Supersymmetry searches in events with three leptons and missing energy at the ATLAS detector

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Outline

- Introduction
- Treatment of backgrounds
- Models of new physics considered
- Signal regions
- Data/MC validation
- Statistical procedure
- Results

Introduction

- Events with multiple leptons and missing energy are rare in the Standard Model
- No QCD background - advantage over zero lepton searches
- Can look for direct production of gauginos
- Analysis presented today was performed with 4.7 $\text{fb}^{-1}$of 7 TeV data
- Hot off the press! (released last week)
- Blind analysis
  - High missing energy events not analysed until background estimation validated
- More details in arXiv:1208.3144 (submitted to Physics Letters B) and note presented at ICHEP

Background treatment

- Irreducible backgrounds (at least 3 real leptons)
  - WZ, ZZ, $t\bar{t} + W/Z$ production
  - WZ estimated using semi-data-driven method, others from MC
- Reducible backgrounds (at least 1 fake lepton)
  - Matrix method applied to correct MC to data-driven object efficiencies and purities

Background estimation

- "Real" leptons:
  - From W/Z/γ^* or SUSY particles
- "Fake" leptons:
  - External conversion (interaction with detector material)
  - Lepton from *b* or *c* quark decay

Matrix method relates purity of lepton selection (Tight,Loose) to lepton identity (Real, Fake)

$$\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix} = \begin{pmatrix} \epsilon_1 \epsilon_2 & \epsilon_1 f_2 & f_1 \epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

- ϵ: probability of real loose lepton identified as a tight lepton
- f: probability of loose fake lepton mis-identified as a tight lepton

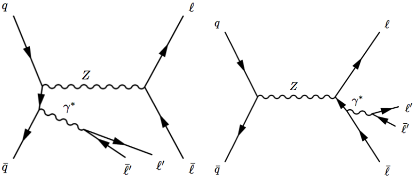
If we know ϵ and f, we can invert the matrix allows to obtain the total number of events with fake leptons

$$N_{RF} + N_{FR} + N_{FF} = \frac{1}{(\epsilon_1 - f_1)(\epsilon_2 - f_2)} [(\epsilon_1 \epsilon_2 - \epsilon_1 f_2 - f_1 \epsilon_2 + f_1 + f_2 - 1) N_{TT} + (\epsilon_1 \epsilon_2 - \epsilon_1 f_2 - f_1 \epsilon_2 + f_2) N_{TL} + (\epsilon_1 \epsilon_2 - \epsilon_1 f_2 - f_1 \epsilon_2 + f_1) N_{LT} + (\epsilon_1 \epsilon_2 - \epsilon_1 f_2 - f_1 \epsilon_2) N_{LL}]$$

Fake electrons from conversions

Two types of conversion:

- External conversion
  - e interacts with detector material $\rightarrow \gamma \rightarrow e^+e^-$
  - only one of e^+e^- is reconstructed
- Internal conversion
  - ISR: no helpful kinematic properties
  - FSR: can reconstruct Z mass
- External conversion treated in detector simulation, estimated in control region
- Internal conversion treated by event generator

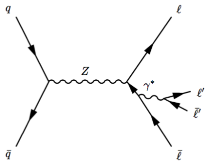


(a) ISR conversion (b) FSR conversion

Background estimation: fakes from conversion

- Define conversion-enriched control region
  - $\mu^+\mu^- e$ selection
  - Require $|m_{\mu^+\mu^- e} - m_Z| < 10$ GeV (FSR conversion)
- Calculate data/MC scale factor

Similar procedures followed for other fake types, then summed to create combined scale factors for matrix method



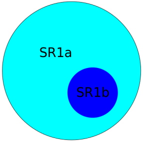
(c) FSR conversion

Signal regions

- Exactly 3 leptons ($\ell = e, \mu$) ($p_{\mathrm{T}} = (20, 10, 10)$ GeV)
- Same flavour, opposite sign (SFOS) pair ($e^+e^-, \mu^+\mu^-$)
- $E_{\mathrm{T}}^{\mathrm{miss}} > 75$ GeV

- SR1a
  - **Veto** events with SFOS pair with $|m_{\ell\ell} - m_Z| < 10$ GeV
  - Veto events with b-jets
  - SR1b
    - Raise lepton p_{T} to 30 GeV
    - $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) > 90$ GeV

- SR2
  - **Require** SFOS pair with $|m_{\ell\ell} - m_Z| < 10$ GeV
  - $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) > 90$ GeV

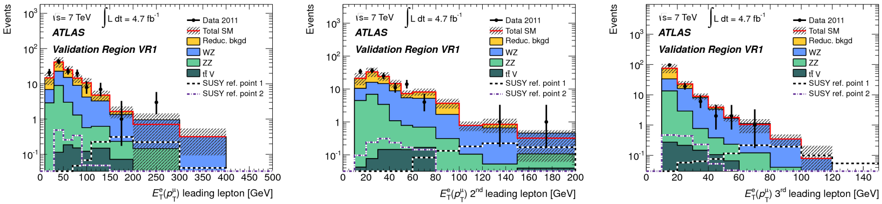


Data/MC validation

While analysis is still blind...

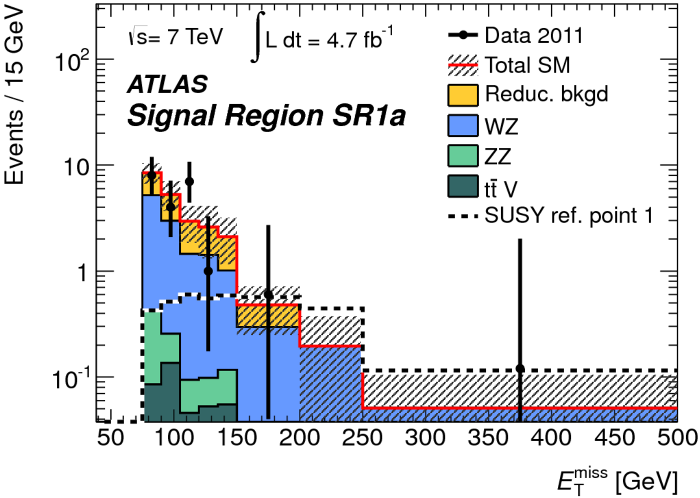
Data/MC validation

- Check data/MC agreement with three different background-enriched selections
- Lepton p_{T} for validation region 1 (Drell Yan and *WZ* dominated) shown here
- Other validation regions also consistent
- Time to look at signal regions!



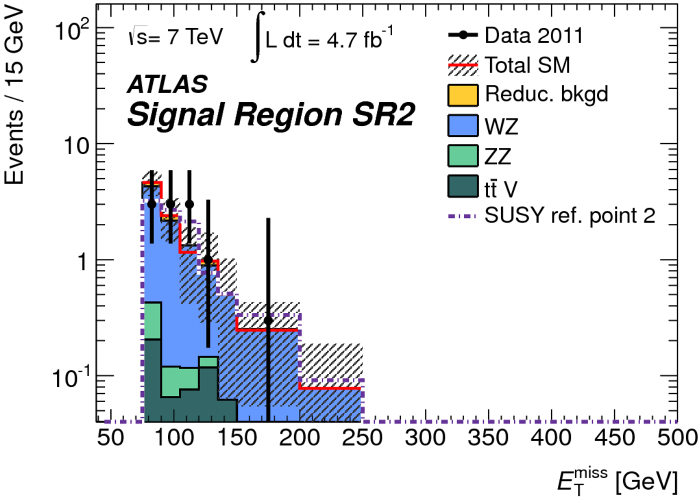
Results

- No excess seen - SR1a



Results

- No excess seen - SR2



Results

- No excess seen
- Limits placed on the visible cross sections of generic new physics models

Selection	SR1a	SR1b	SR2
$t\bar{t}Z$	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±2.9	1.05±0.28	9.3±2.1
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**
SUSY ref. point 1	8.0±0.8	6.5±0.6	0.46±0.05
SUSY ref. point 2	1.03±0.19	0.21±0.09	10.9±1.0
Visible σ (exp)	$<$ 3.0 fb	$<$ 0.8 fb	$<$ 2.0 fb
Visible σ (obs)	$<$ 3.0 fb	$<$ 0.7 fb	$<$ 2.0 fb

Models of new physics

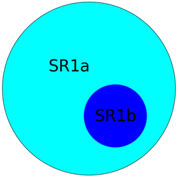
Only time for a selection here - see backup for UED and simplified models

- Phenomenological MSSM (pMSSM) (SR1a,SR1b)
  - $\tan\beta = 6$, M_1, M_2 and μ define mixing of $\tilde{\chi}_i^{\pm}$ and $\tilde{\chi}_j^0$
- General gauge mediation (SR2)
  - Gravitino LSP, phenomenology determined by NLSP
    1. Higgsino-rich and wino-rich considered here
    2. On-shell Z boson in decay $\rightarrow$ SR2

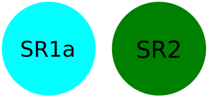
Interpretation of results

- In the absence of any excess ☹, exclusion limits are set in the signal models described above
- Two types of combination:

- Optimised OR
  - If one signal region is a subset of another
  - Calculate exclusion p-value for both signal regions, choose best expected exclusion



- Statistical combination $\bigoplus$
  - If signal regions do not overlap (“orthogonal”)
  - Calculate p-value using a combined likelihood of counts in both regions

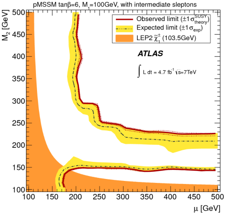


2 and 3 lepton combination

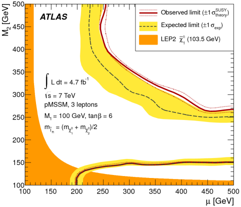
- Complementary 2 lepton analysis has similar reach in pMSSM
- 2 lepton selection orthogonal
  - Requirement of exactly 2 leptons
- "Double" combination performed:
  - (SR1a $\bigoplus$ SR2ℓ) OR (SR1b $\bigoplus$ SR2ℓ)

pMSSM: $M_1 = 100$

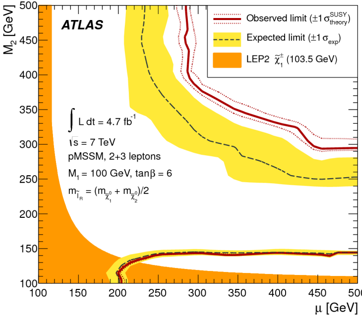
2 lepton



3 lepton

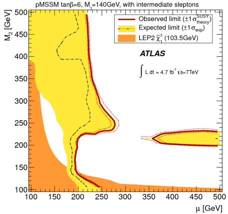


Combination

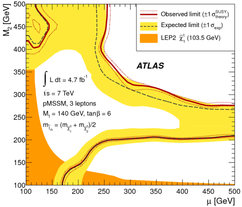


pMSSM: $M_1 = 140$

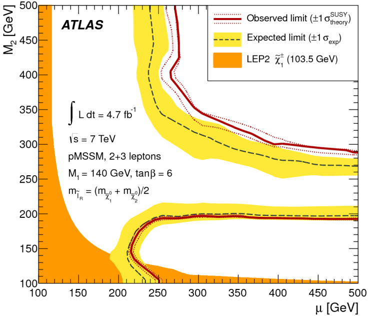
2 lepton



3 lepton

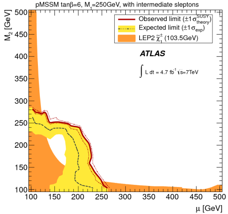


Combination

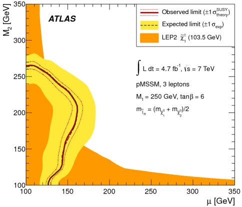


pMSSM: $M_1 = 250$

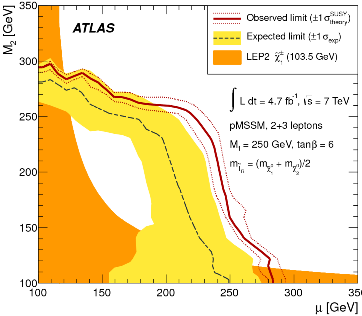
2 lepton



3 lepton

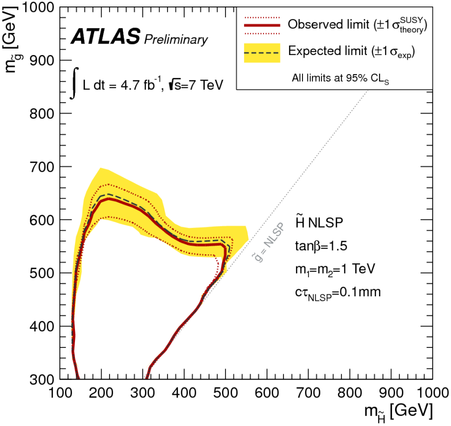


Combination

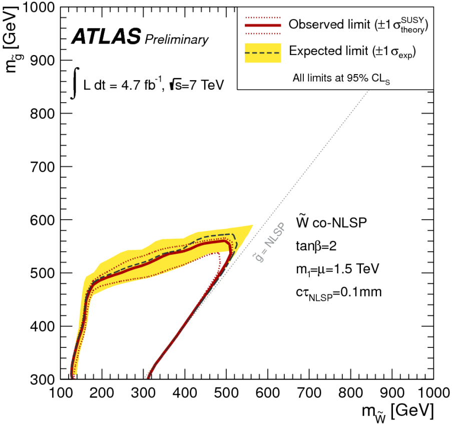


General gauge mediation - results

SR2 only here - on-shell Z bosons



(i) Higgsino NLSP

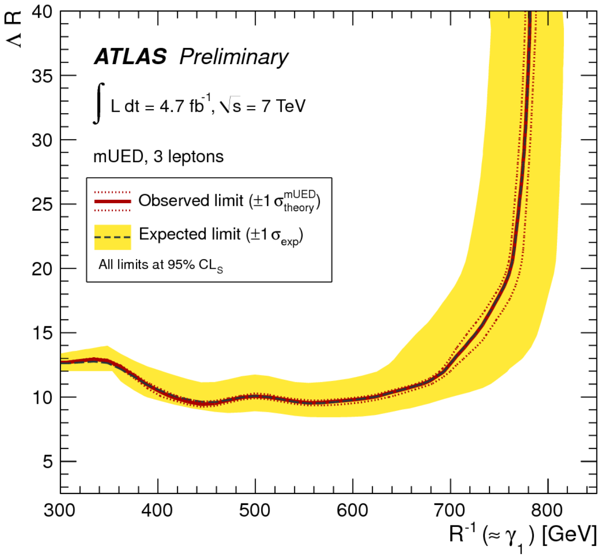


(j) Wino NLSP

Conclusions and outlook

- Search for supersymmetry at the ATLAS detector performed with full 2011 LHC dataset
- Important backgrounds estimated using data-driven methods
- No excess found
- Limits set in multiple signal regions and interpreted in several models of new physics
- Statistical combination with 2 lepton analysis performed
- 2012 8 TeV analysis in progress now - watch this space!

Backup: UED



ATLAS Preliminary
∫ L dt = 4.7 fb^-1, √s = 7 TeV
mUED, 3 leptons
Observed limit (±1 σ theory mUED)
Expected limit (±1 σ exp)
All limits at 95% CLs
Λ R
40
35
30
25
20
15
10
5
300
400
500
600
700
800
R^-1 (≈ γ1) [GeV]

Backup: UED details

Observed and expected 95% CL limit contours for the minimal universal extra dimensions (mUED) model. In the mUED model, one extra dimension is introduced that is compactified on a S^1/Z_2 orbifold with a characteristic length scale R and it is an effective theory valid up to a cutoff scale, Lambda. The SM fields are allowed to propagate in the extra spatial dimension resulting in a Kaluza-Klein (KK) tower of excited SM particles. Conservation of momentum in the extra dimension gives rise to a conserved KK-number and leads to a phenomenology analogous to R-parity conserving SUSY: KK-particles are pair-produced and the lightest KK particle (typically the photon γ^*) is stable and neutral. The production of KK-particles is dominated by pair production of KK-quarks and KK-gluons that decay via excited KK-Ws and KK-Zs to multilepton final states with γ^* producing significant missing transverse momentum. The mUED signal samples are produced with, and normalized to the prediction from, the LO HERWIG++ generator. SR1a provides the best sensitivity to the mUED model, which tends to have soft leptons. The expected and observed limits are calculated without signal cross-section uncertainty taken into account. The yellow band is the +-1 sigma experimental uncertainty on the expected limit. The red dashed band is the +-1 sigma signal theory uncertainty on the observed limit. Linear interpolation is used to account for the discreteness of the signal grids. The results from this search exclude 1/R values below 775 GeV for large values of Lambda R, significantly extending current limits.

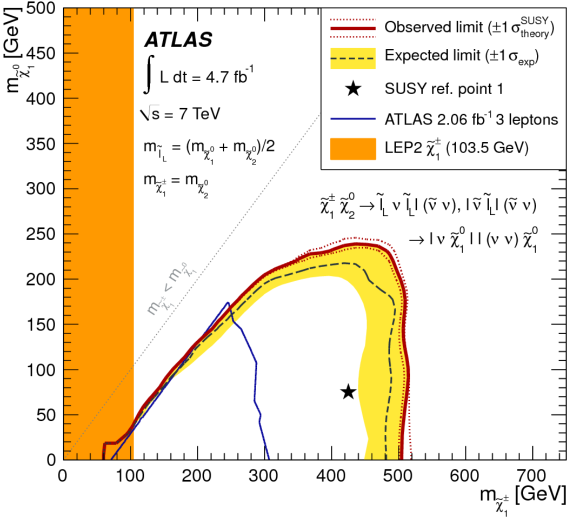
Backup: Simplified models

Simplified models of $\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_1^0/\tilde{\chi}_2^0$ pair production:

- Charginos and heavy neutralinos wino-like and mass degenerate
- Lightest neutralino bino-like
- Two scenarios:
  1. $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ decay via sleptons and sneutrinos $\rightarrow$ SR1b
  2. $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ decay via W and Z bosons $\rightarrow$ SR1a, SR2

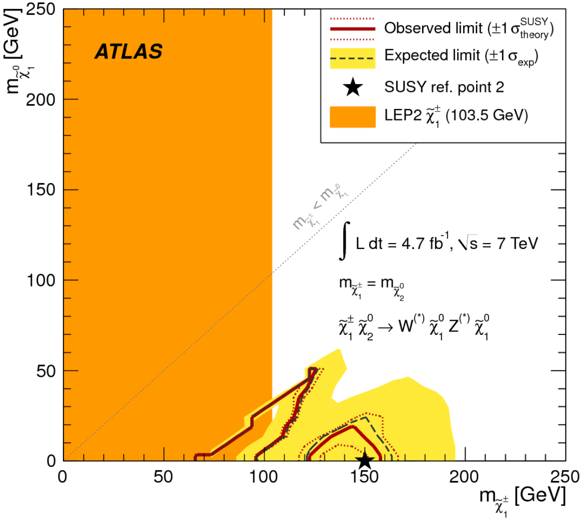
Backup: Simplified models

- Decay via sleptons (SR1b)



Backup: Simplified models

- Decay via gauge bosons (SR1a $\oplus$ SR2)



Backup: Trigger strategy

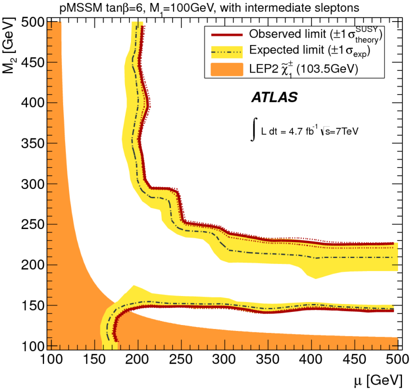
- Single and dilepton triggers used to select events in data
- Reweighting method applied to MC
  - Simple example: Trigger selects 75% of events in data
  - Two choices:
    - Apply trigger to MC $\rightarrow$ throw away 25% of MC events
    - Reweight MC events by 0.75 $\rightarrow$ keep all MC events (lower stat. error) but additional systematic error
- In reality, involved procedure to obtain trigger efficiencies binned in η and p_{T} (tag and probe)

Backup: Statistical procedure

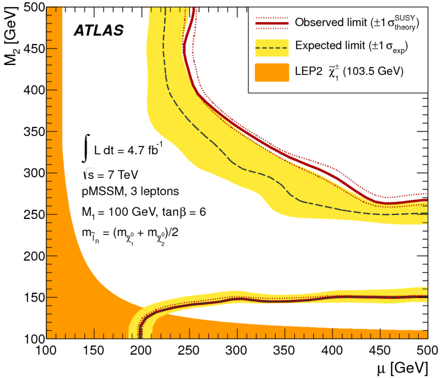
- Statistical and systematic uncertainties treated as nuisance parameters
- Local p-values calculated with toys and cross-checked using asymptotic formulae
- Correlated uncertainties accounted for in statistical combination
- WZ fit to data in a control region
  - $\approx 80\%$ purity
  - Normalisation factor of 1.25 ± 0.12 obtained
  - When setting limits, simultaneous fit to WZ in control region and signal region
  - Potential signal contamination in WZ control region accounted for

pMSSM: $M_1 = 100$

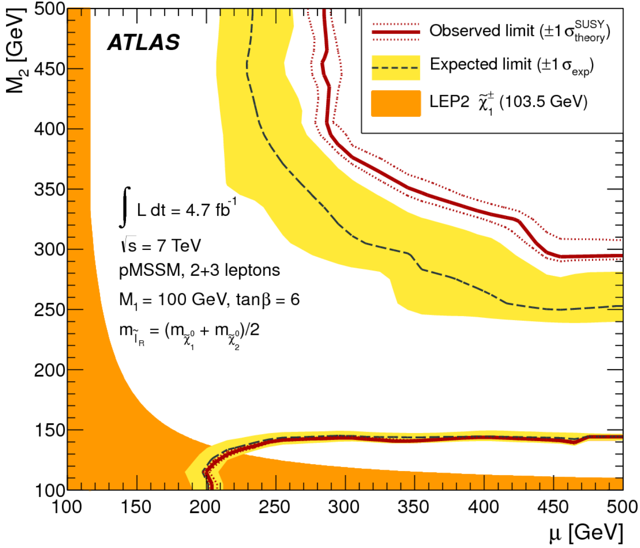
2 lepton



3 lepton

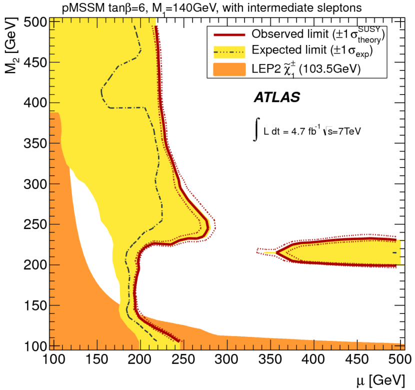


Combination

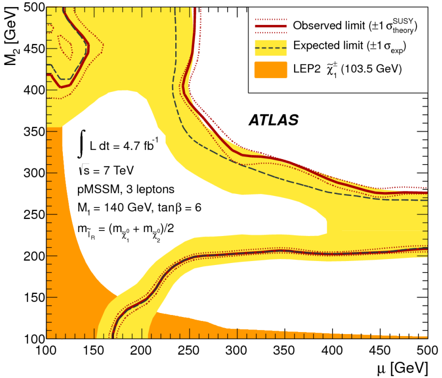


pMSSM: $M_1 = 140$

2 lepton



3 lepton



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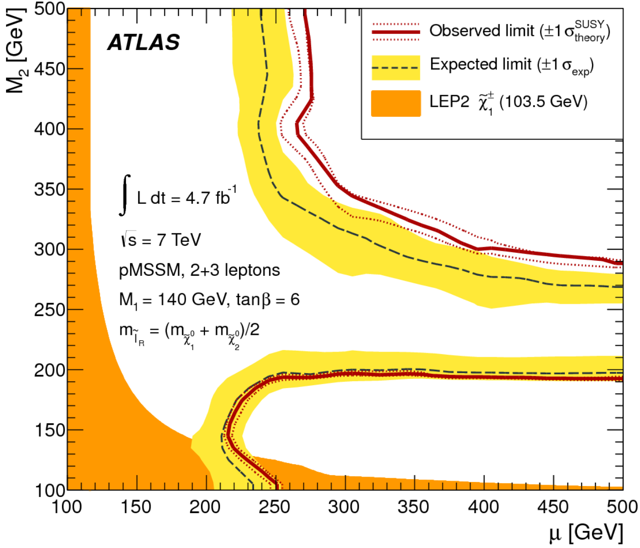
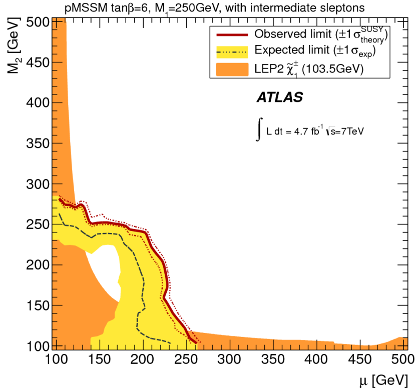
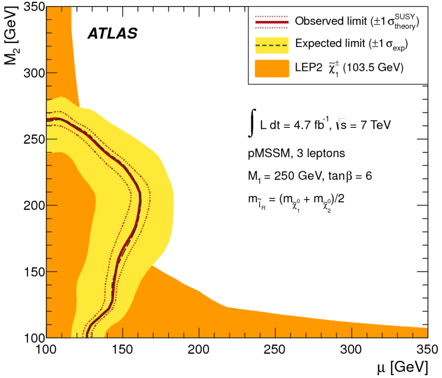


pMSSM: $M_1 = 250$

2 lepton



3 lepton



Combination