SUSY strategy in ATLAS

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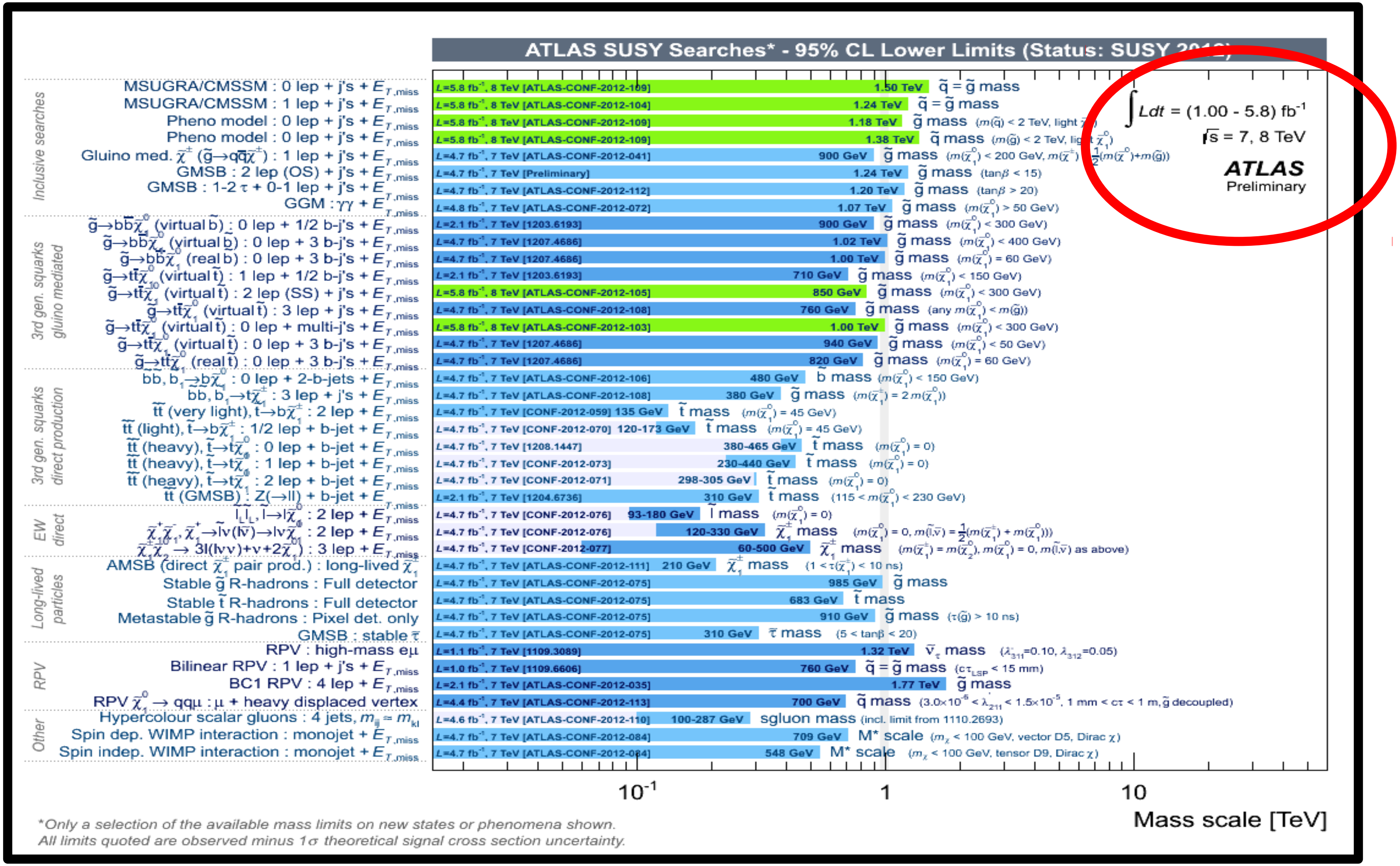
Where we were one year ago:

- In HCP 2011 results shown for typically 1 fb-1, in some cases 2 fb-1. Addressed Etmiss channels:
  - Strong production of squarks and gluinos
    - Fully inclusive analyses requiring Jets, Etmiss (+ leptons, photons) interpreted in:
      - Constrained models (cMSSM, GMSB)
      - Simplified models
    - More complex decays: require b-tagged jets among jets
      - Gluino decays to sbottom/stop real or virtual
  - First studies of direct production of lighter sparticles
    - Direct sbottom

What we said we would do

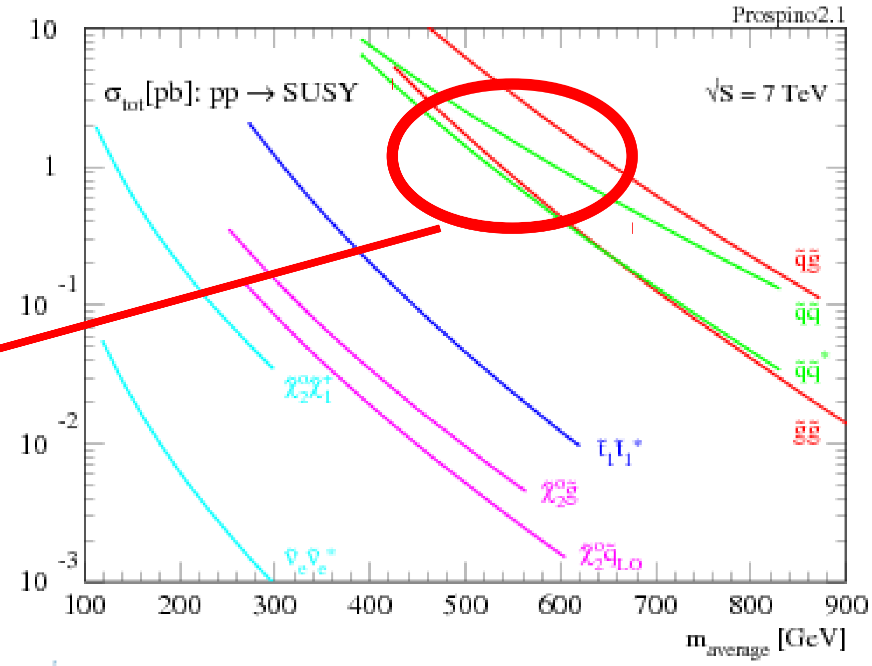
- Further exploration of high-mass sparticles with inclusive searches using additional statistics.
- Focus on sectors uncovered in first exploratory analyses:
  - Remove/reduce kinematic limitations in inclusive analyses:
    - Compressed spectra
      - softer signatures
      - Exotic signatures (long lived particles)
      - ISR
    - Complex decay chains (multijets)
    - Additional signatures: e.g. taus
  - Explore consequences of 'Natural spectra'
    - Gluino-mediated 3rd generation
    - Direct production 3rd generation
    - Direct production EWkino

How did we implement this program

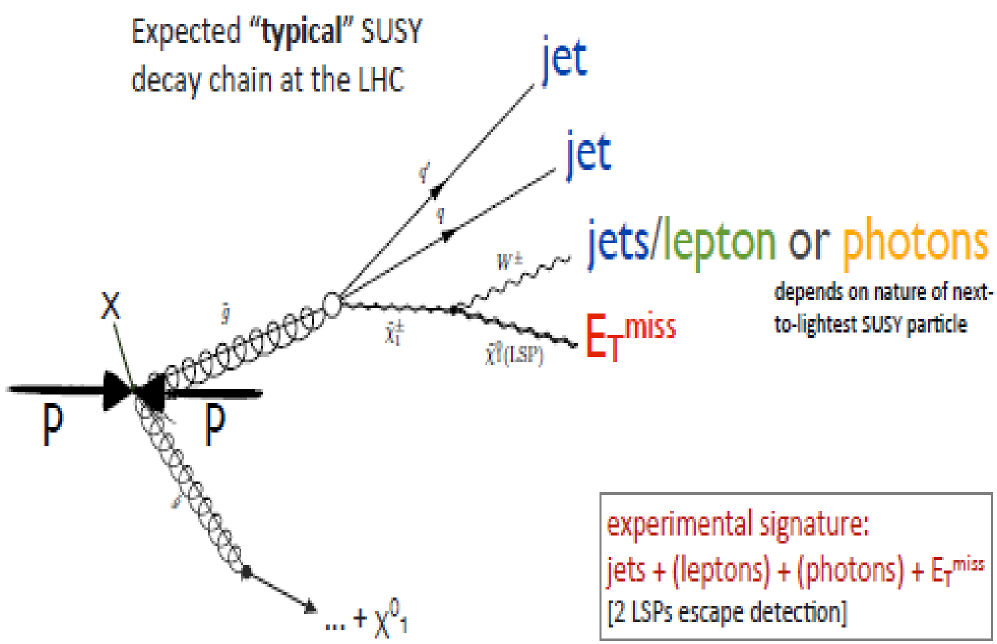


Today guided tour to the Etmiss results,
Wednesday Monica will talk about the Long Lived searches

Inclusive searches



Address highest cross-section processes,
Production of gluinos and squarks of first two generations
Aimed at sensitivity for highest masses

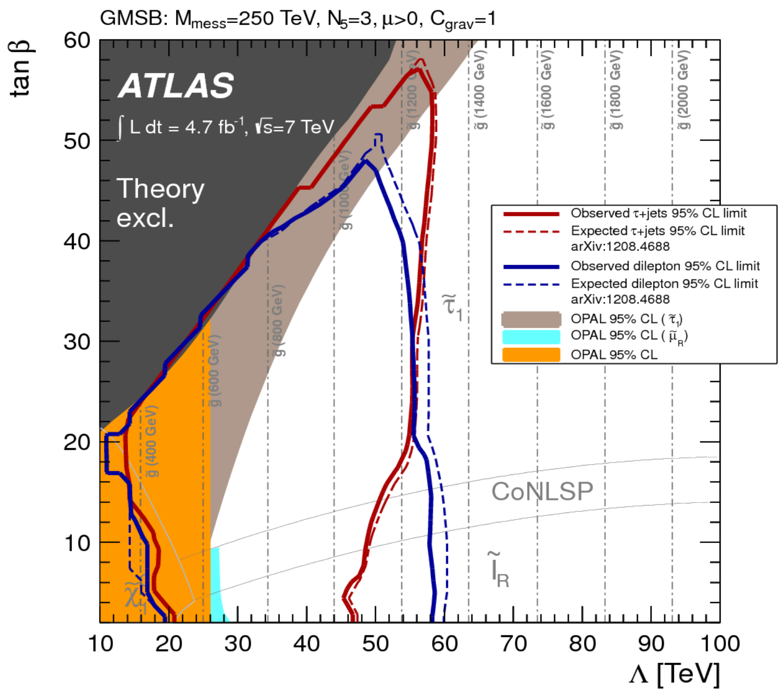


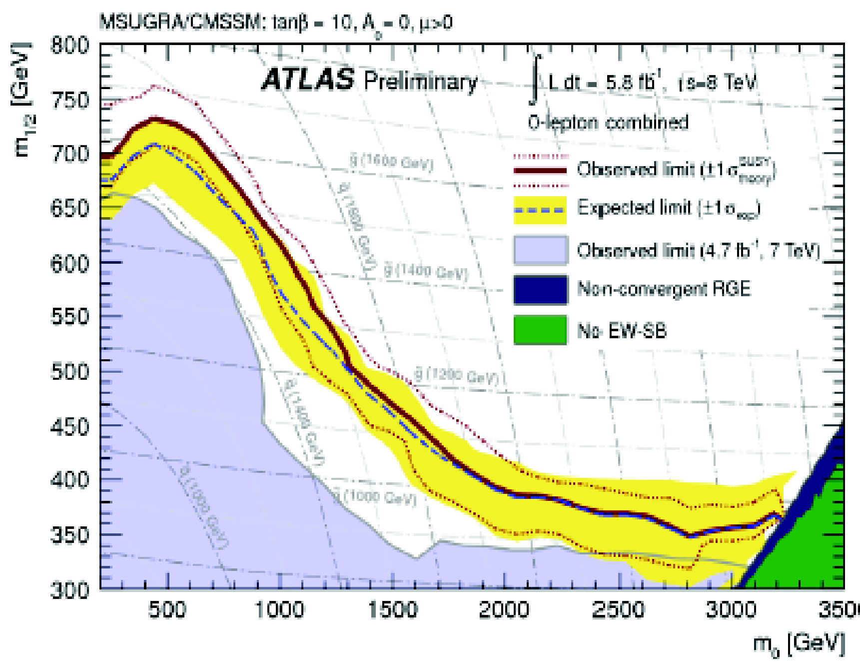
Exploit generic signatures:
- Jets from coloured sparticles
- Leptons from gaugino decays
- Etmiss from LSP

Interpretations in constrained models

GMSB searches requiring
2 photons + jets + Etmiss
(chi01 NLSP)
Tau (s)+jsts+Etmiss
(stau NLSP)

MSUGRA/CMSSM
Maximum sensitivity for
Searches requiring Etmiss jets
And no leptons

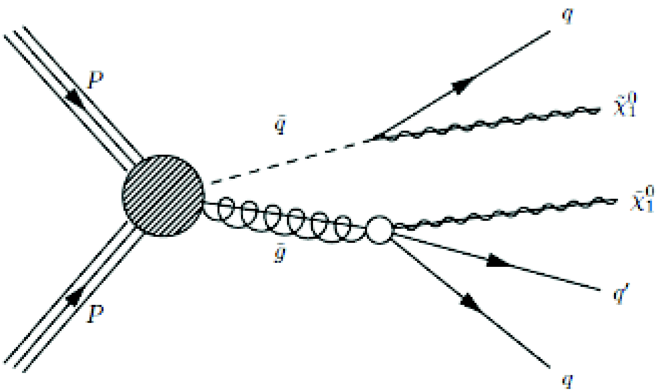


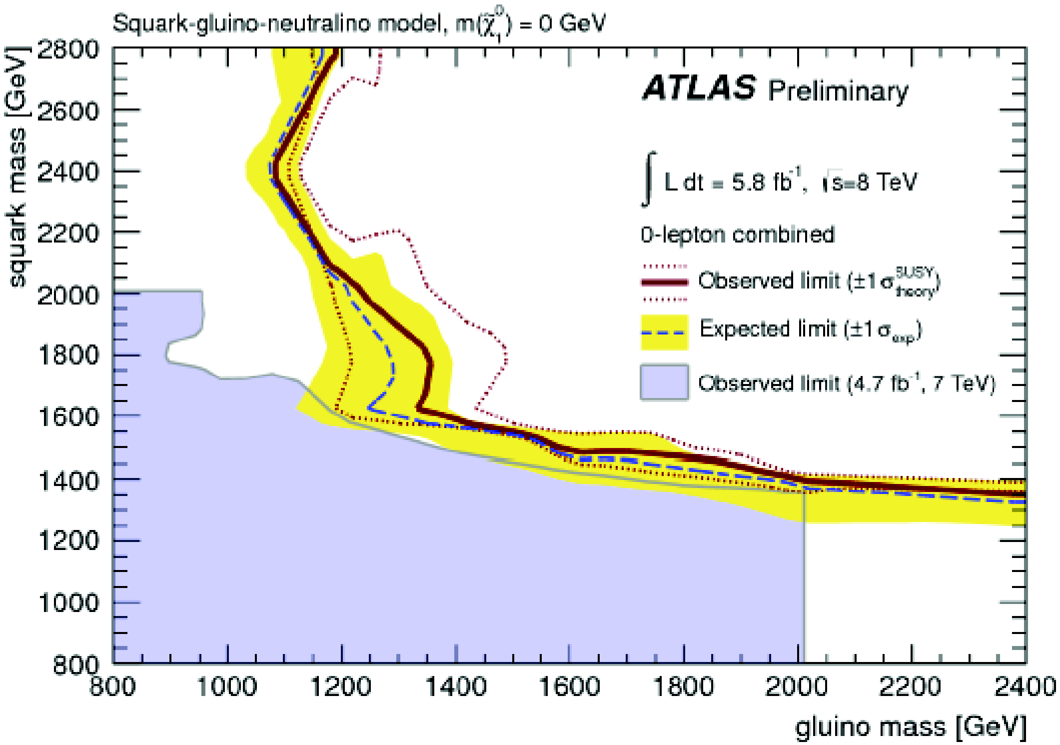


'Simple' squark-gluino decays

Search channels:

1. veto leptons + E_T^{miss} + ≥ (2-6) jets
2. veto leptons + $E_T^{miss}/\sqrt{H_T}$ + ≥ (6-8) jets

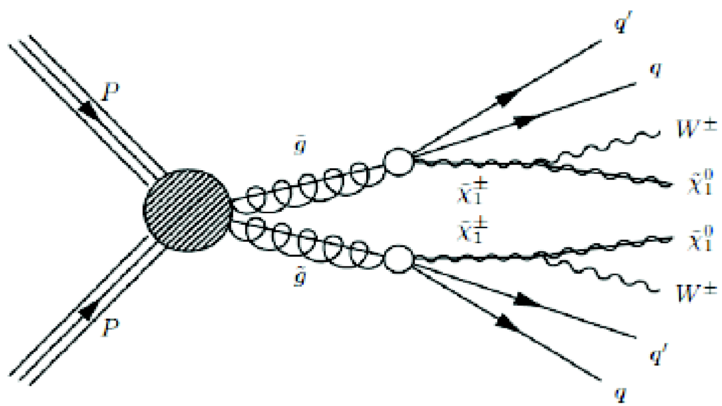




Interpret in model with only Gluinos, squarks and the LSP

$M_{sq} \gtrsim 1.3$ TeV, $M_{gl} \gtrsim 1$ TeV

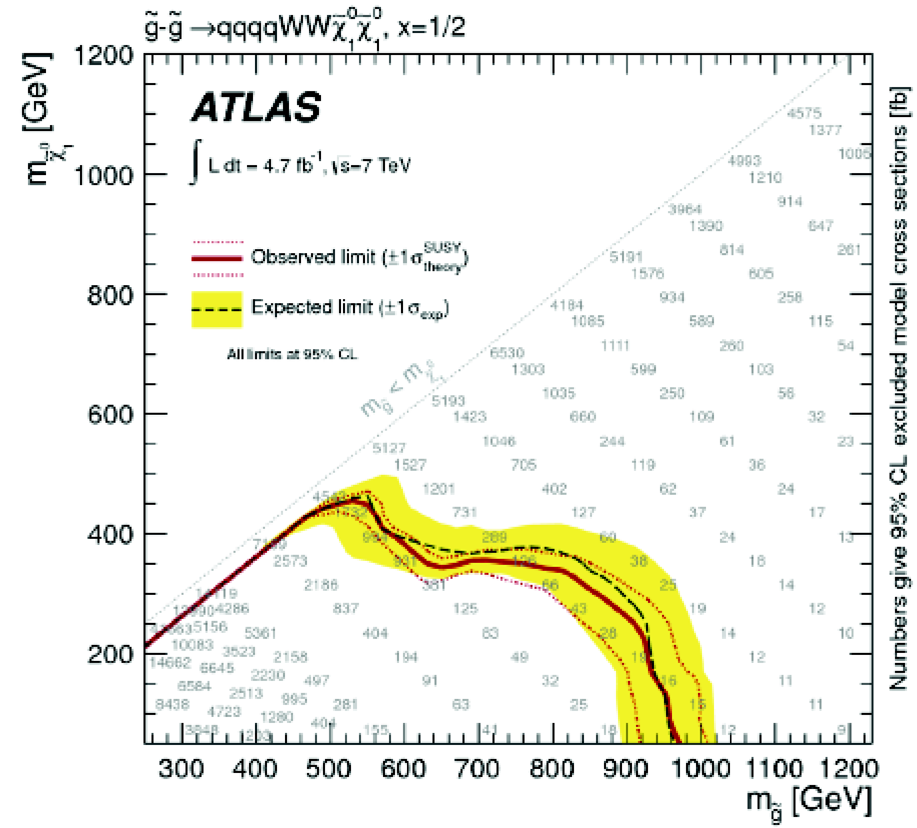
One additional step



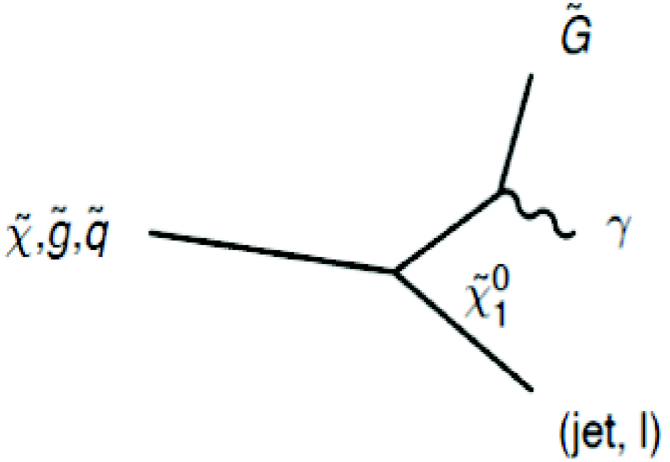
Complicate the model adding
a light chargino
Leptons appear in decay chain

Channels:

1. one (el or mu) + E_T^{miss} + ≥ (3-4) jets
2. one soft (el or mu) + E_T^{miss} + ≥ 2 jets
3. two leptons + E_T^{miss} + ≥ (2-4) jets

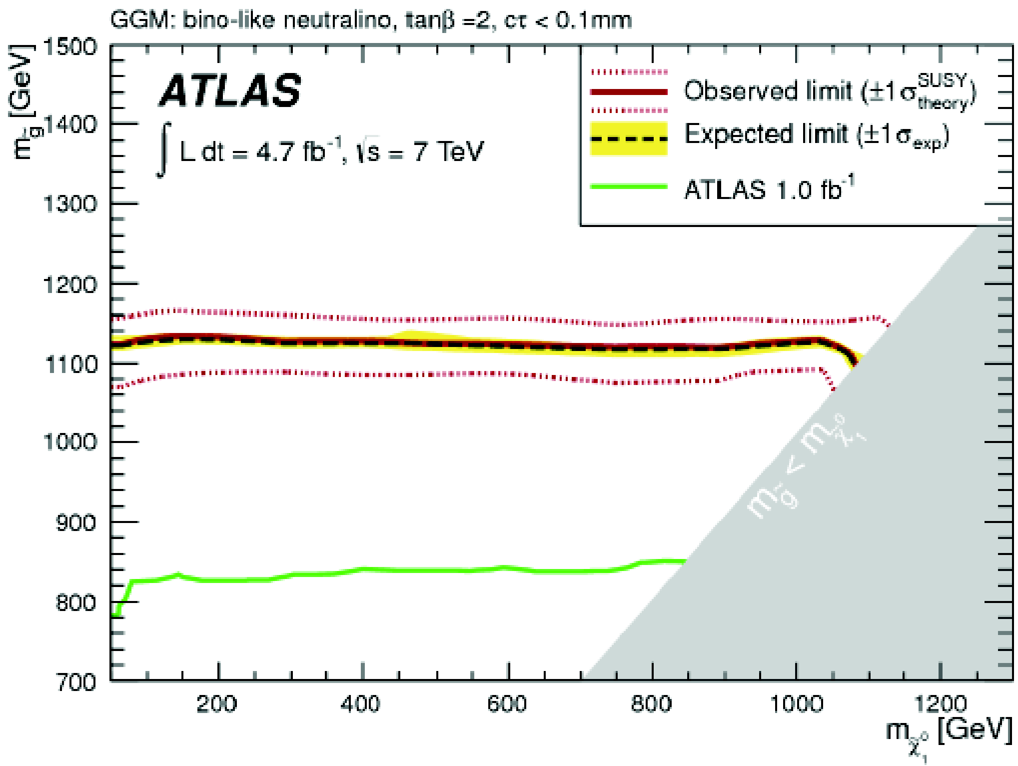


Add one photon at the end of chain



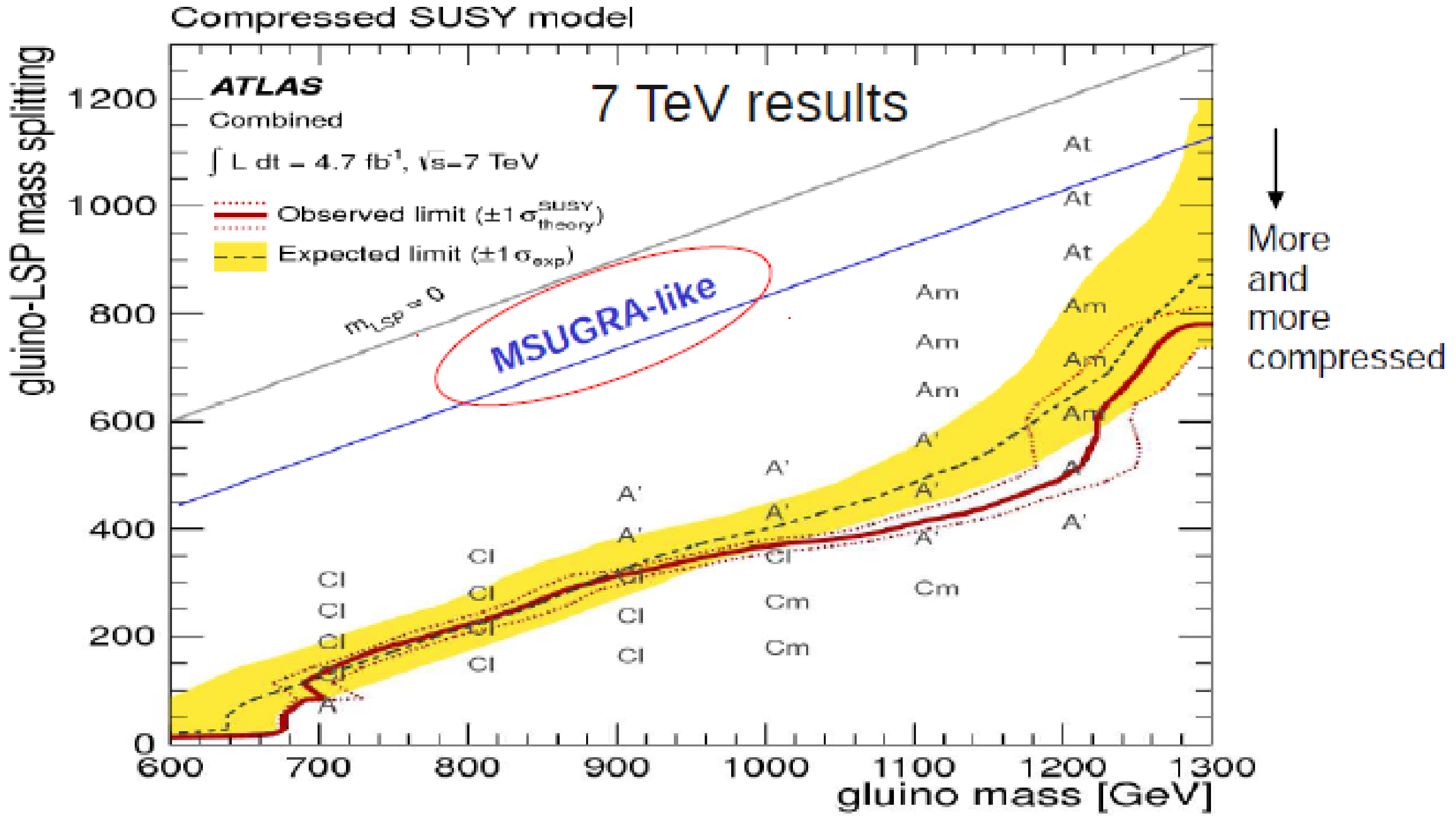
With gravitino NLSP phenomenology driven by nature of NLSP

With chi01 NLSP
Expect two photons for each SUSY events
(or Zs or higgs, depending on chi01 decay pattern)



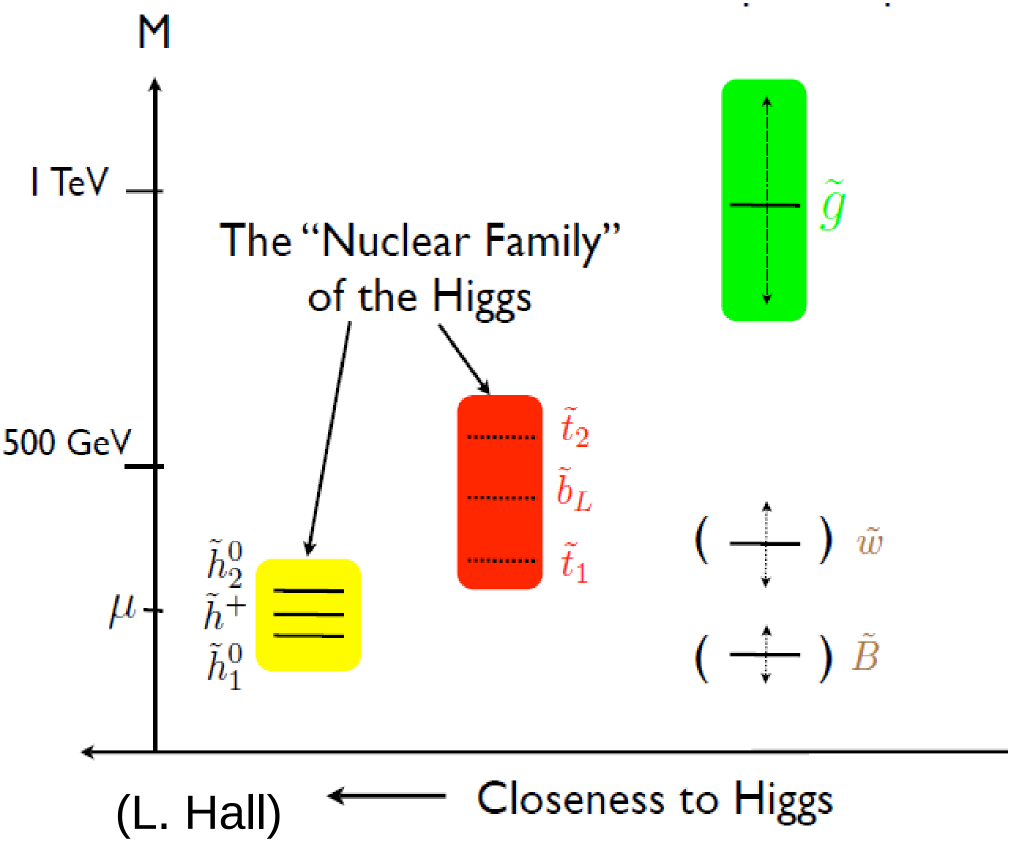
Compressed models

Models with compressed scenarios DM/MSUSY from 0.85 to 0.15



Signal regions based on softer cuts allow to go to lower DM

'Natural' SUSY



Start with separate study of topologies, mass hierarchies

When program advanced enough study the interplay of different searches Inside 'realistic' models

Assume other squarks too heavy
Three steps:

- Search for gluino decay through real/virtual 3rd generation quarks
  - b-jets in decay
  - high multiplicity

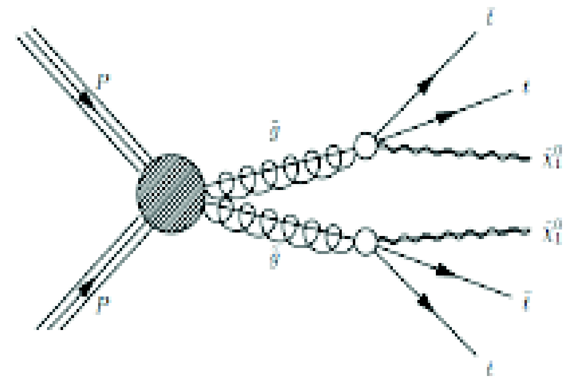
- Search for direct production of stop/sbottom
- Try to cover all possible phenomenology (9-parameter space!)

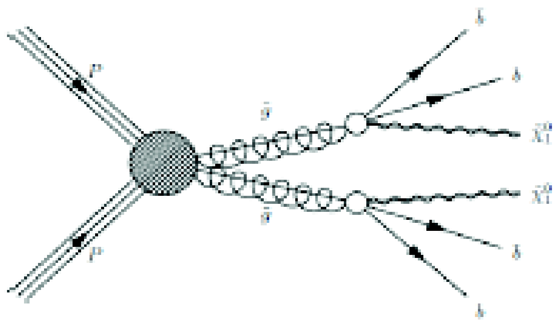
- Search for direct production of Ewkino (4 parameters + slepton sector)

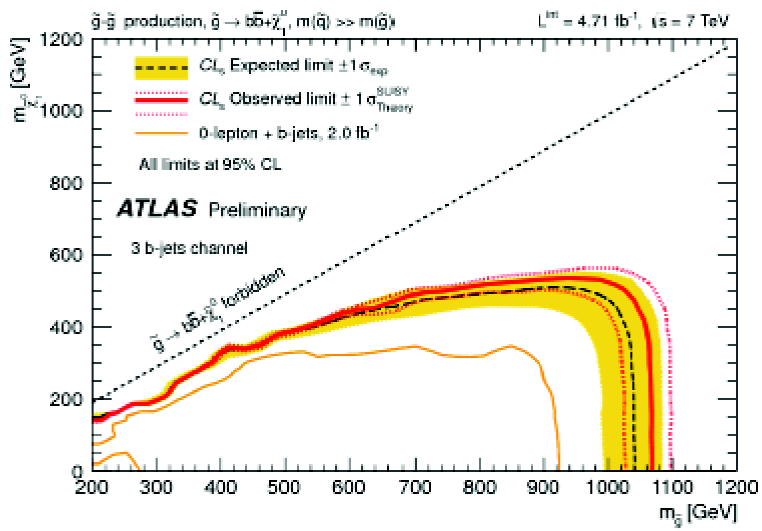
Gluino-mediated stop-sbottom

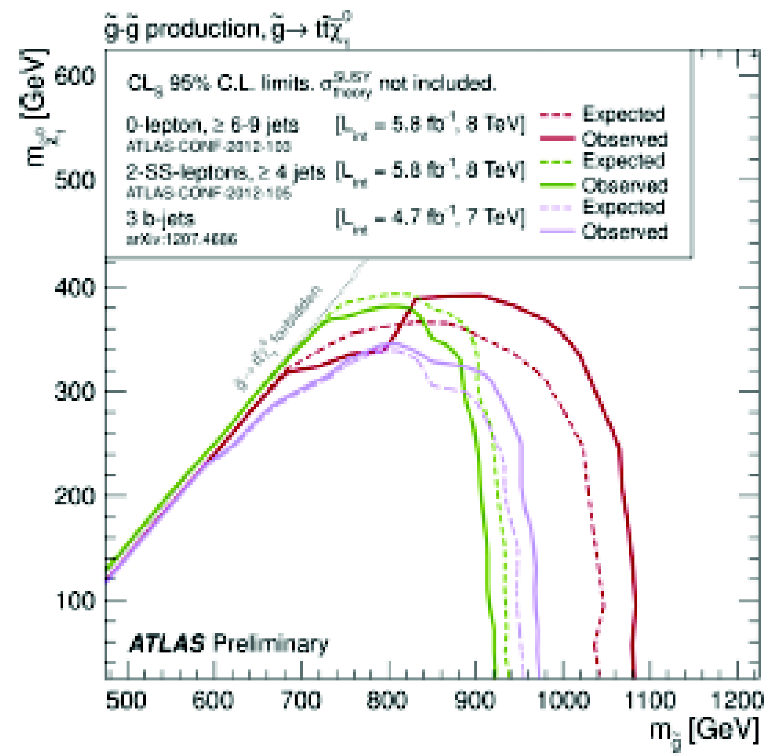
Search channel:

1. veto leptons + E_T^{miss} + ≥ (4,6) jets + ≥ 3 b-jets
2. veto leptons + medium E_T^{miss} + ≥ 6-8 jets
3. 2-SS leptons + E_T^{miss} + ≥ 4 jets







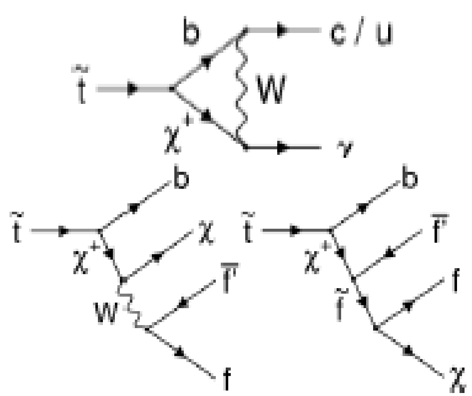


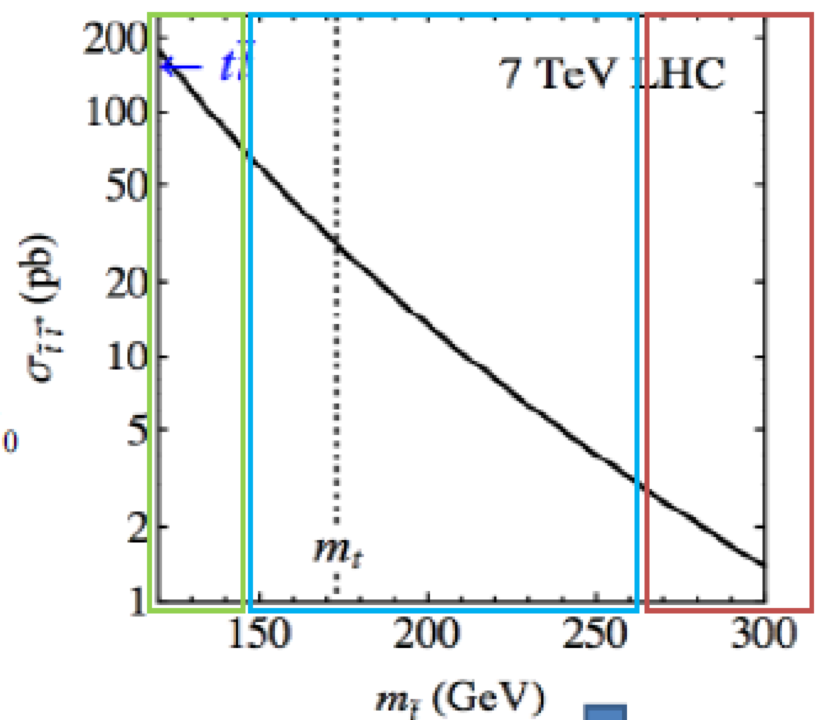
Stop decay phenomenology

Different decay modes depending on the mass hierarchy

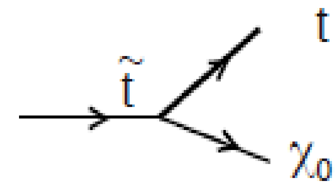
High cross sections, very similar to SM background

$$\tilde{t}_1 \rightarrow b\,\tilde{\chi}_1^{\pm} \rightarrow bW^{\pm}\tilde{\chi}_0$$
$$\tilde{t}_1 \rightarrow c\,\tilde{\chi}_0$$





Low cross section (2 pb or less), high mass: Mostly stop → top +LSP



$b + \tilde{\chi}^{\pm}$ and, where kinematically allowed, $t + \tilde{\chi}^{0}$

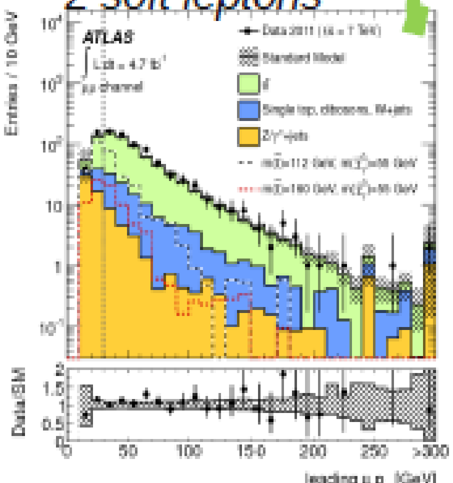
Need powerful discriminating variables to reject top BG

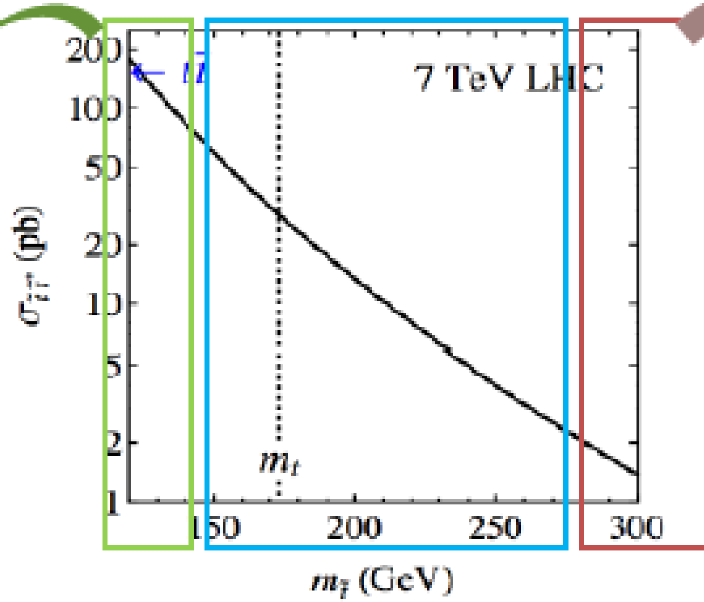
Searches at 7 TeV

- Five searches with 5 fb^{-1} (+ 1 in natural GMSB with 2 fb^{-1}) @ 7 TeV

$\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to bW^{\pm}\tilde{\chi}_0$

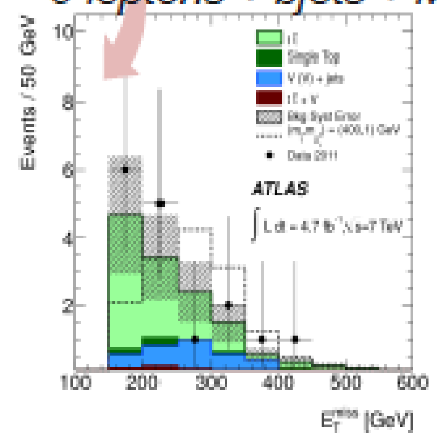
2 soft leptons



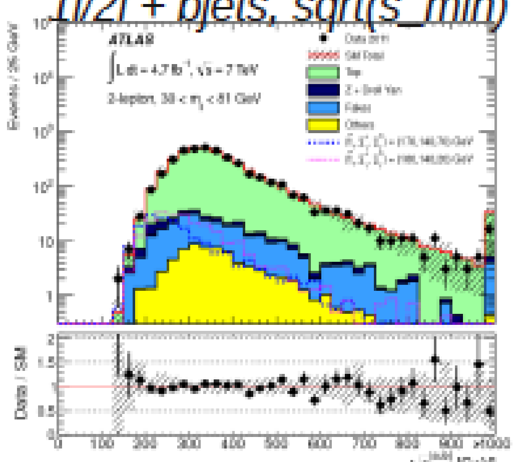


$t + \tilde{\chi}^0$

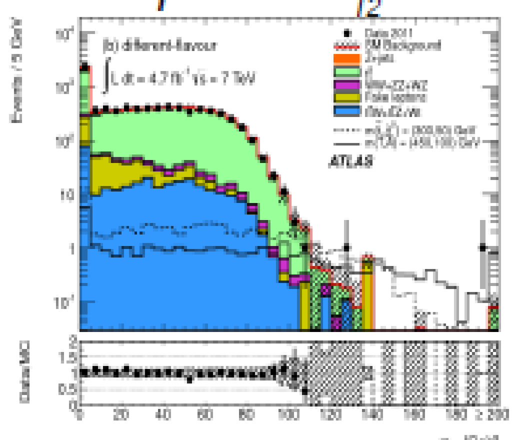
0 leptons + bjets + MET



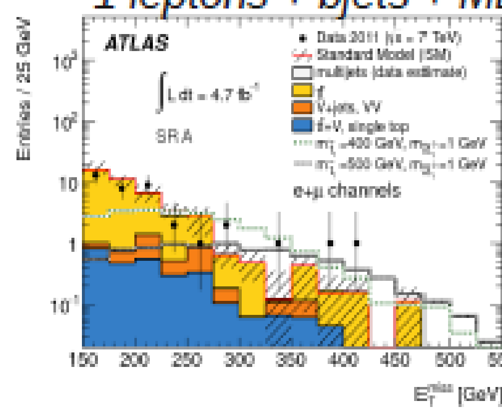
1l/2l + bjets, sqrt(s_min)



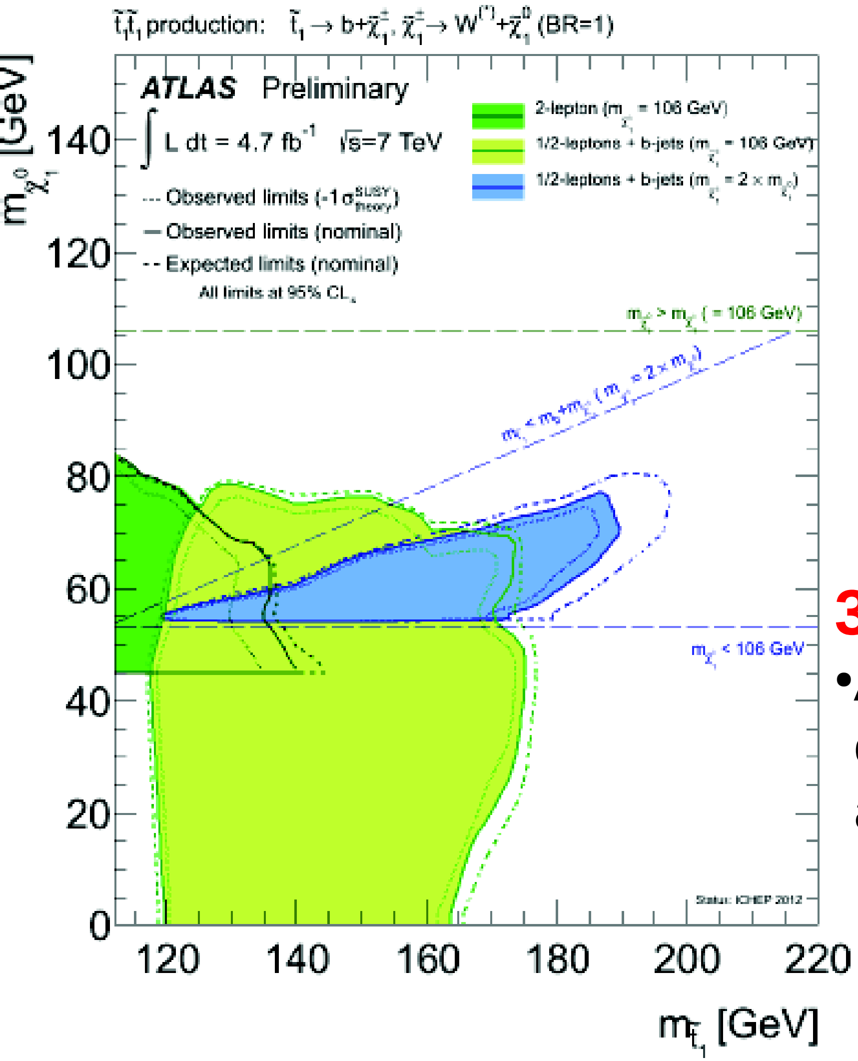
2 leptons + m_{T2}

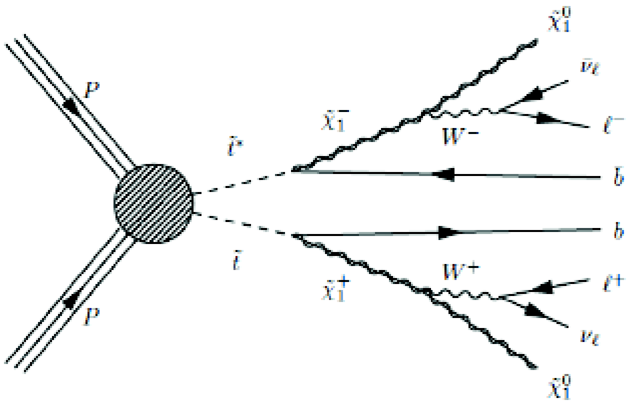


1 leptons + bjets + MET



Stop to chargino

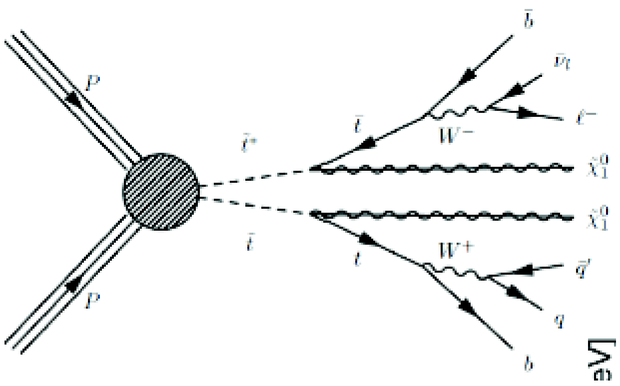


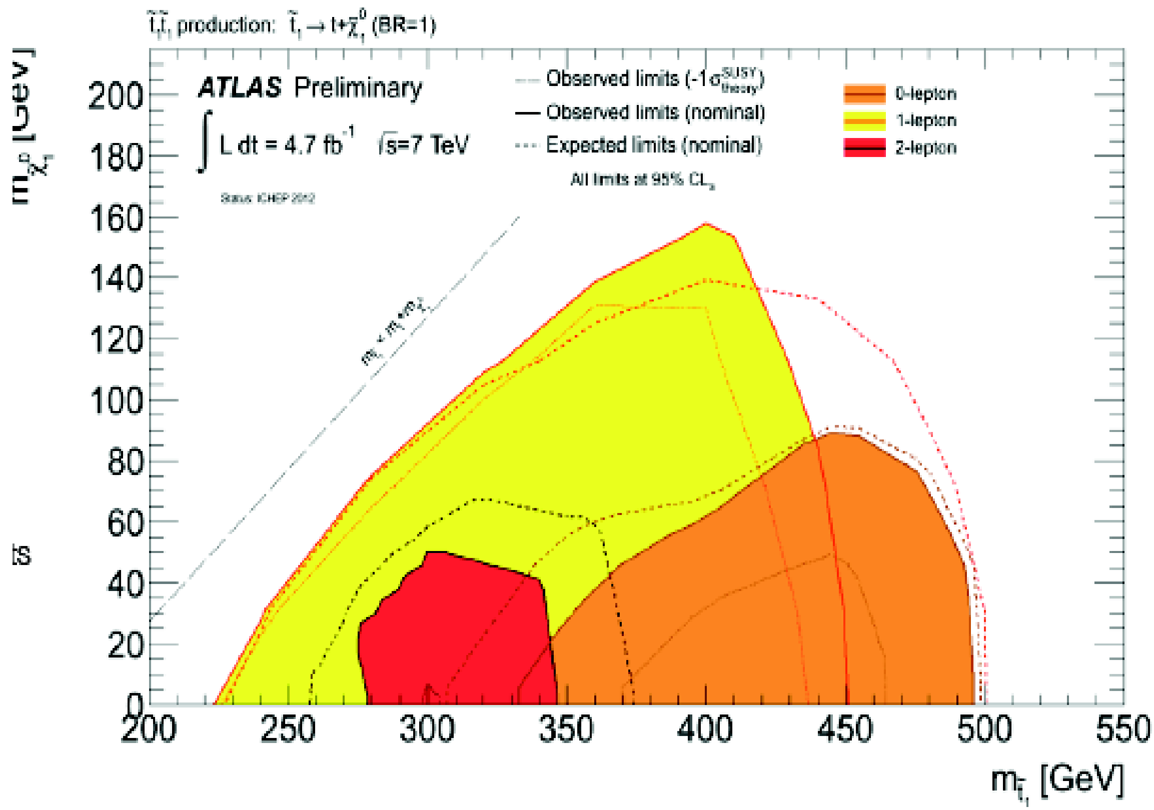


3-d mass space

- Analyses up to now concentrated on m(stop)<= m(top) with fixed assumptions on chargino mass:
  - m(chargino)=2m(chi01)
  - m(chargino)=minimum allowed by LEP

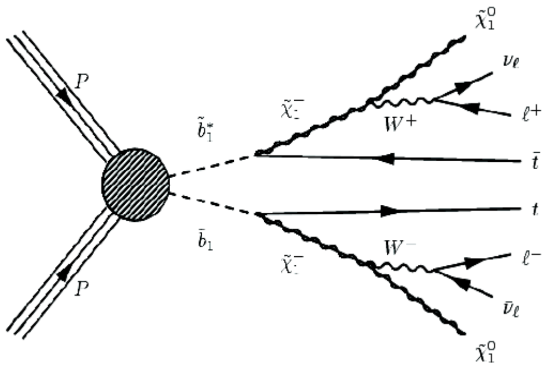
Stop to neutralino

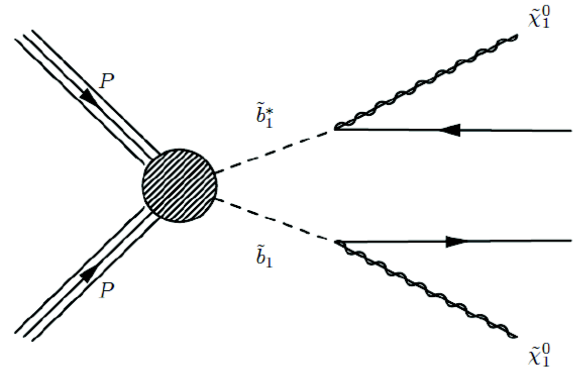


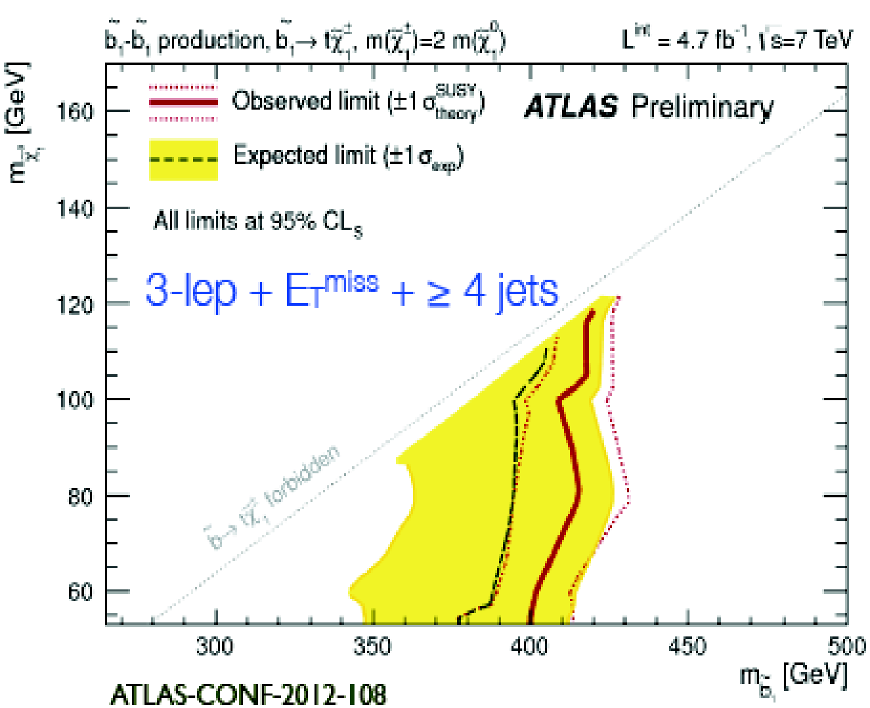


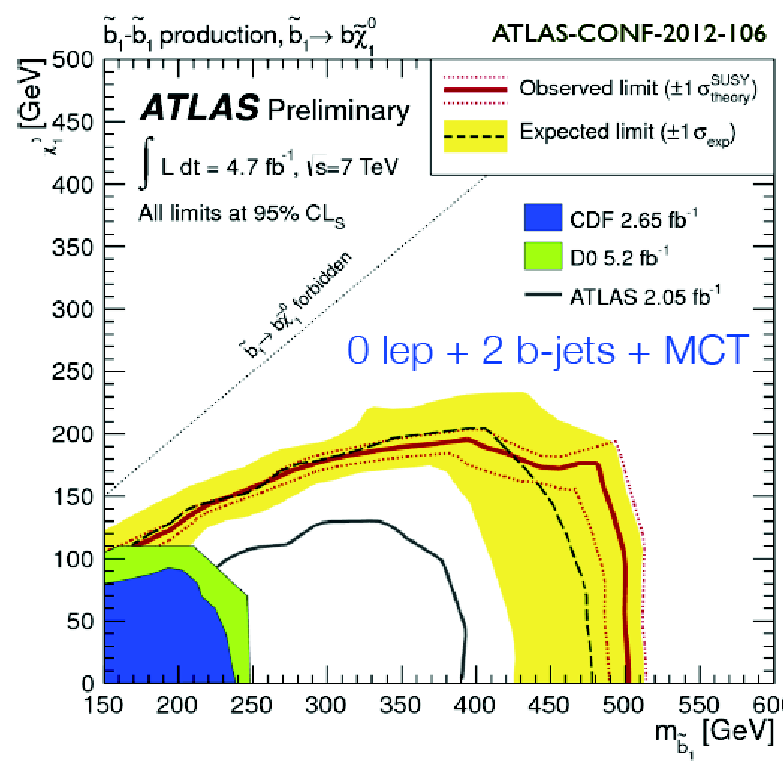
- Analyses addressing high mass
- Signature is tt+Etmiss
- Maximum discrimination power when chi01 is approximately massless
- As m(stop)-m(top) approaches m(chi01) experimental signature becomes identical to tt

Direct sbottom

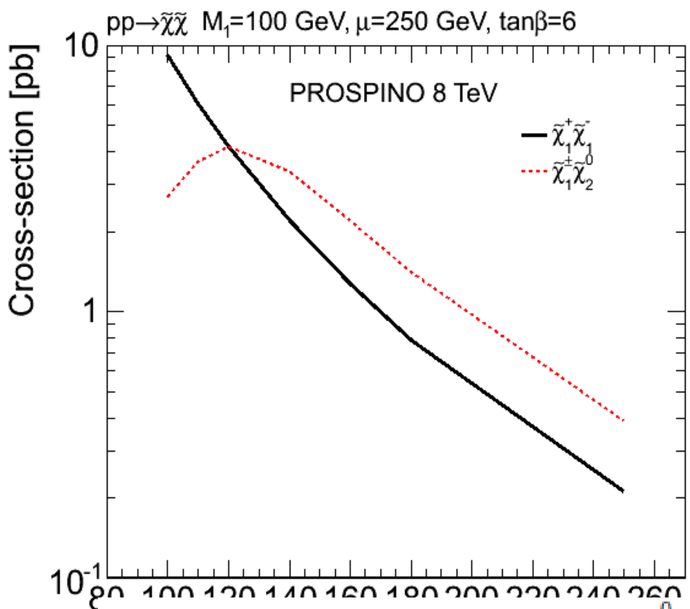






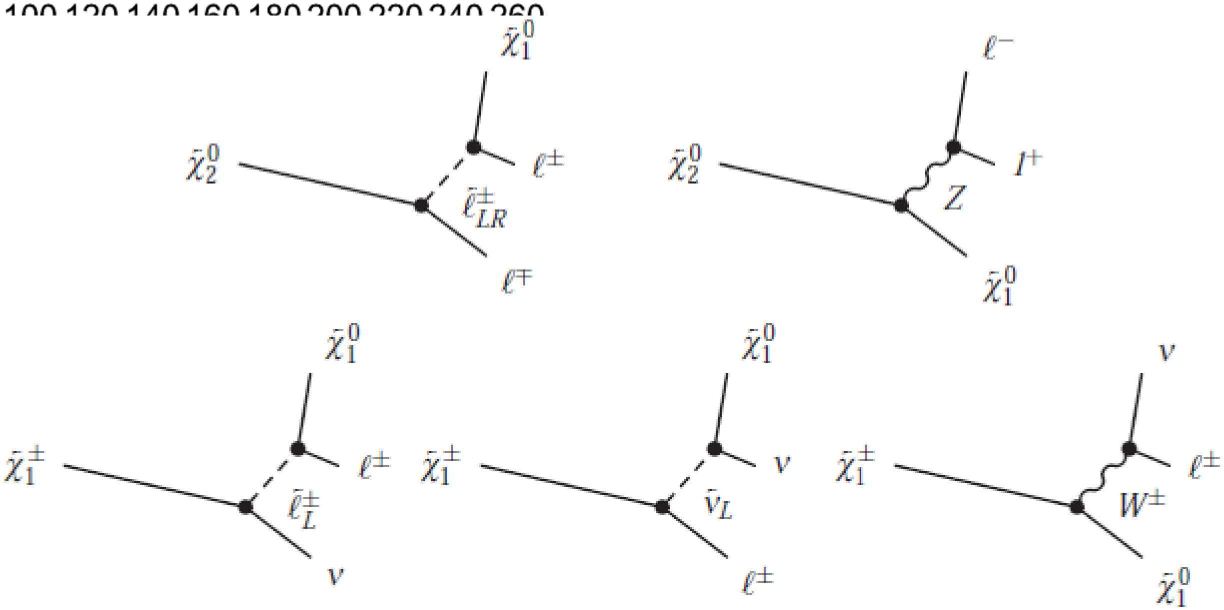


Electroweak production



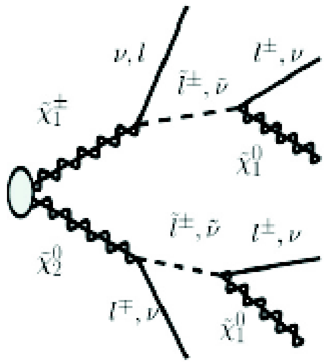
Low cross-section processes
If squark mass high, production
Cross-section depends on
M_1, M_2, μ, and mildly on tanβ

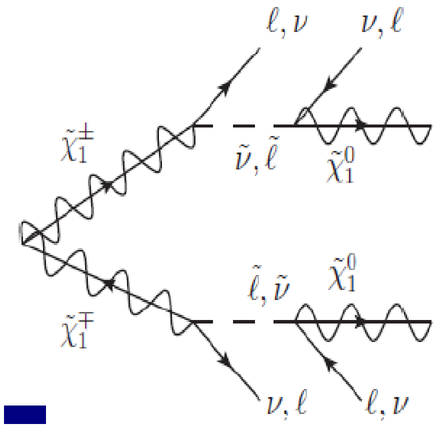
Concentrate on multilepton decays:
2 or 3 leptons

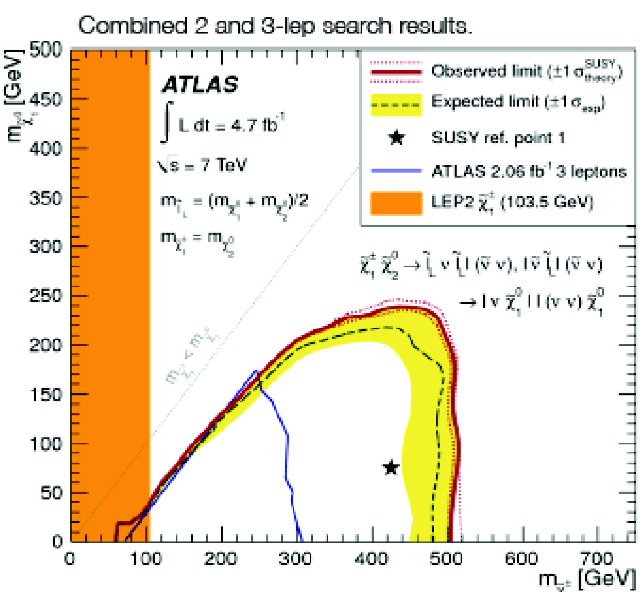


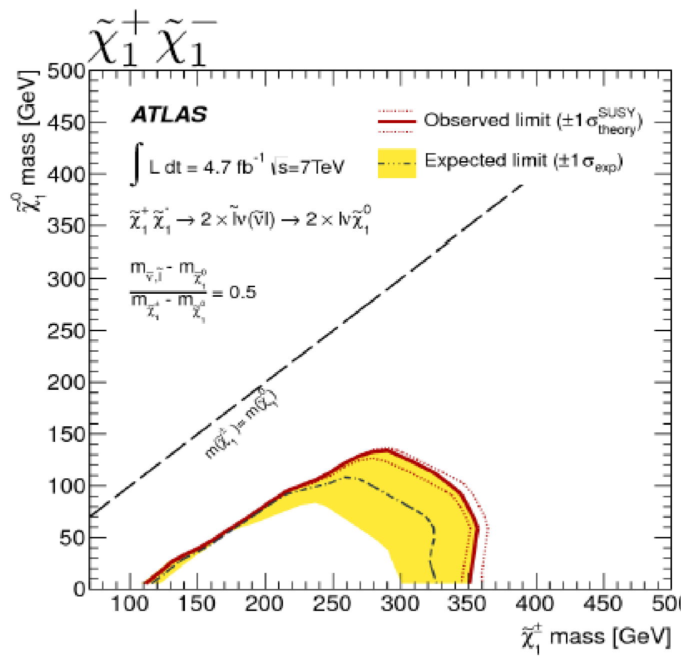
Electroweak production

If sleptons are light enough to be relevant in the decays ow EWKinos



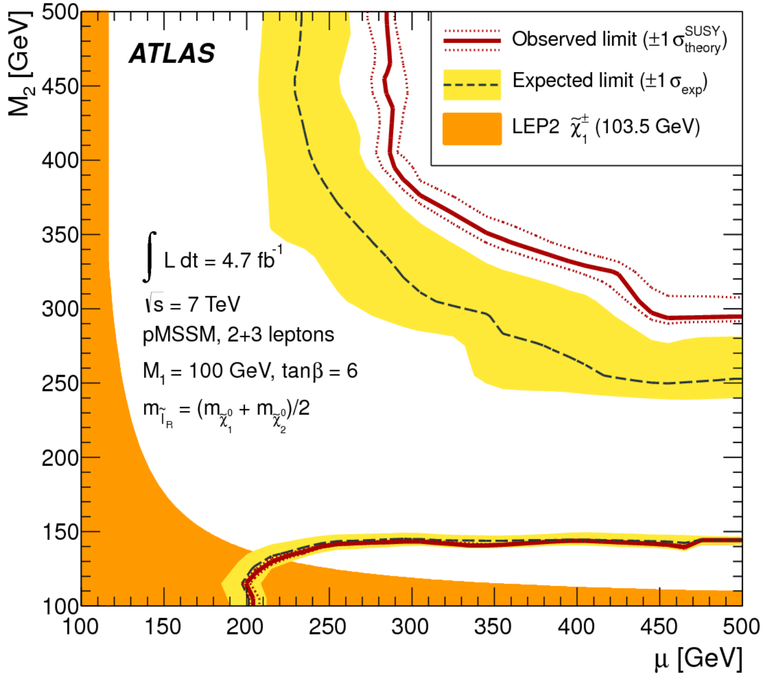


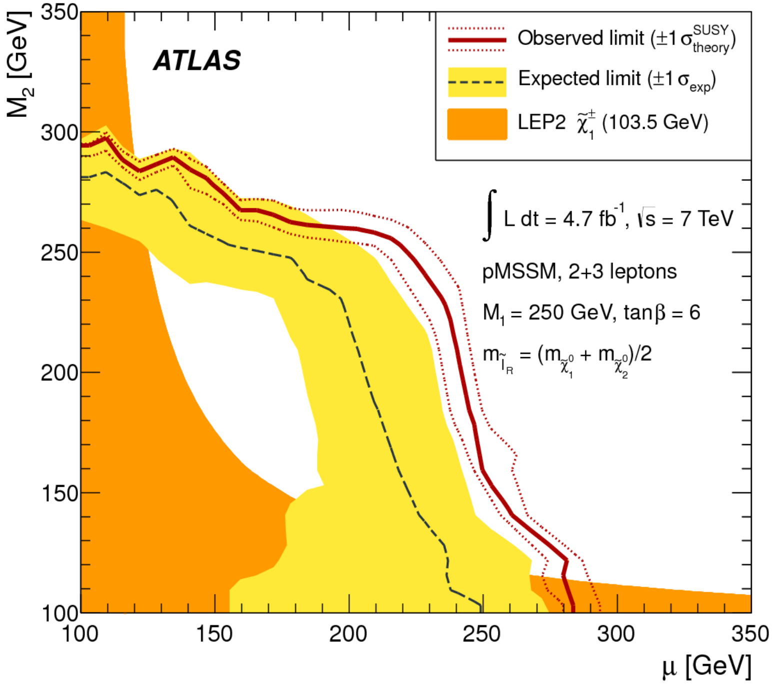




Electroweak production in MSSM parameter space

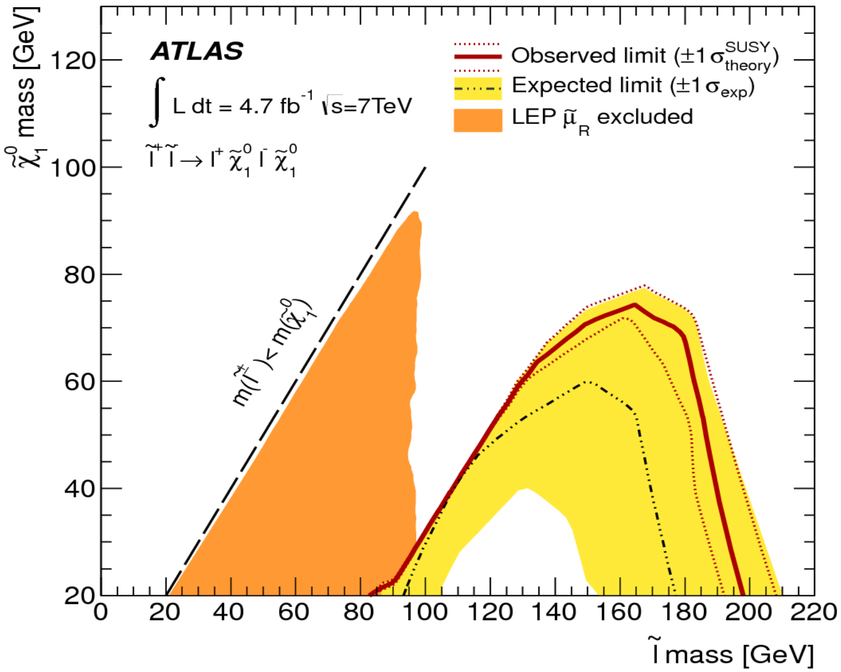
The result of the 2 and 3-lepton search for chargino neutralino Production can be cast as a limit in the pMSSM (μ,M_2) plane for fixed values of M_1





Electroweak production

But slepton direct searches may push sleptons higher
(but mind the large gap between Slepton and chi01)

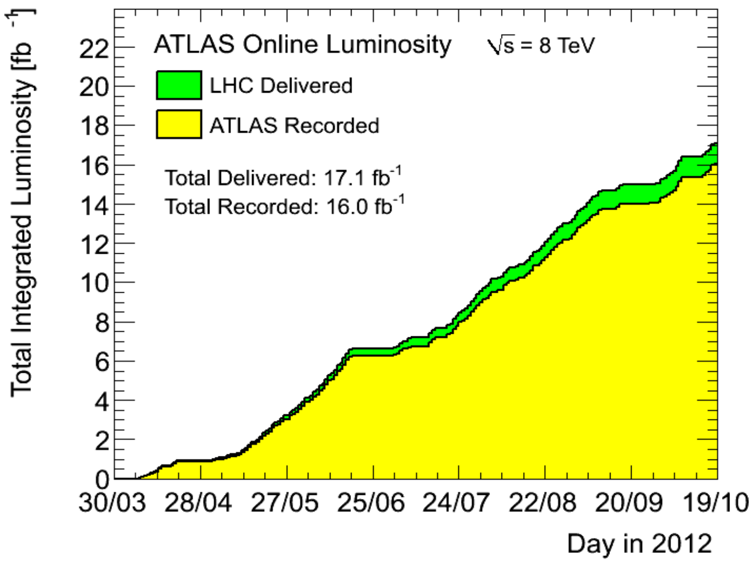


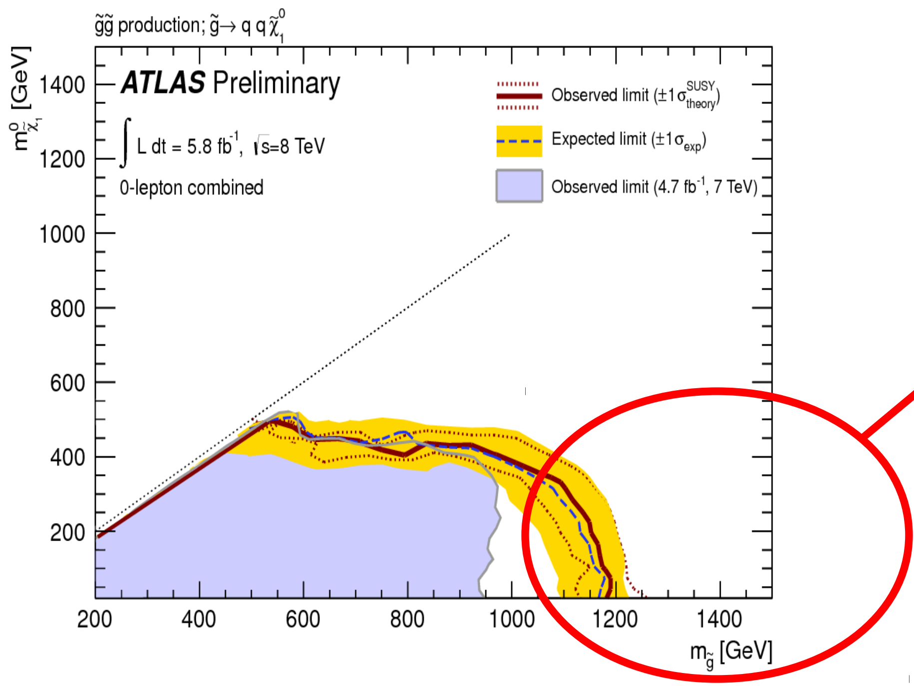
If leptons do not appear in decays, need to factorize in Br's into leptons of W and Z:
0.22*0.22=5% for $\chi^+\chi^-$ to 2 leptons
0.22*0.066=1.5% for $\chi^\pm\,\chi_2^0$ to 3 leptons

Need lots of statistics...

What Next?

8 TeV luminosity collected to date 16 fb^{-1}
Order 25 fb^{-1} by the end of the year
Inclusive analyses should
push sensitivity to first two generations
and gluino in the 1.5-1.8 TeV region





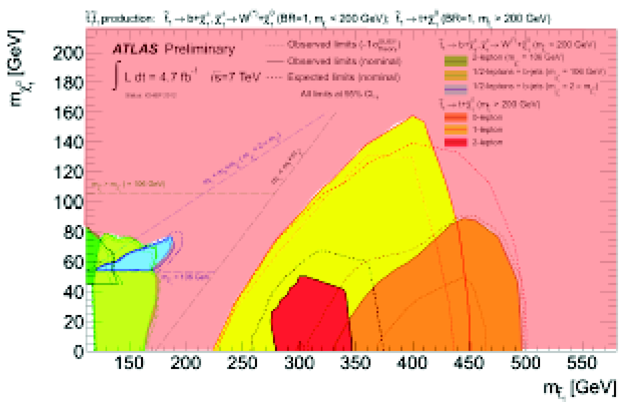
Natural extension of present searches,
Also eagerly awaited by theory colleagues

What next: 3rd generation

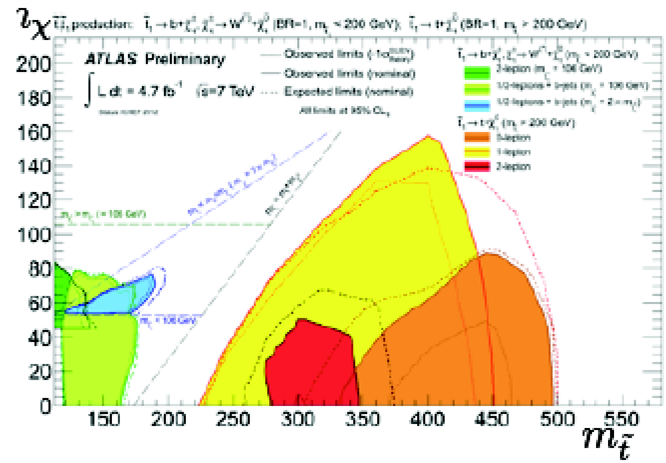
Several theory talks asking us to close the 'holes' in our stop plot

- This year
  - Fill the stop gap

OR right-plot plane fully explored



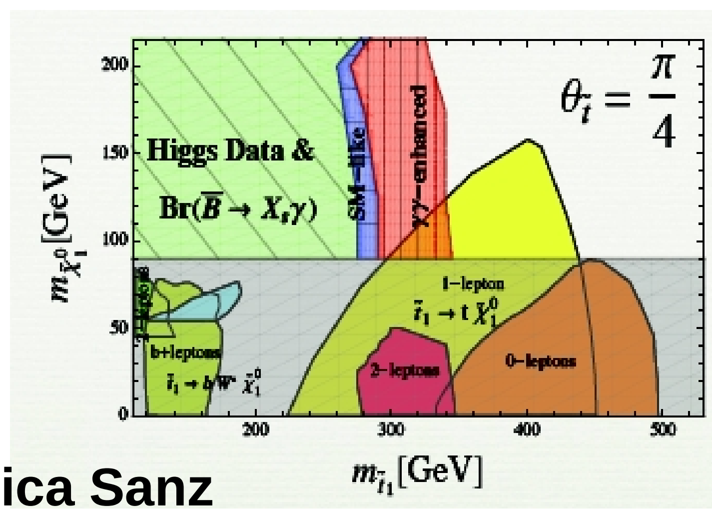
Savas Dimopoulos



Riccardo Barbieri

We will oblige, developing ideas for it

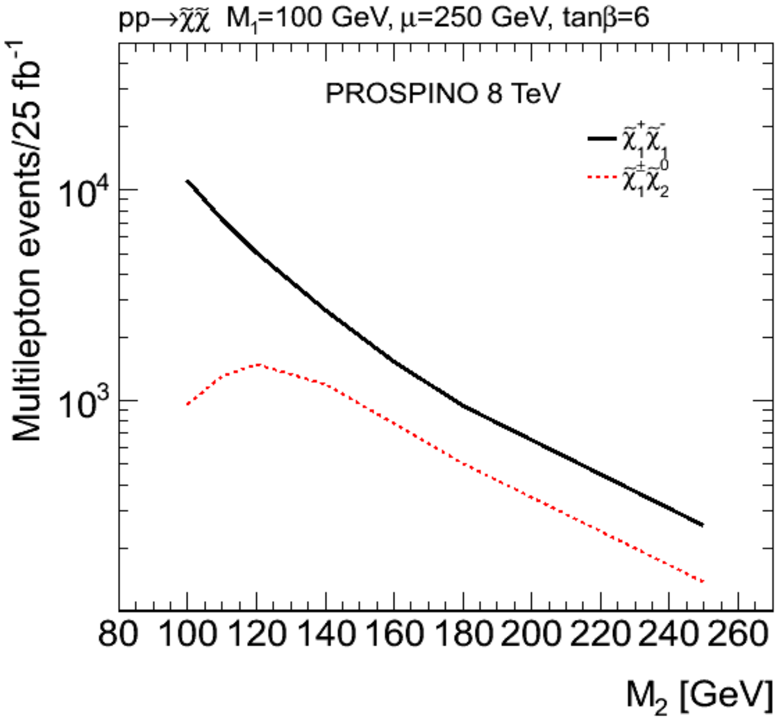
Also interesting to take into account
Interplay with other searches



Veronica Sanz

What next EWK

8 TeV and >20 fb^{-1}: can attack seriously parameter space without requiring sleptons in the decay chain



2-300 multilepton events before any cut for M_2=250 GeV

For gaugino decay through W/Z(*)

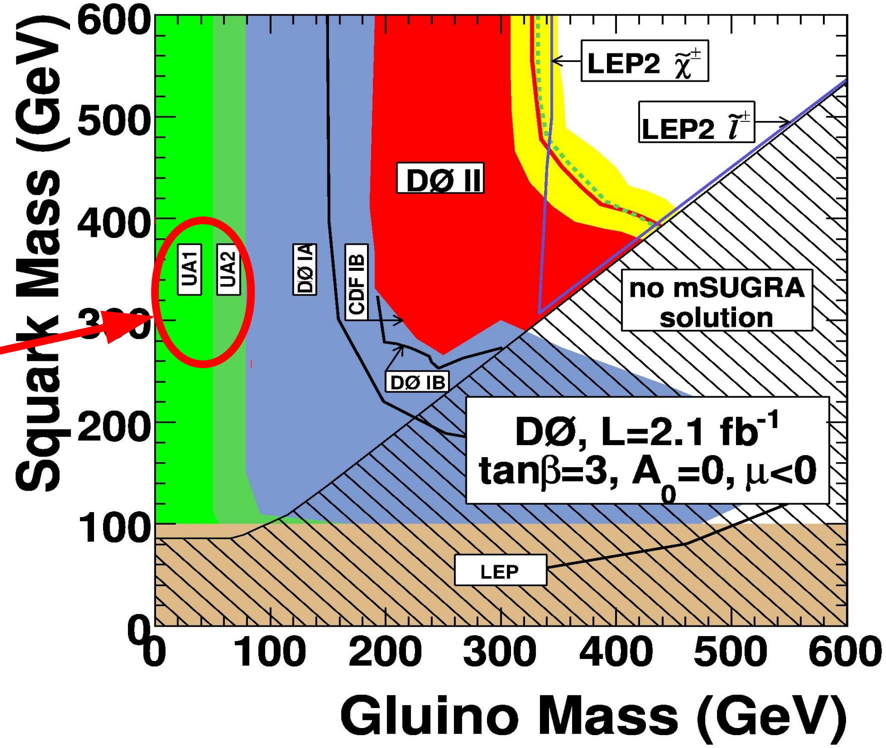
Conclusions

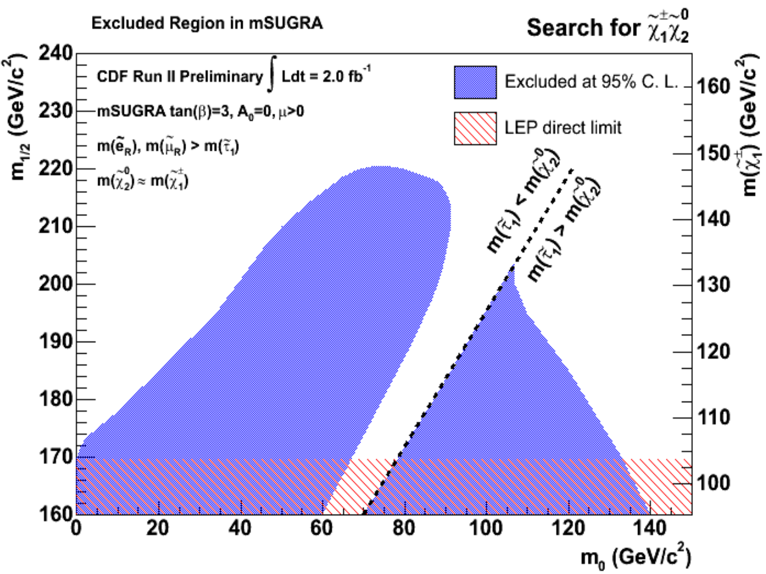
- During 2012 ATLAS has completed the analysis of 2011 data at 7 TeV and shown the first 8 TeV results
  - We extended limits on first two generations
  - We eroded in quite a bit of the available space for a light stop squark
  - First results on EWK production
  - Lot or results on exotic/degenerate models with long lived particles → **see talk by Monica**
- Plan for 2013 is to extend these results based on the approximately five-fold increase of statistics at 8 TeV, hoping to finally find something!
- After this we have two years for playing with these data
  - What are the analysis we may think of doing after the first run-trough of 2012 statistics?
  - How can we best use these data to prepare for 14 TeV run?

Backup

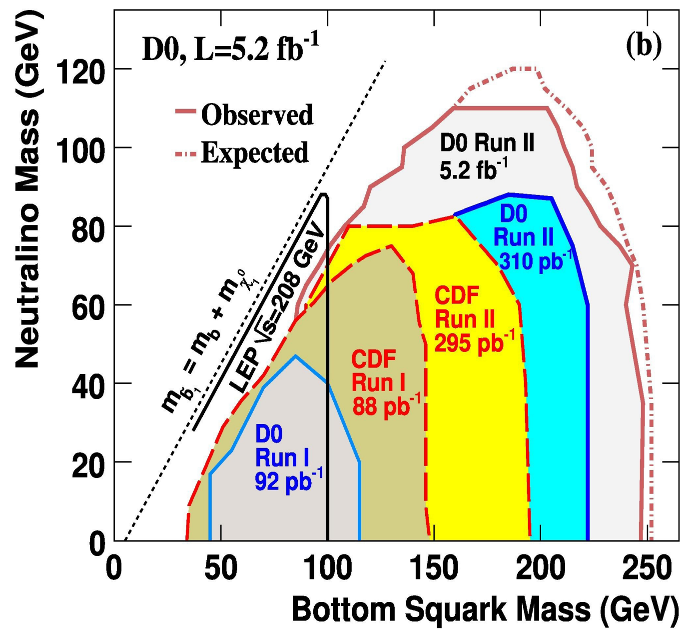
SUSY before LHC: Hadron colliders

Asymptotic sensitivity on squark-gluino production:
SppS : ~100 GeV (1989)
Tevatron: ~400 GeV
LHC 7 TeV: ~1.5 TeV (2012)



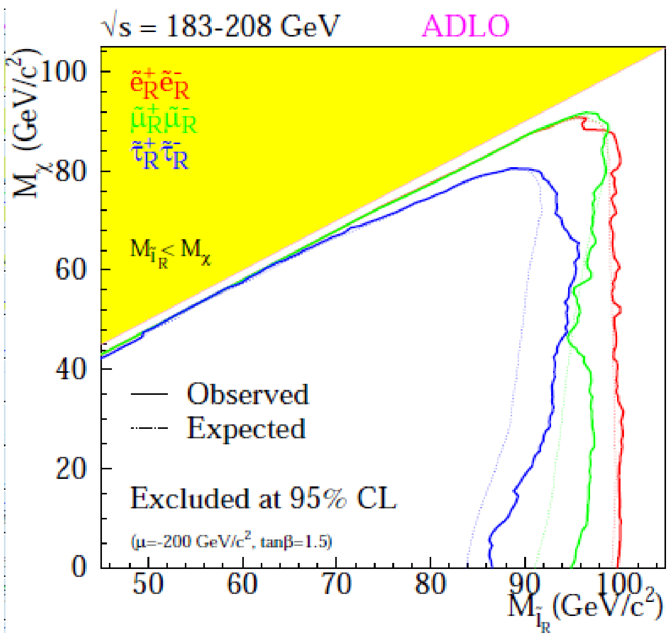


EW production of
Chargino-neutralino:
mSUGRA interpretation



Dedicated
3rd generation
searches

SUSY before LHC: LEP

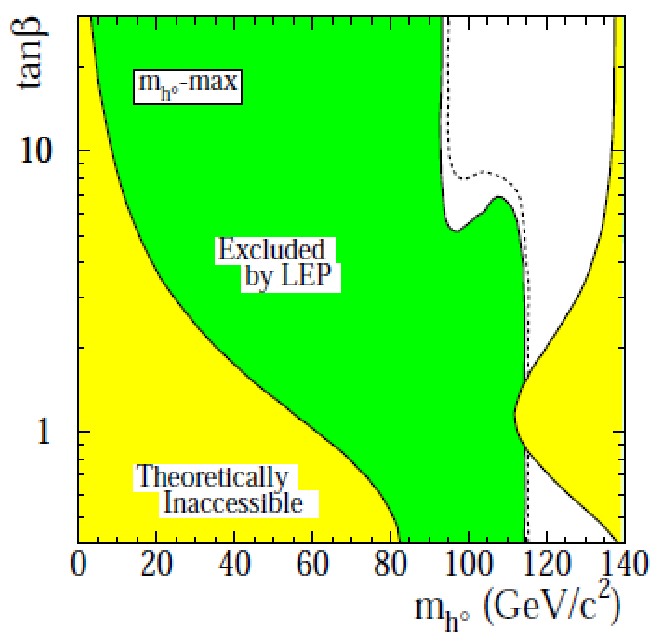


Model-independent limits of ~100 GeV on all sparticles coupling to the Z, in particular:

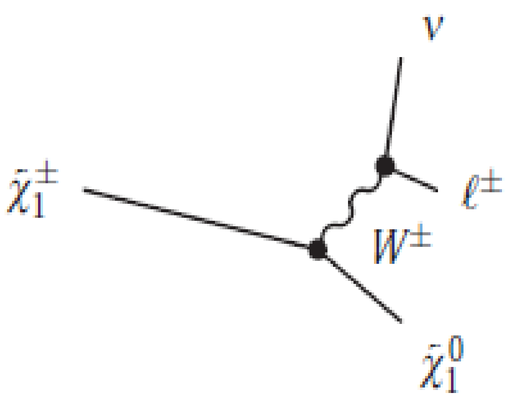
- Sleptons
- Chargino

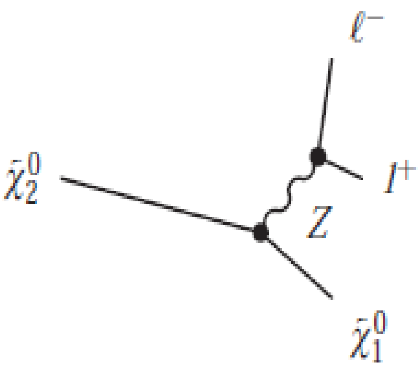
Results also interpreted in terms of cMSSM/mSUGRA

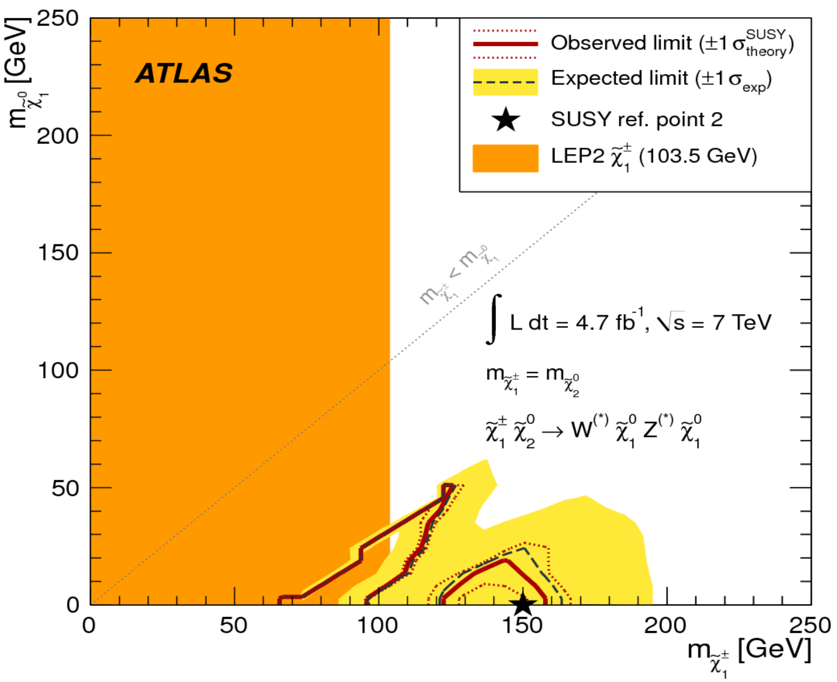
Very stringent limits on m(higgs)-tanβ plane from Higgs direct searches



Electroweak production







Chargino-neutralino production,
Only 3-lep analysis

Reach up to ~150 GeV
In m(chi02) for m(chi01)=0
Region of lower sensitivity for m(chi02)-m(chi01)=100 GeV because of similarity in kinematics With WZ backgrounds

EWK signal regions-3l

Table 1: The selection requirements for the three signal regions. The Z-veto (Z-requirement) rejects (selects) events with m_{SFOS} within 10 GeV of the Z mass (91.2 GeV). The m_{T} is calculated from the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the lepton not forming the best Z candidate.

Selection	SR1a	SR1b	SR2
Targeted Intermediate Decay	$\tilde{l}^{(*)}$ or Z^{*}		on-shell Z
N leptons (e, μ)	Exactly 3		
Lepton charge, flavour	At least one SFOS pair with $m_{\ell\ell} > 20$ GeV		
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 75 GeV		
m_{SFOS}	Z-veto	Z-veto	Z-requirement
N b-jets	0	0	any
m_{T}	any	> 90 GeV	> 90 GeV
p_{T} all ℓ	> 10 GeV	> 30 GeV	> 10 GeV

EWK signal regions-2l

Targeted Process	Signal Region
Two-lepton Final States	
$\tilde{\ell}^{\pm}\tilde{\ell}^{\mp} \rightarrow (\ell^{\mp}\tilde{\chi}_1^0) + (\ell^{\mp}\tilde{\chi}_1^0)$	SR-m_{T2}
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \rightarrow (\ell^{\mp}\nu\tilde{\chi}_1^0) + (\ell^{\mp}\nu\tilde{\chi}_1^0)$	SR-m_{T2}, SR-OSjveto
$\tilde{\chi}_2^0\tilde{\chi}_i \rightarrow (\ell^{\mp}\ell^{\mp}\tilde{\chi}_1^0) + (q\bar{q}'\tilde{\chi}_1^0)$	SR-2jets
Three-lepton Final States	
$\tilde{\chi}_2^0\tilde{\chi}_1^{\pm} \rightarrow (\ell^{\mp}\ell^{\mp}\tilde{\chi}_1^0) + (\ell^{\mp}\nu\tilde{\chi}_1^0)$	SR-OSjveto, SR-SSjveto

SR-	m_{T2}	OSjveto	SSjveto	2jets
charge	OS	OS	SS	OS
flavour	any	any		SF
$m_{\ell\ell}$	Z-veto	Z-veto	-	Z-veto
signal jets	$= 0$	$= 0$		≥ 2
signal b-jets	-	-		$= 0$
$E_T^{miss,rel.}$	> 40	> 100		> 50
other	$m_{T2} > 90$	-		m_{CT}-veto

Table 2: Signal regions. OS (SS) denotes two opposite-sign (same-sign) signal leptons, of same (SF) or different (DF) flavour. The Z-veto rejects events with $m_{\ell\ell}$ within 10 GeV of the Z boson mass (91.2 GeV). The m_{CT}-veto rejects events kinematically consistent with $t\bar{t}$. The values quoted for $E_T^{miss,rel}$ and m_{T2} are in units of GeV.

Variables

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} - 2\mathbf{p}_{\mathrm{T}}^{\ell} \cdot \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}}$$

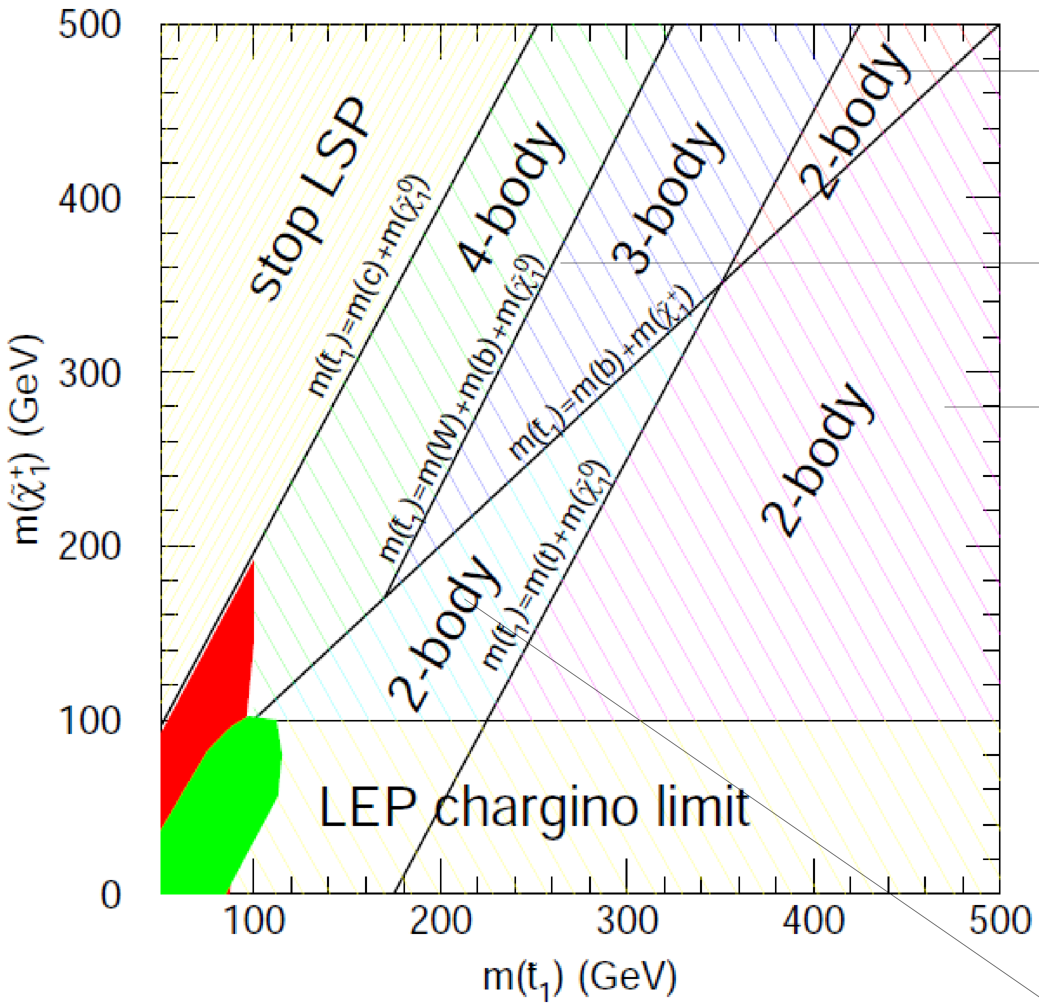
$$m_{\mathrm{T2}} = \min_{\mathbf{q}_{\mathrm{T}}+\mathbf{r}_{\mathrm{T}}=\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}} \left[\max\left(m_T(\mathbf{p}_{\mathrm{T}}^{\ell_1}, \mathbf{q}_{\mathrm{T}}), m_T(\mathbf{p}_{\mathrm{T}}^{\ell_2}, \mathbf{r}_{\mathrm{T}})\right)\right]$$

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

$$\sqrt{s}_{\mathrm{min}}^{(\mathrm{sub})} = \left\{\left(\sqrt{m_{(\mathrm{sub})}^2 + {p_{\mathrm{T}}}_{(\mathrm{sub})}^2} + \sqrt{(m^{\mathrm{miss}})^2 + (E_{\mathrm{T}}^{\mathrm{miss}})^2}\right)^2 - \left(\mathbf{p}_{\mathrm{T}(\mathrm{sub})} + \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\right)^2\right\}^{\frac{1}{2}} ,$$

Stop decay patterns

Assume m(chip)=2m(chi01)



(plot from ATLAS-Phys 2001 workshop)

→ Only stop to top chi01

→ Stop to charm chi01
Or multibody

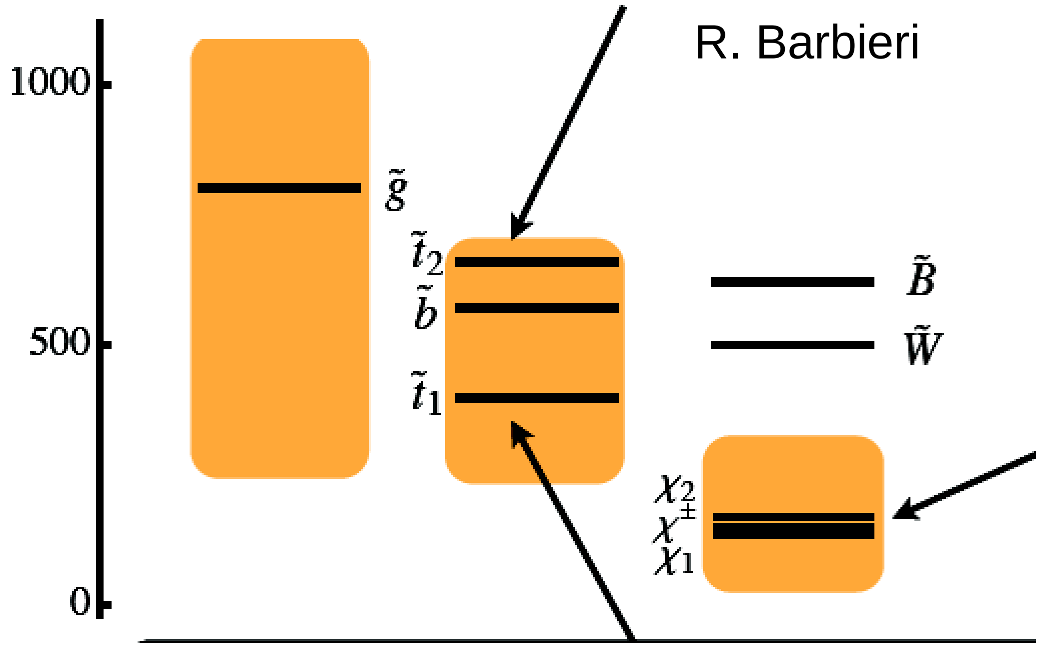
→ all decays

→ Only stop to chargino b

Perspectives (3)

- Even if squark & gluinos are inaccessible at the LHC, other sparticles may/should be lighter
- Focus on sparticles which must be light if SUSY wants to solve the fine-tuning problem. From theoretical guidance:

- Look for direct production of light stop/sbottom:
  - Consider all possible decay chains
  - Ad hoc selections taking into account kinematics
- Look for EW production of gauginos:
  - mostly leptonic signatures
  - go as low as possible in lepton p_T



Fine tuning equations and SUSY spectrum

The key equations:

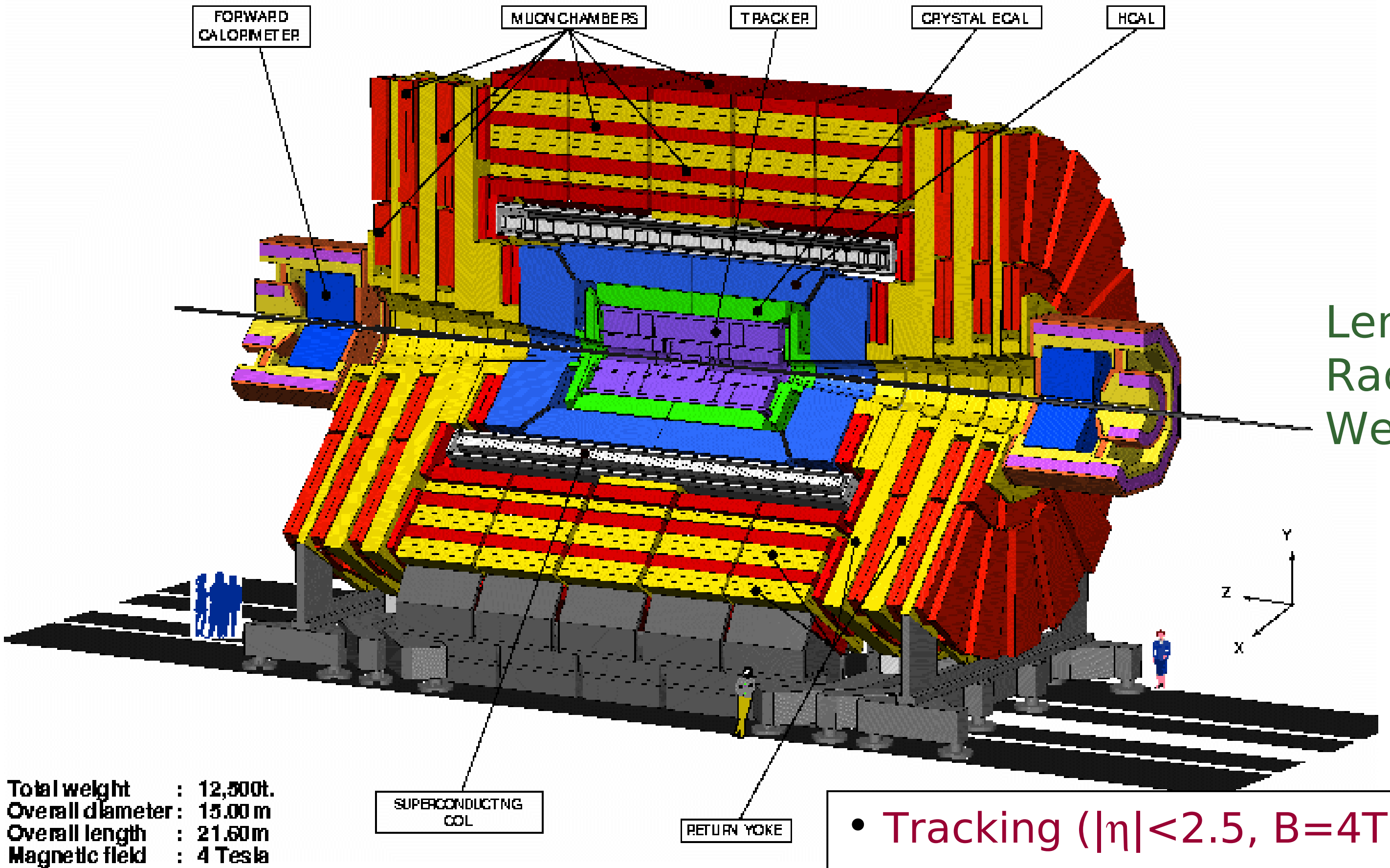
$$\frac{m_h^2}{2} \approx -|\mu|^2 + m_u^2 + \dots$$

$$\delta m_u^2 \approx -\frac{3y_t^2}{8\pi^2}(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + A_t^2) \log M/m_{\tilde{t}}$$

$m_{\tilde{b}_L}$

$$\delta m_{\tilde{t}}^2 \approx \frac{8\alpha_s}{3\pi} m_{\tilde{g}}^2 \log M/m_{\tilde{t}}$$

CMS



Length : ~22 m
Radius : ~7 m
Weight : ~ 12500 tons

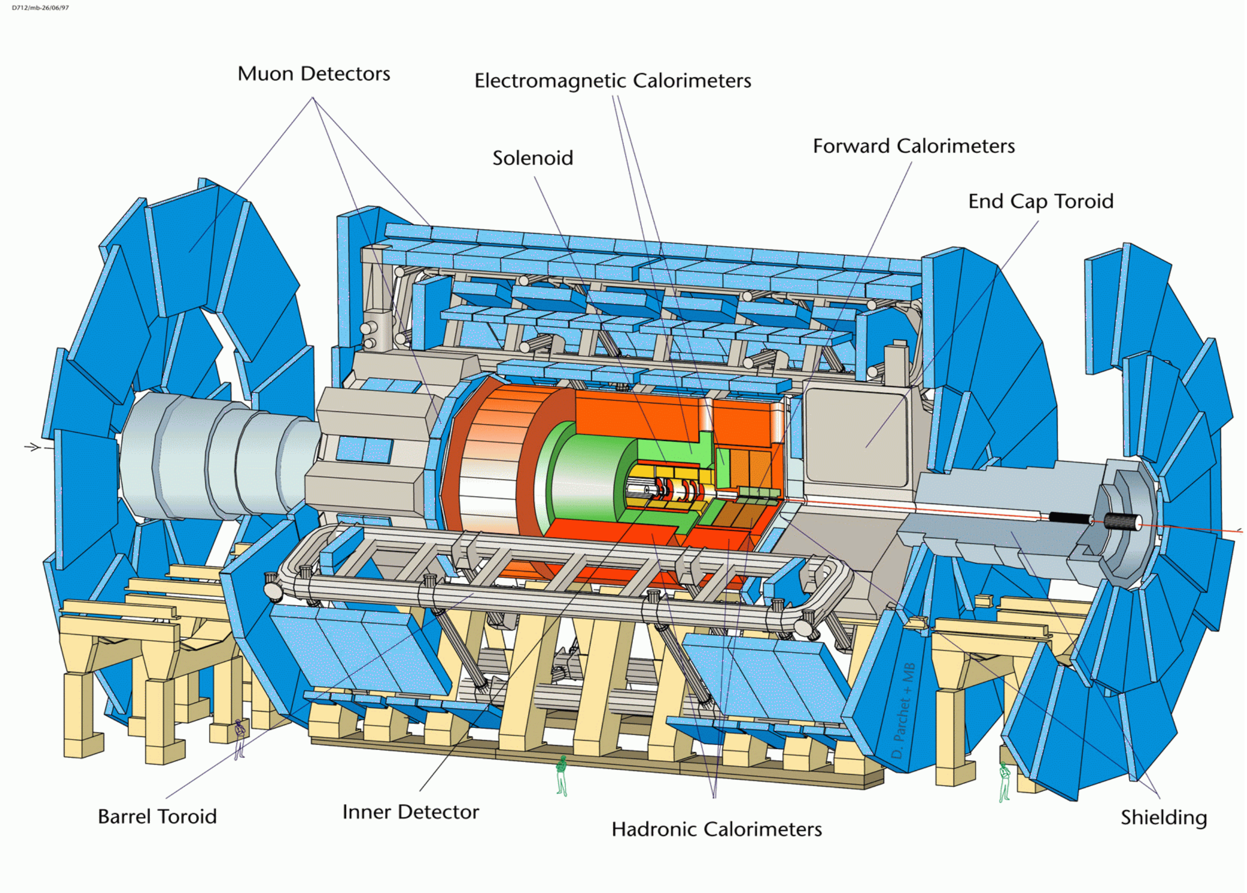
- Tracking (|η|<2.5, B=4T) : Si pixels and strips

- Calorimetry (|η|<5) :
  -- EM : $PbWO_4$ crystals
  -- HAD: brass/scintillator (central+ end-cap),
  Fe/Quartz (fwd)

- Muon Spectrometer (|η|<2.5) : return yoke of solenoid instrumented with muon chambers

And .... > 2500 physicists from
180 Institutions from 38 countries
from 5 continents

ATLAS



Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
~ 3000 km of cables

- Inner Detector ($|\eta|<2.5$, B=2T) :
  -- Si pixels and strips
  -- Transition Radiation Detector (e/π separation)
- Calorimetry ($|\eta|<5$) :
  -- EM : Pb-LAr
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer ($|\eta|<2.7$) :
  air-core toroids with muon chambers

And ~2800 physicists from 169 Institutions, 37 countries, 5 continents