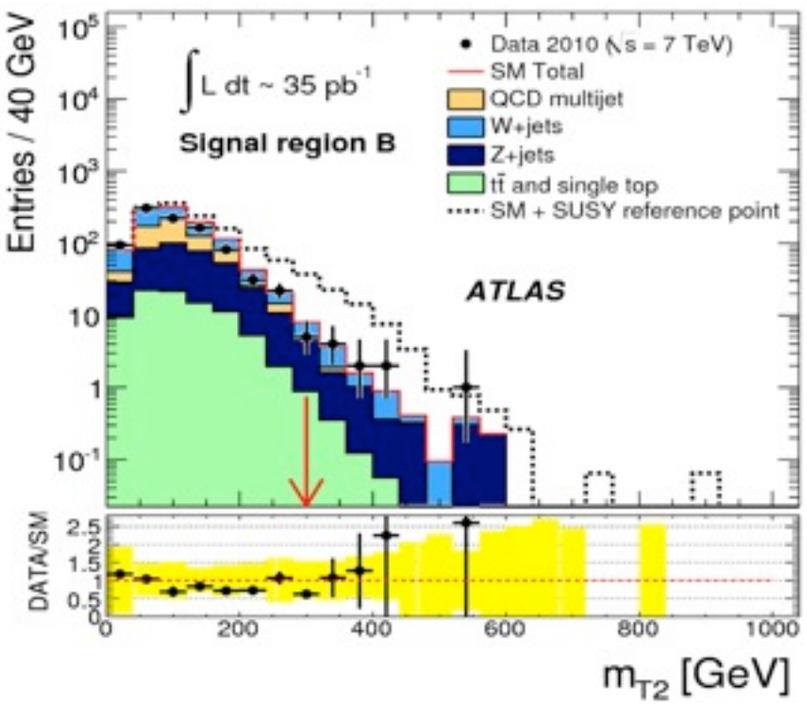
cross-checked with data driven methods

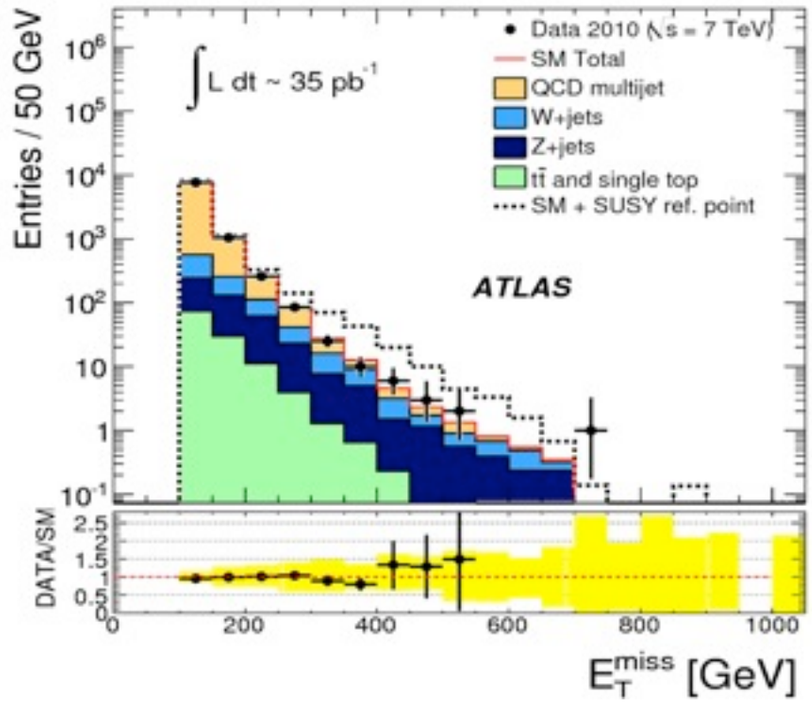
		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

TABLE I: Criteria for admission to one of the four signal regions A to D. All variables are defined in the text.

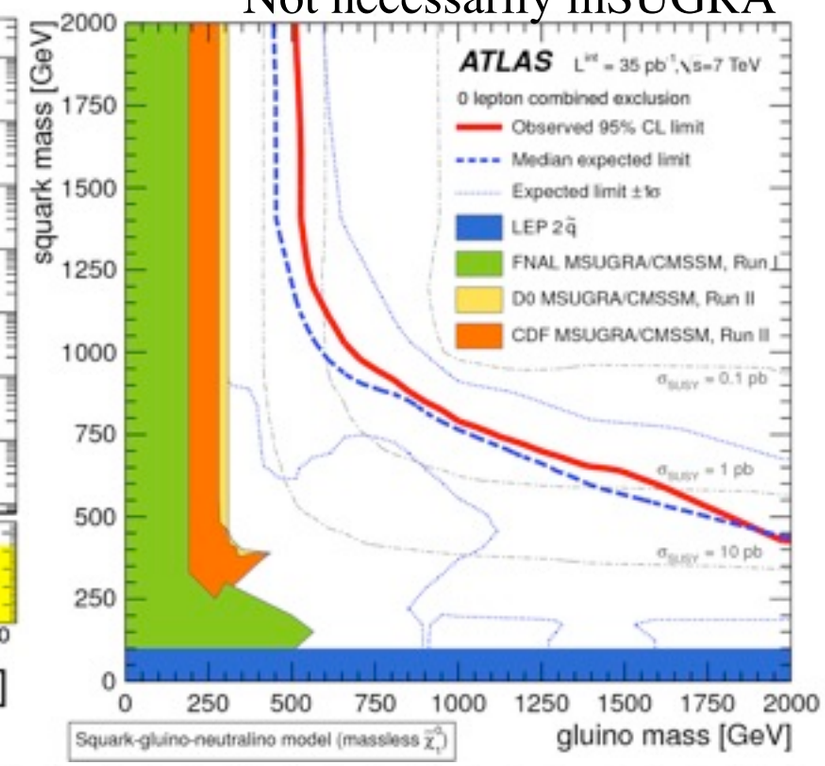


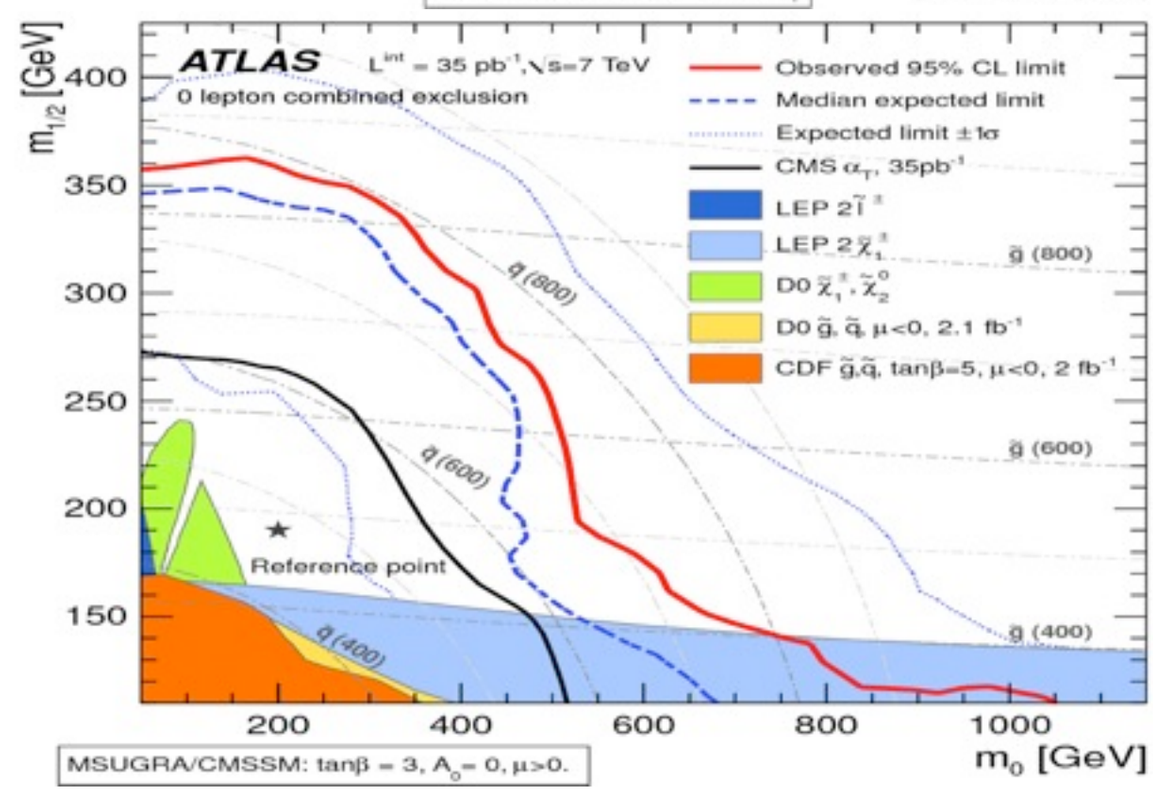
Missing p_T + jets - Results





Not necessarily mSUGRA



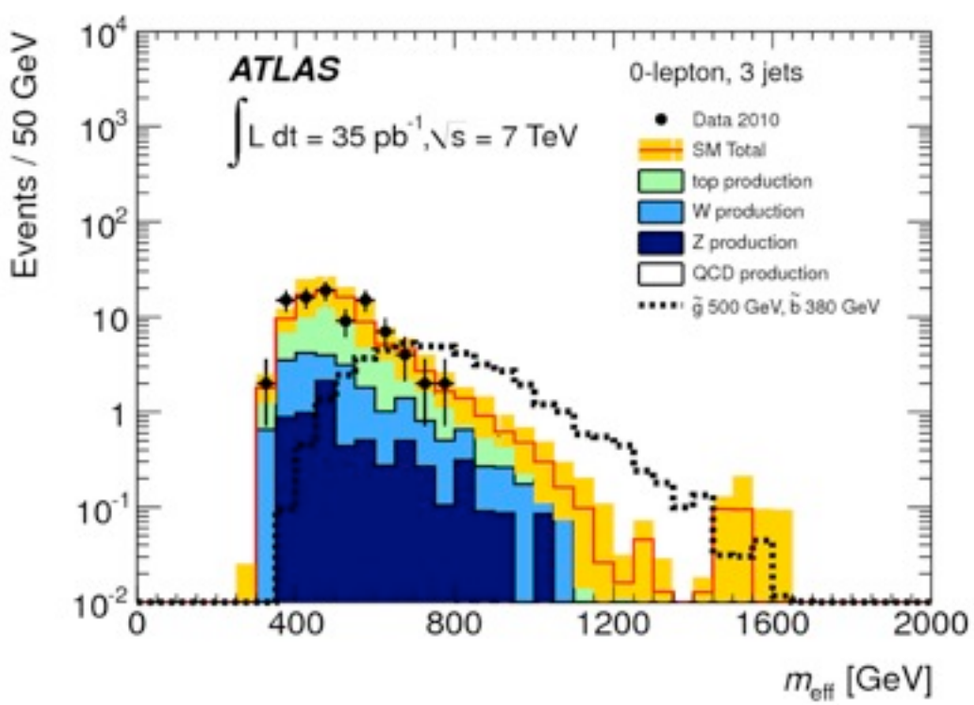


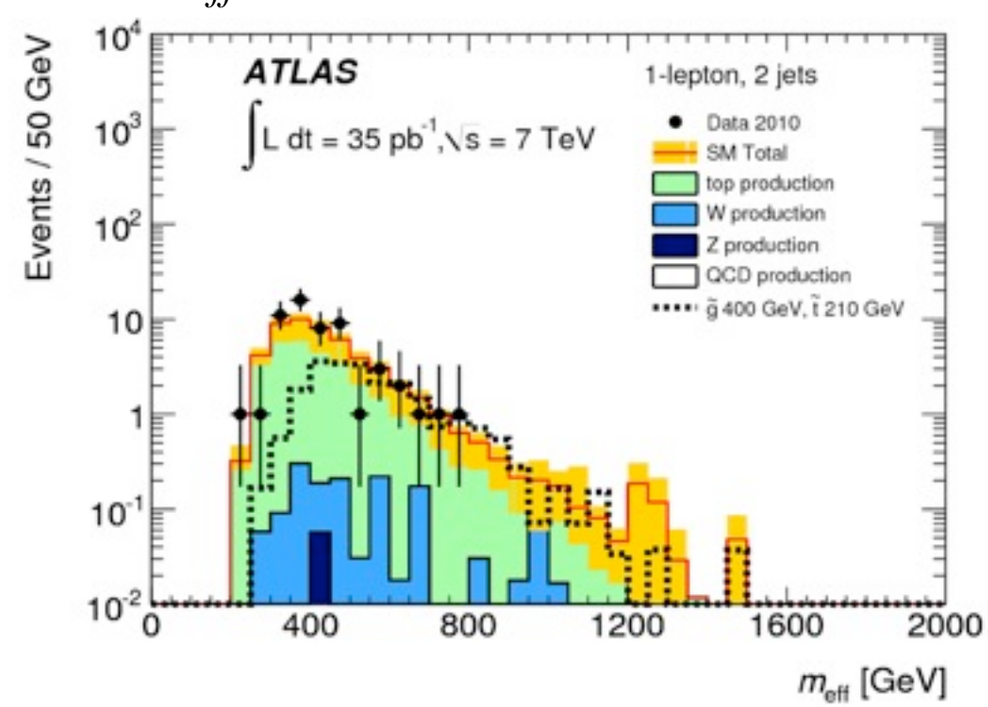
- ***Data in the SR***
  - A- 87 B-11 C-66 D-2
- ***Expected background***
  - A-118±25 B-10.0±4.3
  - C-88±18 D-2.5±1
- ***Limits*** (95% CL)
  - tanβ=3 A_0=0GeV sign(μ)=1

- $m_{\tilde{g}} = m_{\tilde{q}} > 775 GeV$

Missing E_T + b-jets

- ***Motivation:*** $mixing(\tilde{q}_L, \tilde{q}_R) \propto m_q \rightarrow light\left(\tilde{b}, \tilde{t}\right) \quad \tilde{g} \rightarrow \tilde{b}_1 b, \tilde{g} \rightarrow \tilde{t}_1 t$
- ***2 signal regions:*** both require at least 1 b-jet
- ***Zero leptons:*** $\tilde{g} \rightarrow \tilde{b}_1 b, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$
  - high p_T jet trigger and E_T-miss
  - At least *3 jets* p_T>**120**/30/30GeV
  - *High* $E_T^{miss} > 100GeV$
  - QCD rejection (misreco. jet or ν)
    - $E_T^{miss} / m_{eff} > 0.2, m_{eff}(sum(E_T^{miss}, jet \times 4))$
    - $\Delta\phi_{\min}\left(E_T^{miss}, jets\right) > 0.4$
  - $m_{eff} > 600GeV$
- ***1 lepton:*** $\tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 l^{\pm}\nu$
  - e/μ trigger
  - At least *2 jets* p_T>**60**/30GeV
    - *Lower* $E_T^{miss} > 80GeV$
  - W+jets rejection
    - $m_T(E_T^{miss}, l_{highest-p_T}) > 100GeV$
  - $m_{eff} > 500GeV$





Missing E_T + b-jets

- ***Background***
- Most dominant: ttbar and single top
- W+jets, z/γ*+jets, di-boson: WW,WZ,ZZ
- jets production via QCD processes

- ***Zero leptons***
- QCD: estimated by normalizing the MC prediction to QCD enriched control region in the data.
- Non QCD: estimated from MC

- ***1 lepton***
- QCD: estimated using a matrix method
- Non QCD: data driven estimation
  - Based on the low correlation between m_{eff} and m_T
  - Define 4 regions

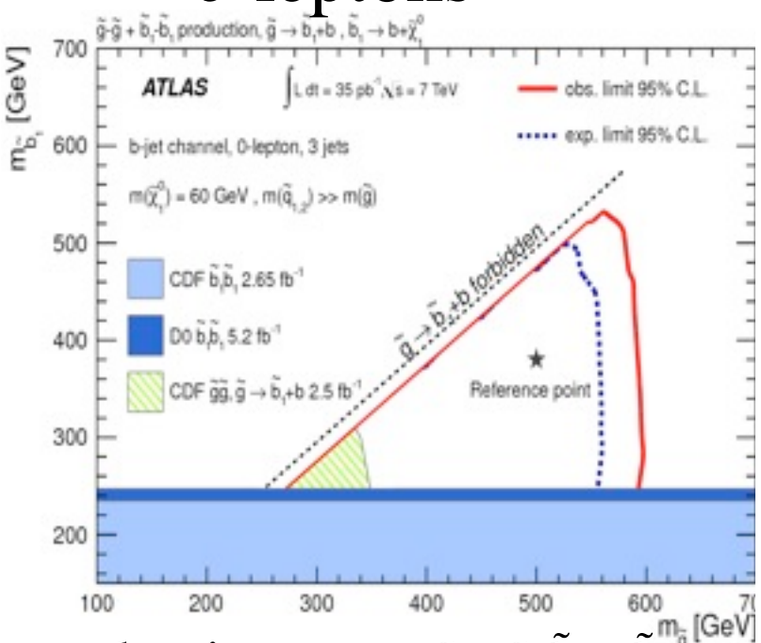
A	$40<m_T<100$; $m_{eff}<500$	bkg rich
B	$m_T>100$; $m_{eff}<500$	bkg rich
C	$40<m_T<100$; $m_{eff}>500$	bkg rich
D	$m_T>100$; $m_{eff}>500$	

  - $N_D=N_C \times NB/N_A$

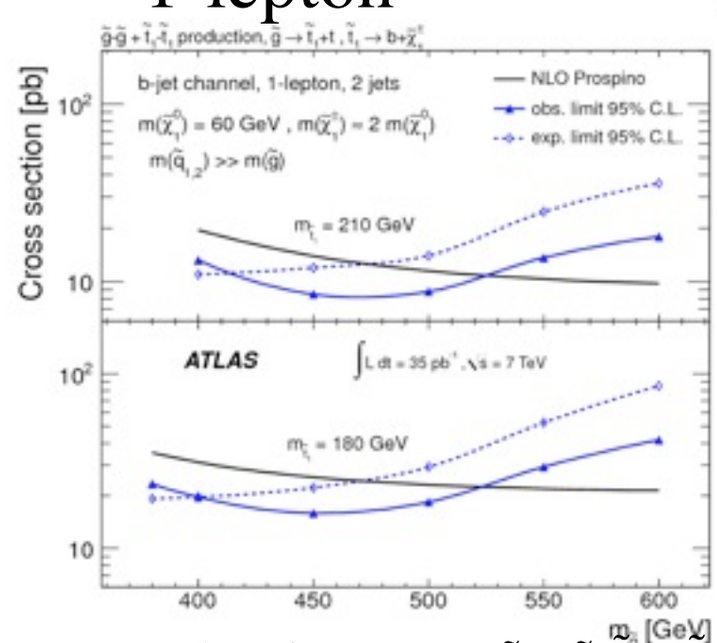
Missing E_T + b-jets - Results

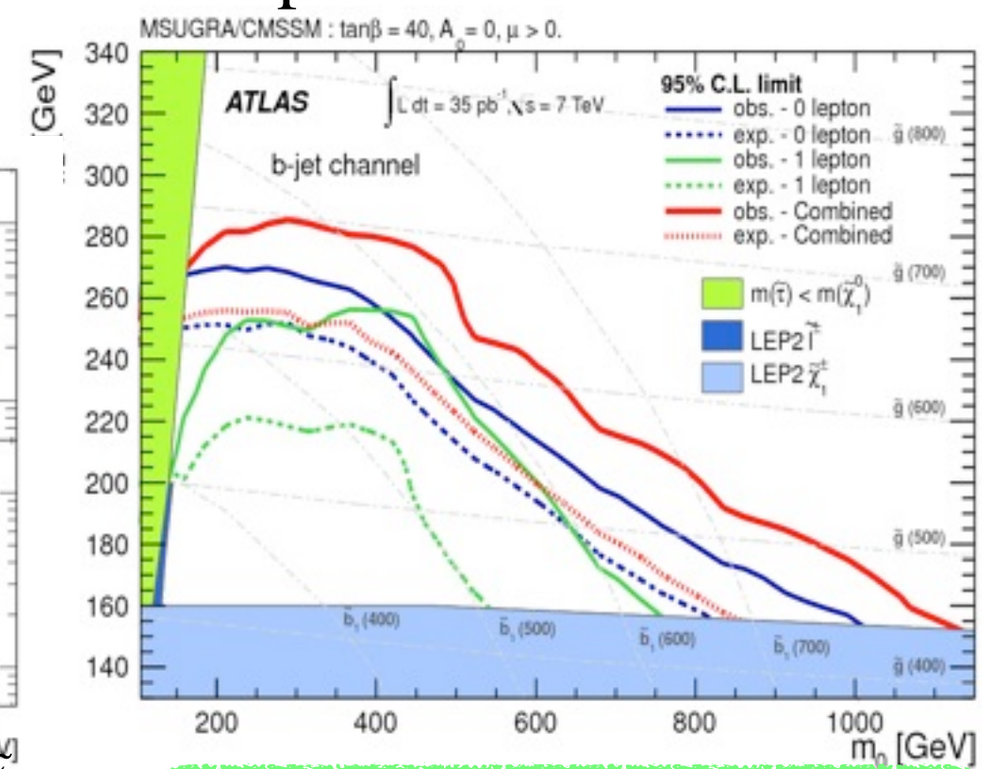
- ***Data in the SR:*** 0-leptons: 15 1-lepton: 9
- ***Expected background:*** 0-leptons: 19.6±16.9 1-lepton: 14.7±3.7
- ***Limits events/cross-section*** (95% CL)
  - 0-leptons: 10.4/0.32pb 1-lepton: 4.7/0.13pb

0-leptons



1-lepton





production $\tilde{g}+\tilde{g},\tilde{b}_1+\tilde{b}_1$

exclusive decay $\tilde{g}\rightarrow\tilde{b}_1 b\rightarrow bb\tilde{\chi}_1^0$

$for - m_{\tilde{b}} < 500GeV, m_{\tilde{g}} > 590GeV$

production $\tilde{g}+\tilde{g},\tilde{t}_1+\tilde{t}_1$

exclusive decay $\tilde{g}\rightarrow\tilde{t}_1 t\rightarrow tb\tilde{\chi}_1^{\pm}$

$for - 130 < m_{\tilde{t}} < 300GeV;$

$m_{\tilde{g}} > 520GeV$

$\tan\beta = 40, A_0 = 0GeV, \mu > 0$

$m_{\tilde{b}} > 550GeV, m_{\tilde{t}} > 470GeV$

1st and 2nd generation squark

$for - m_{\tilde{g}} \simeq m_{\tilde{q}} : m_{\tilde{q}} > 600GeV$

S0(10) models

$DR3 : \tilde{g} -> b\bar{b}\tilde{\chi}_1^0; m_{\tilde{g}} > 500GeV$

$HS : \tilde{g} -> b\bar{b}\tilde{\chi}_2^0; m_{\tilde{g}} > 420GeV$

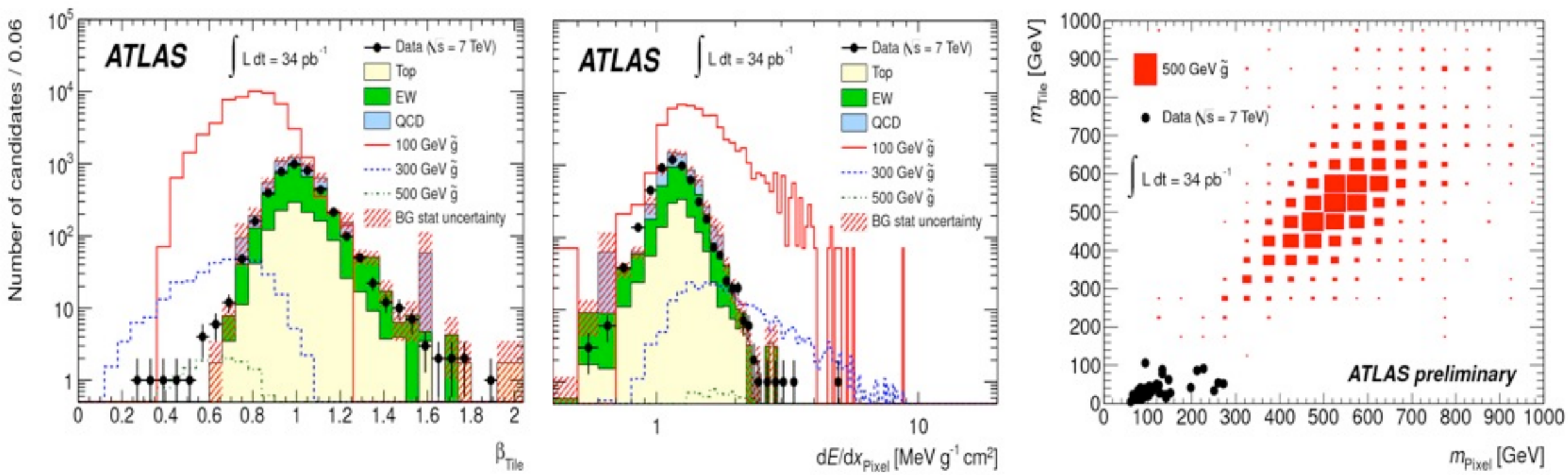
Stable hadronizing squarks and gluinos

ArXiV:1103.1984 Submitted to PLB

Stable hadronizing squarks and gluinos

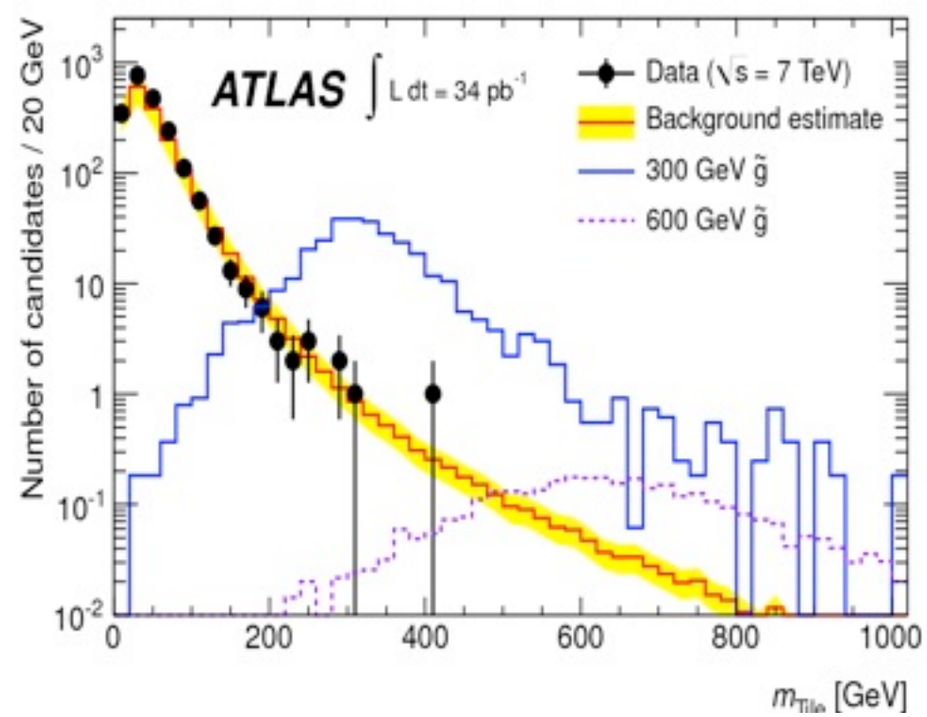
- ***Motivation:***
- Hadronizing Stable Massive Particles (SMPs) are allowed by many models
- May be charged in the Inner Detector (ID) and neutral in the Muon Spectrometer (MS)

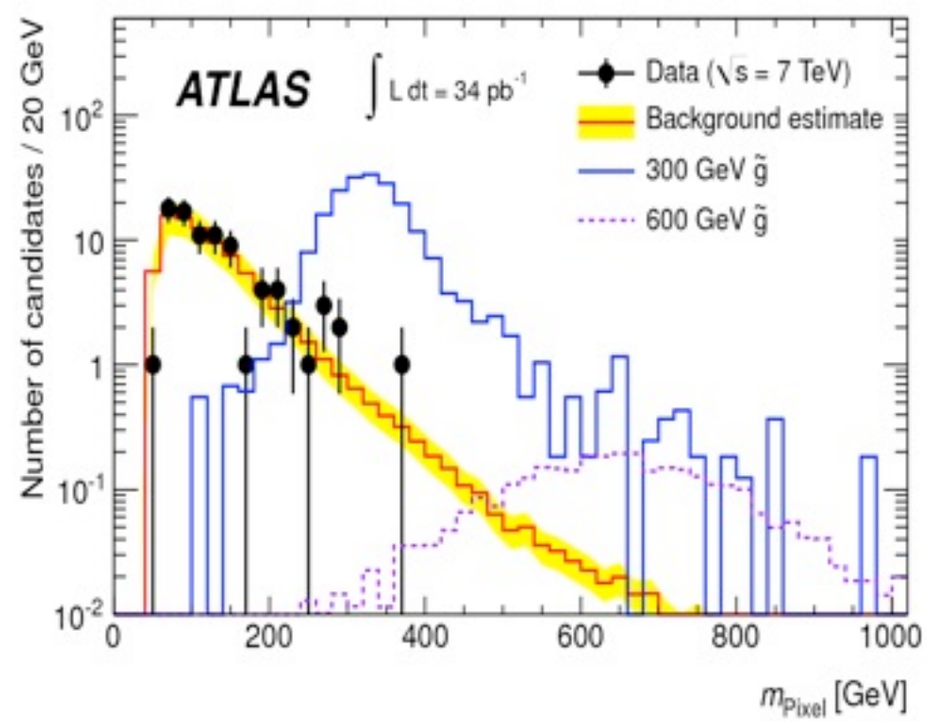
- ***Method:***
- MS agnostic
- Direct estimation of $m=p/\gamma\beta$
- 3 individual β ($\beta\gamma$) estimations:
  - β from the ToF to the TileCal
  - $\gamma\beta$ from the pixel dE/dx
  - $\gamma\beta$ from the TRT dE/dx (cross-check)



Stable hadronizing squarks and gluinos

- ***Trigger:*** energetic jet and large missing E_T
- ***Candidate definition:***
  - High quality track , $p_T > 50$GeV
  - Isolated - suppress background from jets
  - $|\eta|<1.7$ - tile coverage
  - β ($\beta\gamma$) estimation from both tile and pixel
    - sensitivity up to β=0.87
  - M>100GeV in both tile and pixel

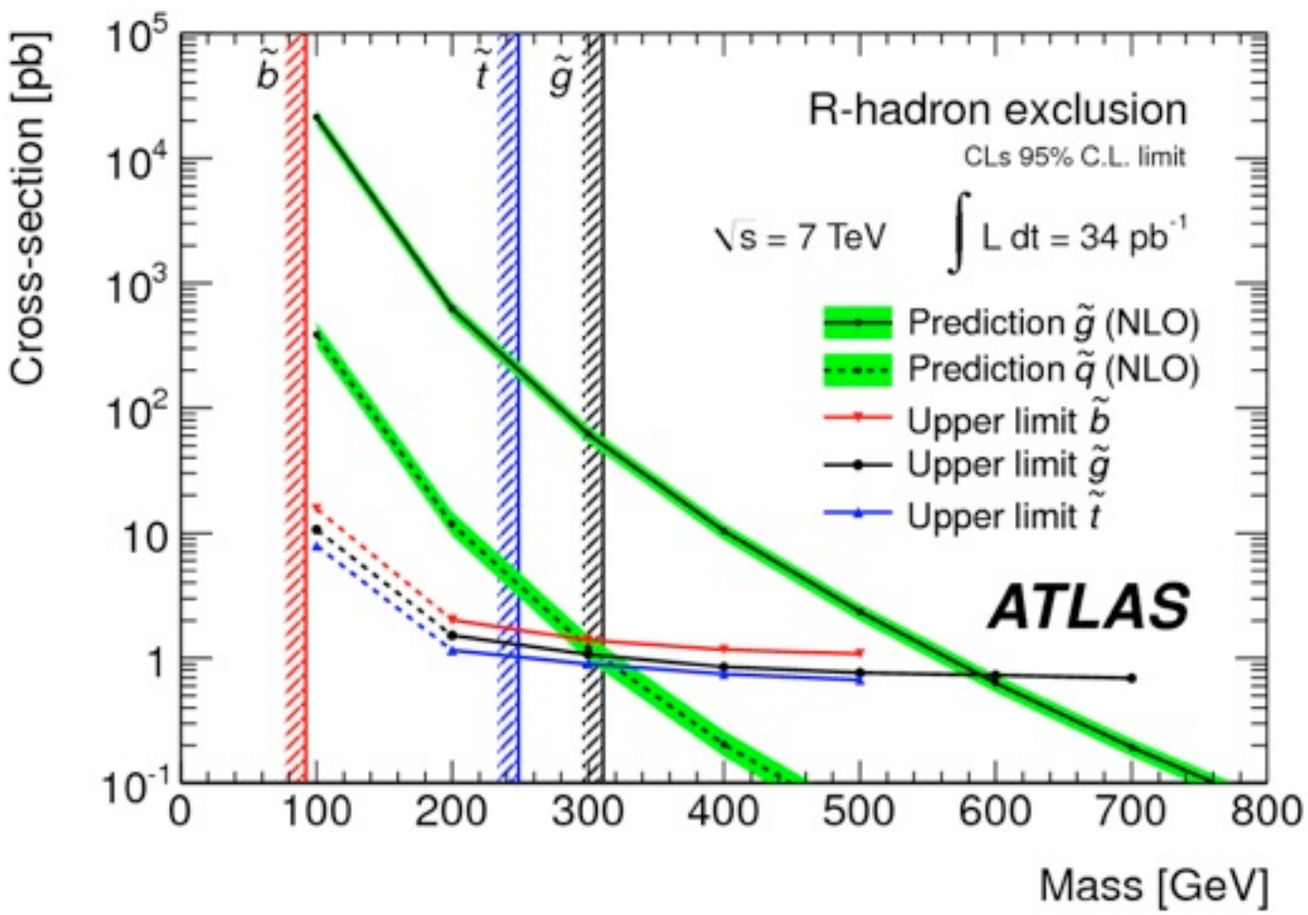




- ***Background estimation***
  - Directly from data
  - Relies on no correlation between p and β (dE/dx)
  - Combination of measured momentum with random β ($\beta\gamma$)

Stable hadronizing squarks and gluinos - Results

- ***Remaining candidates:***
  - m>100GeV - 5 m>200GeV - 0
- ***Expected background:***
  - m>100GeV - 5.4 m>200GeV - 0.87
- ***Limits*** (95% CL)



Most stringent limits to date:

$$m_{\tilde{b}-Rhad} > 294 GeV$$

$$m_{\tilde{t}-Rhad} > 309 GeV$$

$$m_{\tilde{g}-Rhad} > 586 GeV$$

Summary

- ~35pb^{-1} of data collected with the ATLAS detector during 2010 LHC run was analyzed
- 7 papers (+1 CONF note) approved by ATLAS
  - 1 paper accepted by PRL
  - 6 in journal review
  - More analyses are in different stages of the collaboration approval
- No deviation from the Standard Model predictions was observed
- Limits on the masses of SUSY particles in different scenarios were set
  - Most of them most stringent to date

- ***Looking forward to the data of 2011…***

Backup

Common issues

- rigger: different analyses uses different trigger chains, but
  - Trigger chains changes with data taking period
  - Cuts are applied to ensure trigger efficiency plateau
  - MC/Data scaling factors (and associated systematic uncertainties) are taken into account

Common issues

- Leptons: isolated e/μ (not τ)
- Missing transverse momentum (p_T) and it's magnitude (E_T)
  - Vectorial sum of all reconstructed object
- Theoretical uncertainties
  - The signal cross-section
  - The parton PDF

Common issues - Jets

- Jets:
  - Reconstructed using the anti-k_T jet clustering algorithm (distance parameter R=0.4)
  - Associated systematic uncertainties:
    - Jet Energy Scale, Jet Energy Resolution
- b-jets:
  - b-jets are identified among jets with p_T>30GeV and a displaced vertex
  - The b-tagging efficiency is 50% (1%) for b-jets (light flavor/gluon jets) in ttbar event in MC