Recent prospects for Supersymmetry searches at the High Luminosity LHC

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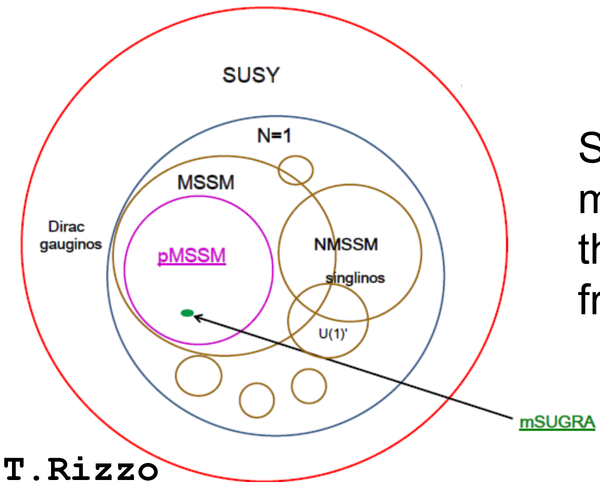
DESY LHC discussion, 19/11/2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

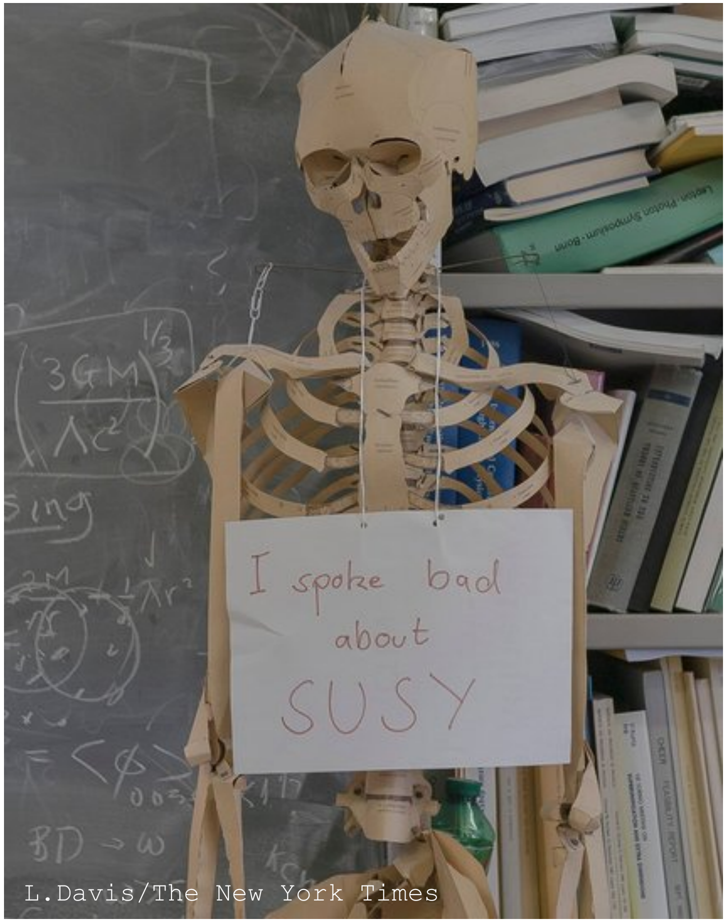
Introduction

At the LHC turn-on, many hoped that SUSY would be just around the corner.

- However, the search continues…



SUSY is not a model, but a theoretical framework!



ESPP update due for approval by CERN council in May 2020

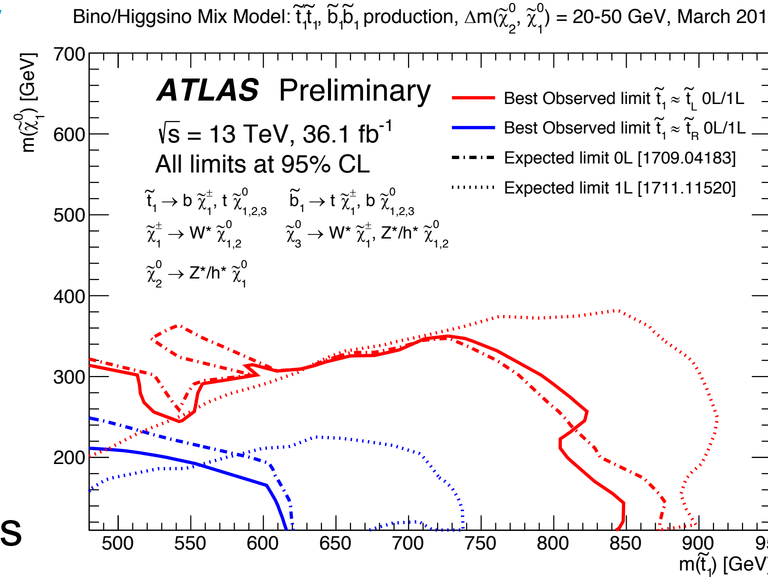
- Large effort to quantify the reach of the HL-LHC
- Yellow Report expected in December 2018

Naturalness at the HL-LHC

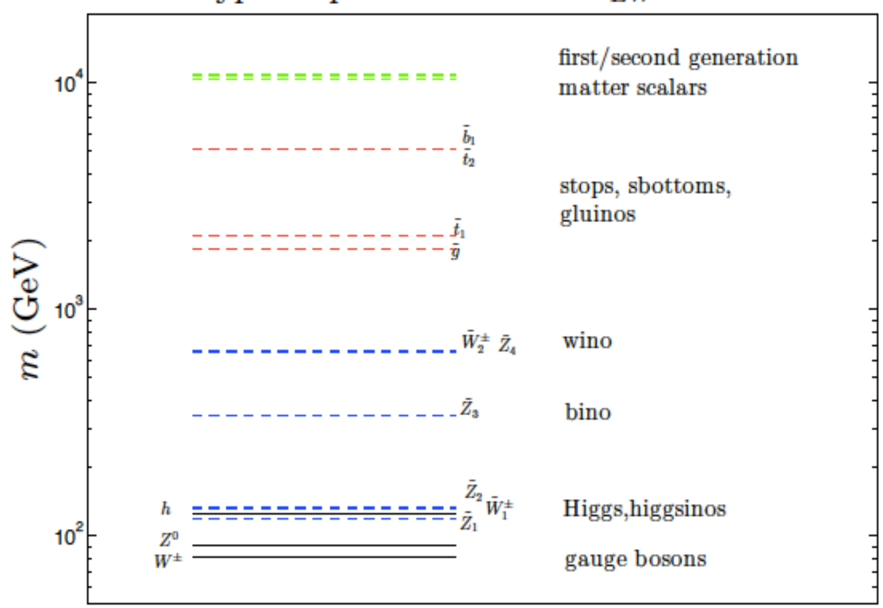
Probing a guiding principle

But where is SUSY?

- Barbieri-Giudice 3% naturalness
  - $m(\tilde{g}) \lesssim 1000$ GeV
  - $m(\tilde{t}_1) \lesssim 500$ GeV
- LHC limits severly constraining these models



Typical spectrum for low Δ_{EW} models



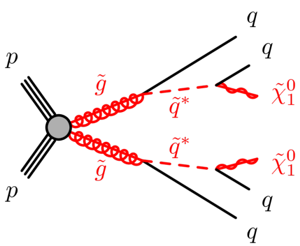
Is SUSY unnatural? Is it dead? Not really…

- Considering the electroweak fine-tuning (Δ_{EW}), SUSY is natural (**3-10%**) with:
  - $m(\tilde{g}) \lesssim$ 5-6 TeV
  - $m(\tilde{t}_1) \lesssim$ 2-3 TeV
  - $m(\tilde{q}) \lesssim$ 10-20 TeV
- Need **low μ ~ 100-300 GeV**

H. Baer, FNAL HL/HE-LHC workshop

Naturalness at the HL-LHC

What do we expect to be able to say?



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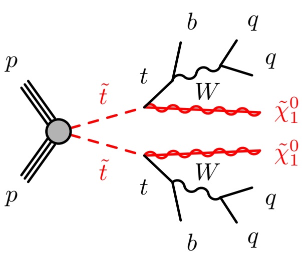

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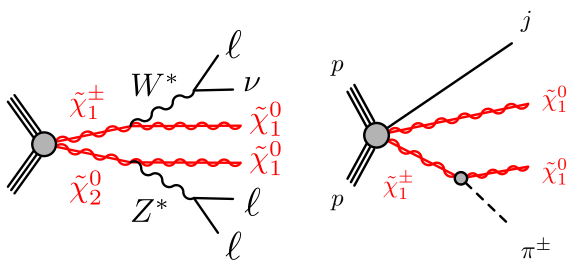

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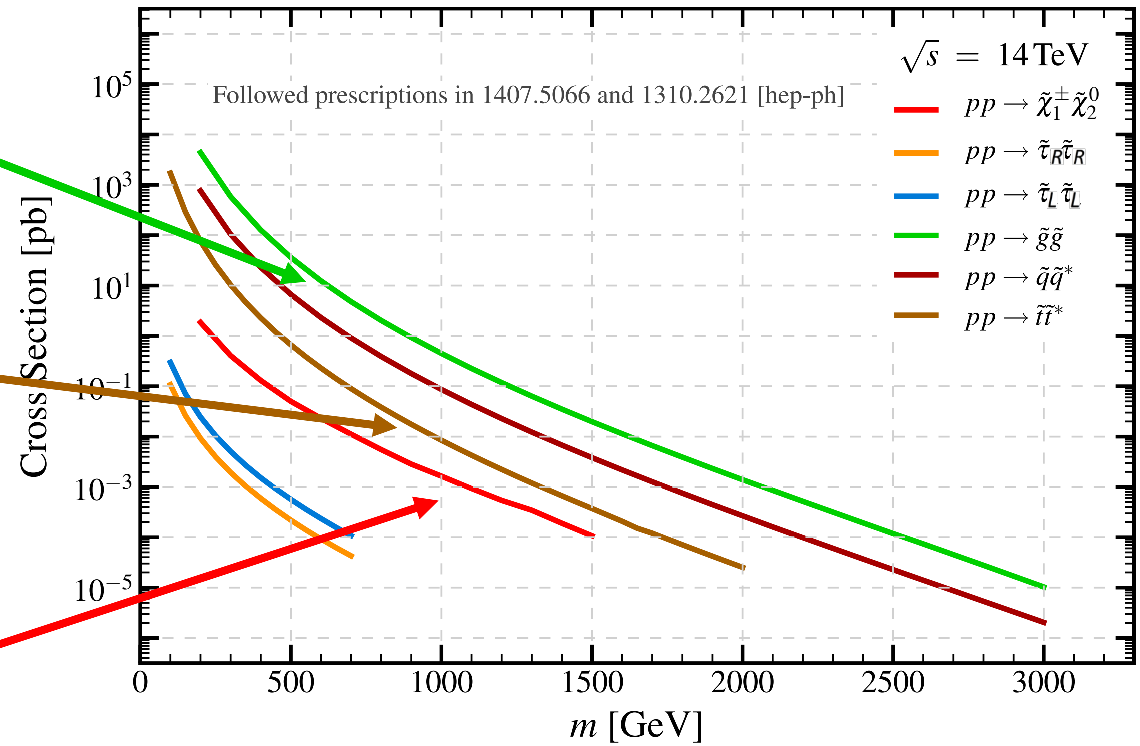


The HL-LHC Yellow Report studies

Some commonalities

Three main approaches:

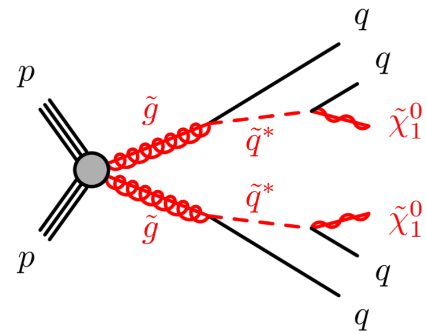
- Full simulation
- **Analysis with parameterized detector performance** (e.g. DELPHES with up-to-date phase-2 detector performance)
- Projections using Run-2 signal and background samples scaled at 14 TeV

Harmonised treatment of detector and theory uncertainties evolution with time

- Agreement between experimental collaborations and theorists involved in the Yellow Report
- General “rules of thumb”:
  - detector and theory/modelling uncertainties will be halved
  - MC statistics are supposed to be infinite

Search for long lived gluinos

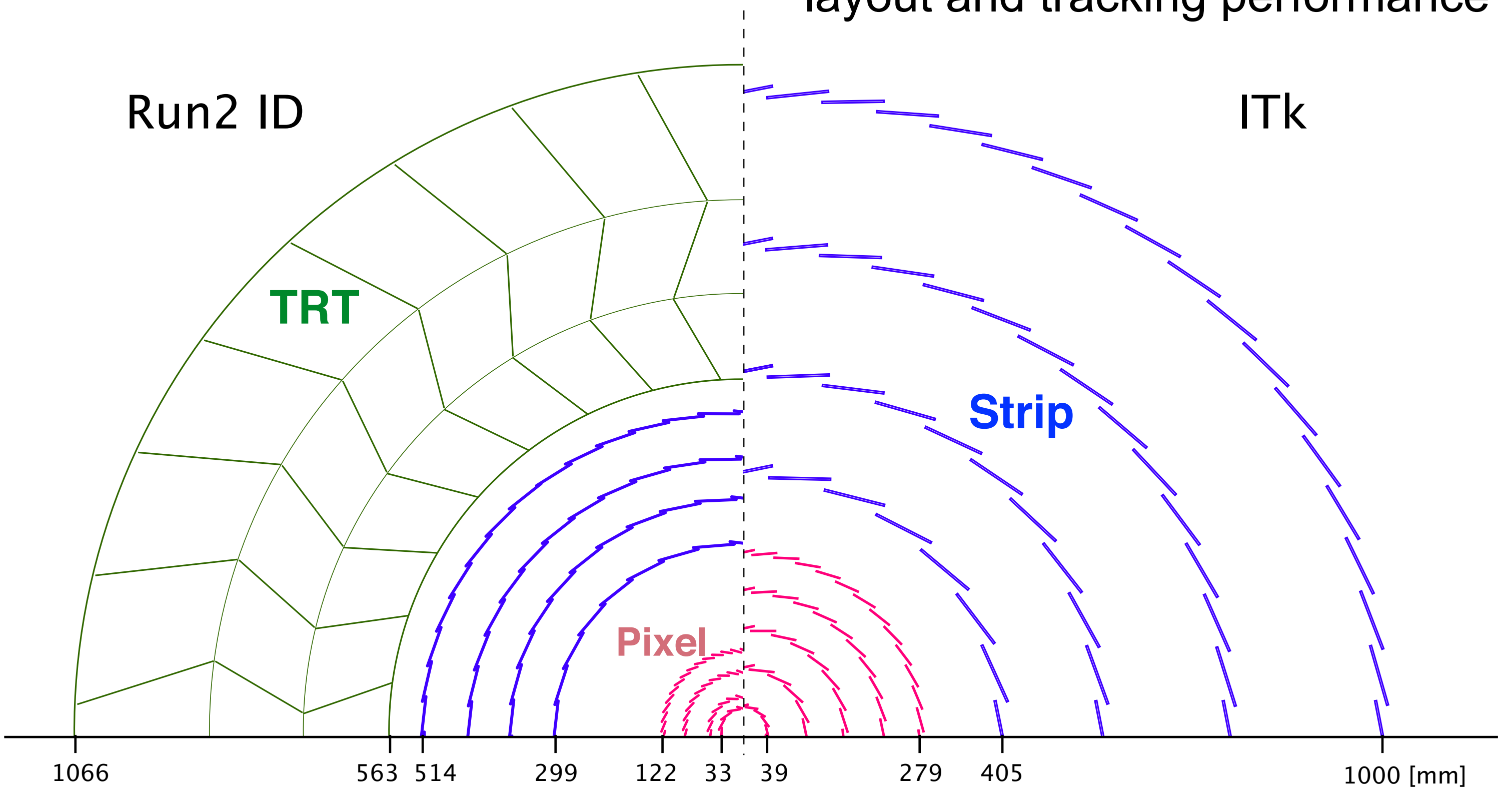
Probing high mass gluinos



Gluinos can acquire discernible lifetimes due to heavy intermediate particles in the decay chain.

- Follow strategy of arXiv: 1710.04901

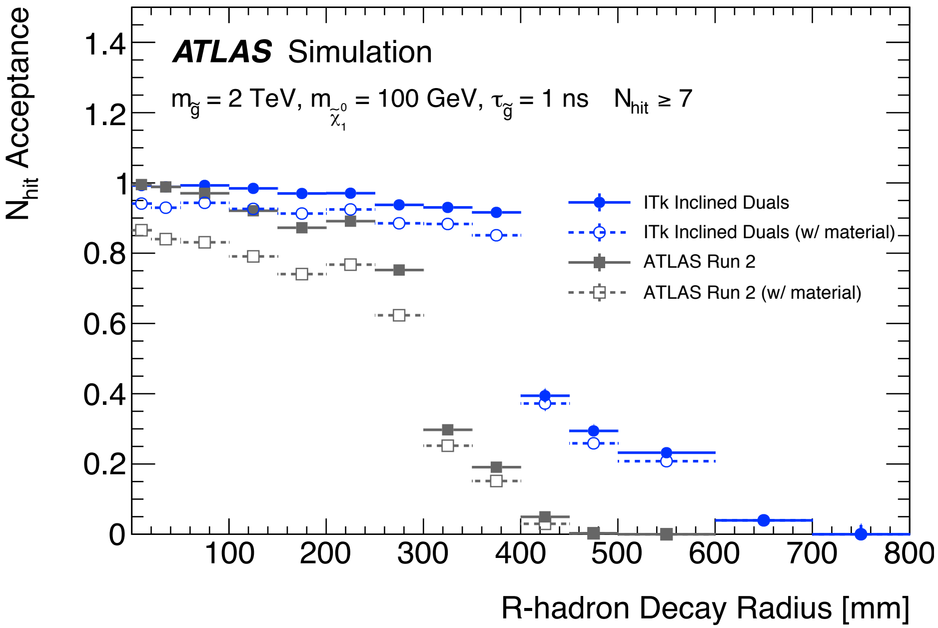
- Exploit displaced decay vertices
- Sensitivity dependent on detector layout and tracking performance

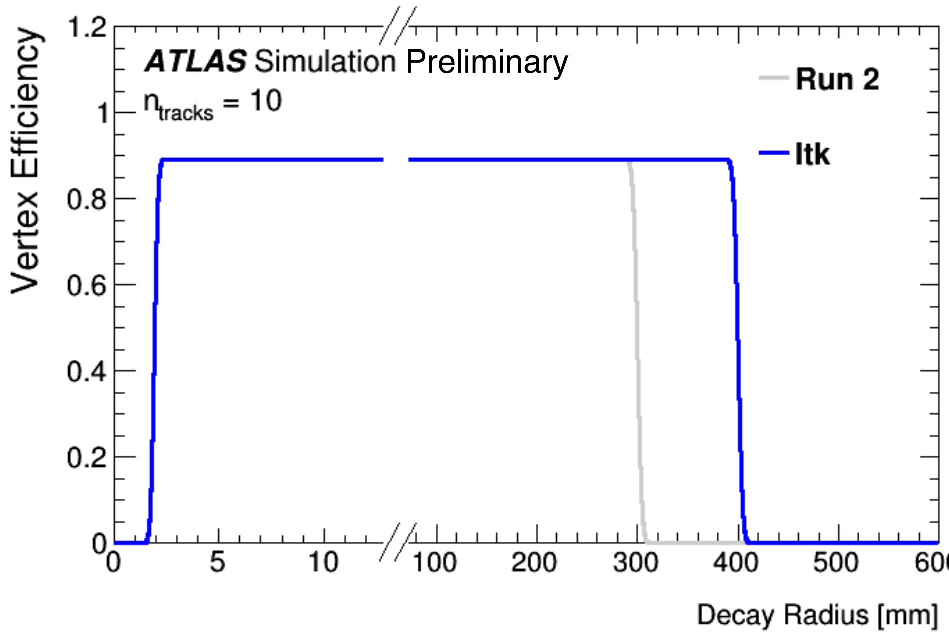


Search for long lived gluinos

Displaced tracking performance

Standard and displaced tracking reconstruction require that each track have at least seven silicon-detector hits (strip detectors are double-sided).

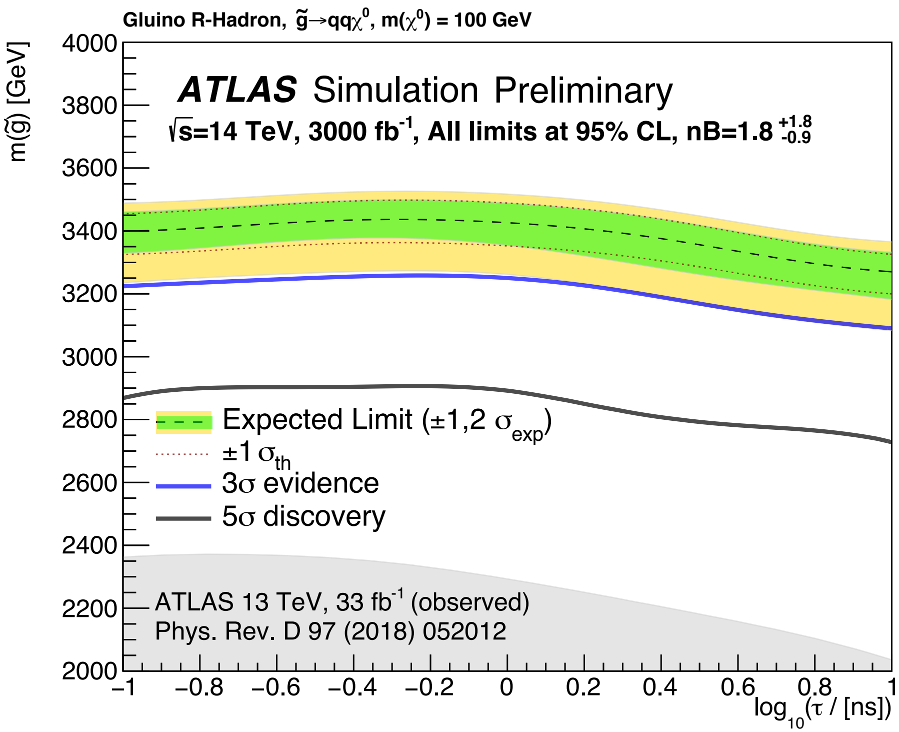


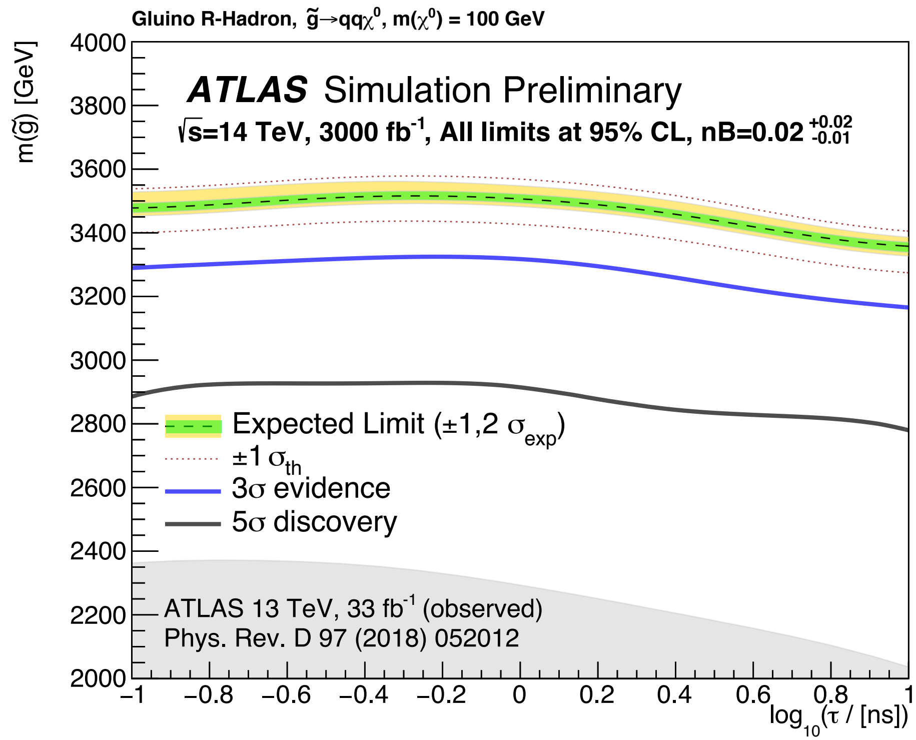


- Track reconstruction efficiency assumed to be 1
- Silicon detector hit efficiency assumed to be 1

Long lived gluinos expected sensitivity

Same selection of Run-2 ($E_T^{miss} > 250$ GeV, $m_{DV} > 10$ GeV, $n_{tracks} > 4$)

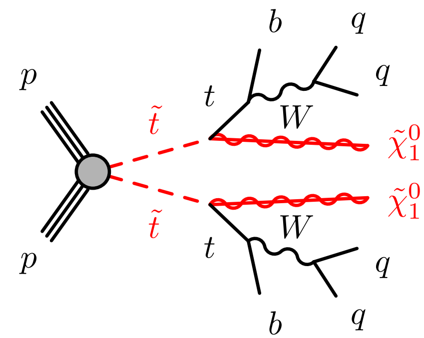




Two hypotheses for backgrounds (scaling with luminosity or the same as Run-2)

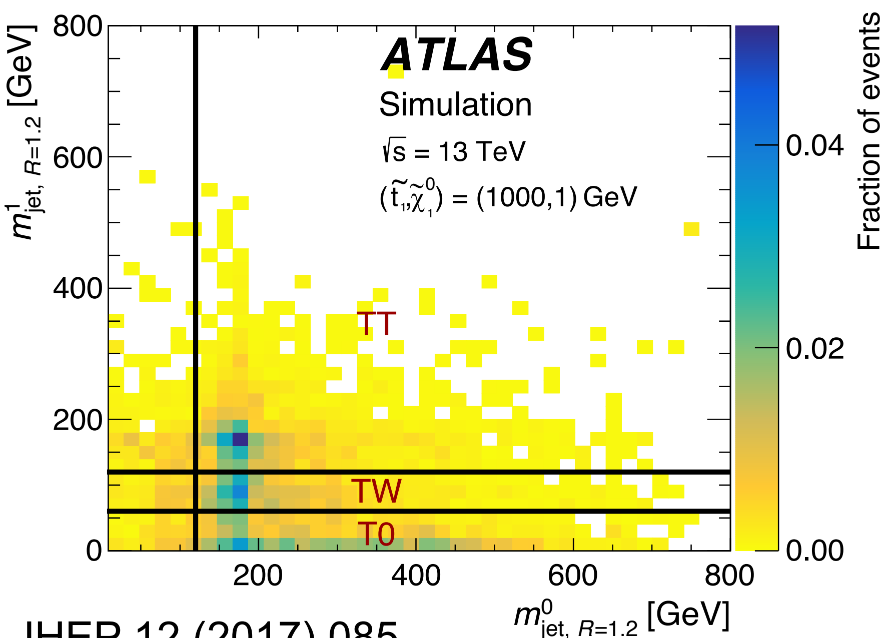
Search for top squarks

High-mass region

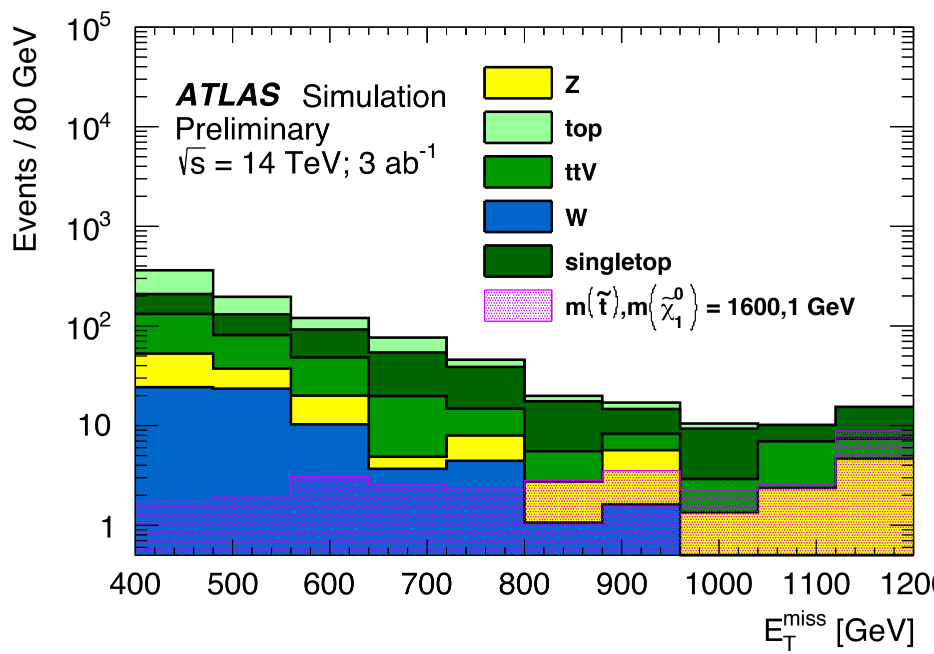


Fully hadronic final state

- Exploits large-R jets (anti-$k_t^{1.2}$ and anti-$k_t^{0.8}$) masses to tag potential boosted top quarks and W-bosons in the final state.
- Multi-bin selection on E_T^{miss}, m(anti-$k_t^{1.2}$) and $n_{b\text{-jet}}$



JHEP 12 (2017) 085



$$N_{b-\text{jet}} \geq 2,\ m_2^{\text{anti-}k_t^{1.2}} > 120\ \text{GeV}$$

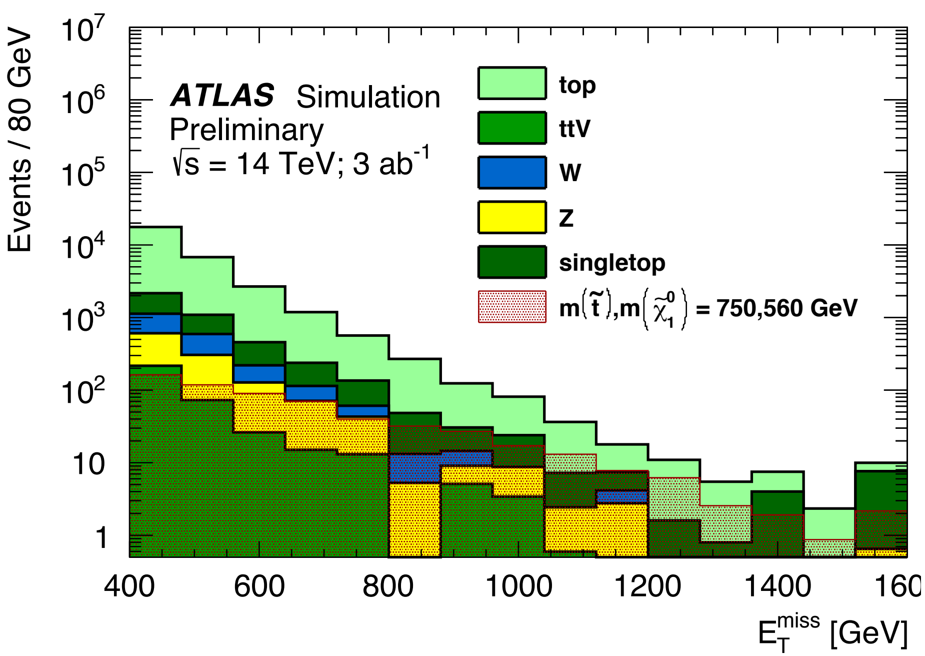
Search for top squarks

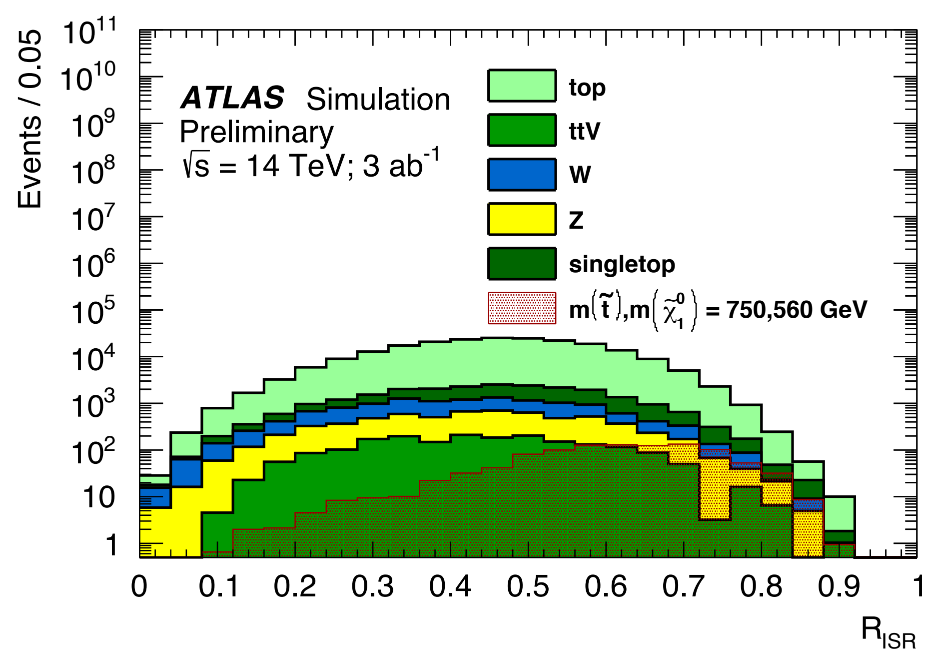
Compressed models

Fully hadronic final state

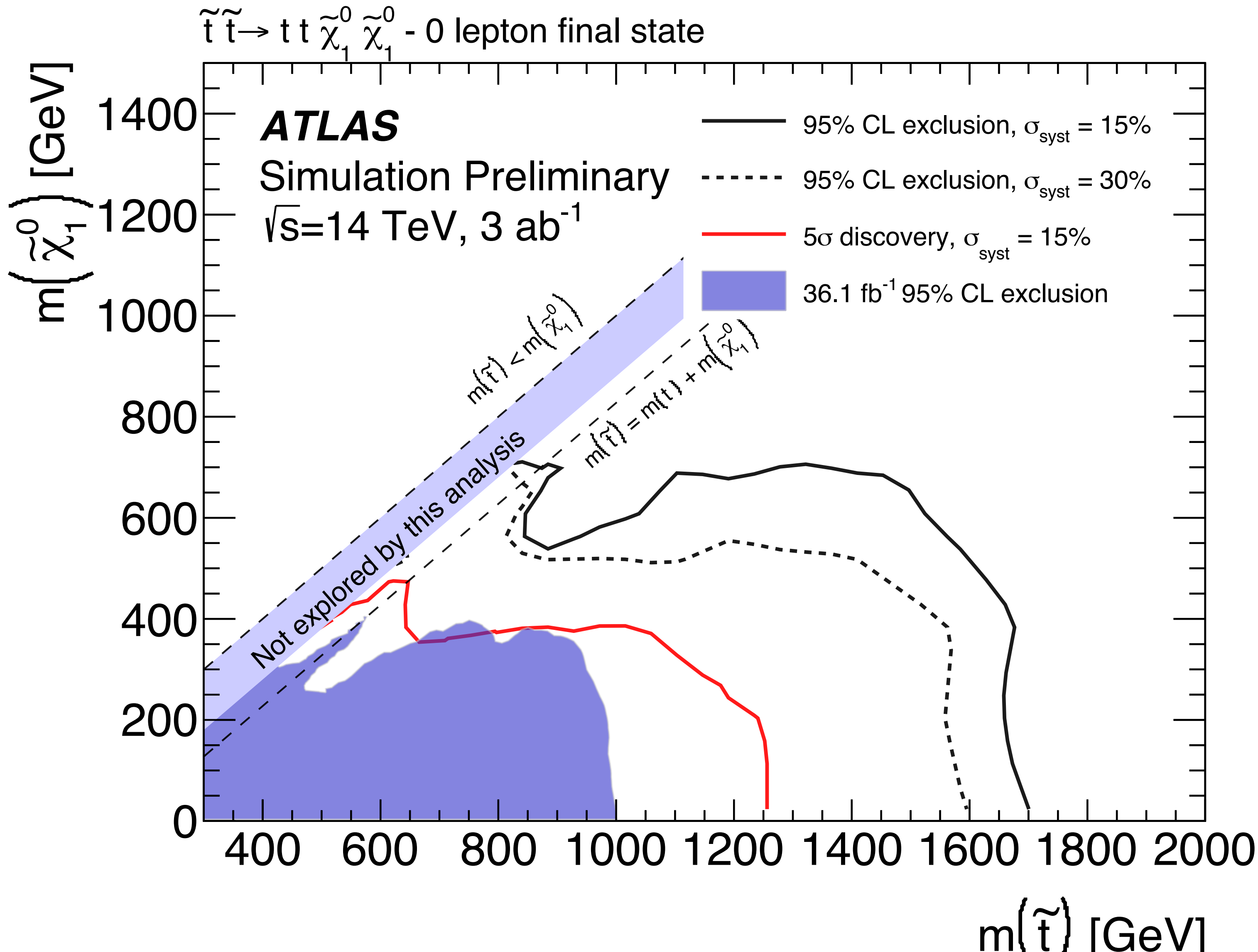
$$R_{\mathrm{ISR}} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{p_{\mathrm{T}}^{\mathrm{ISR}}} \sim \frac{m\left(\tilde{\chi}_1^0\right)}{m\left(\tilde{t}_1\right)}$$

- Exploits the Recursive Jigsaw technique
- ISR to boost stop-system
- Multi-bin selection on R_{ISR} and E_T^{miss}





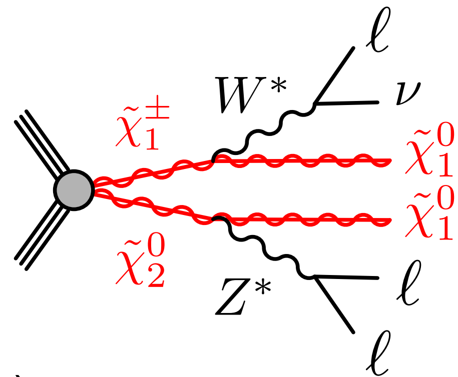
Top squarks expected sensitivity



Search for Higgsinos

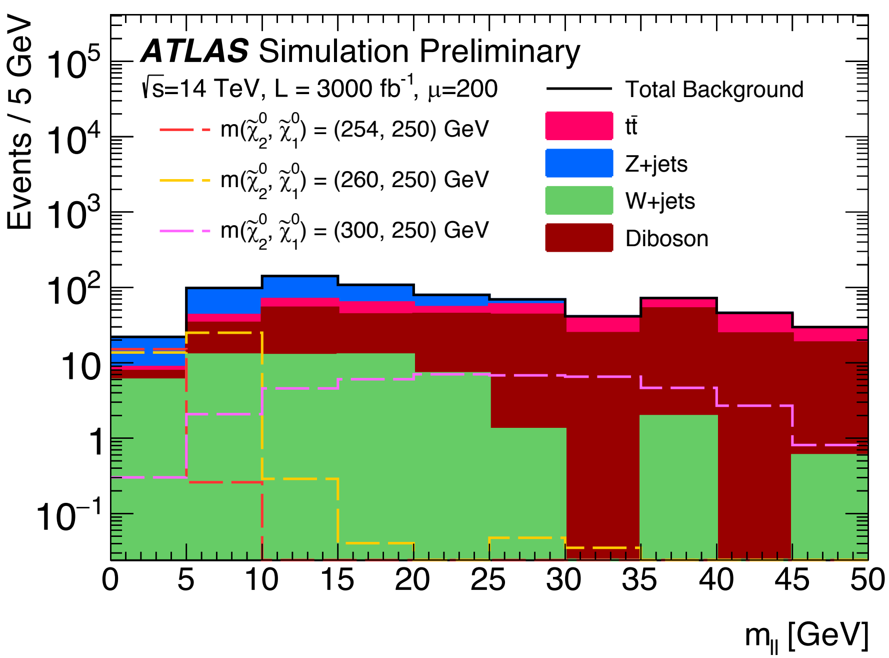
Very compressed electroweak-inos

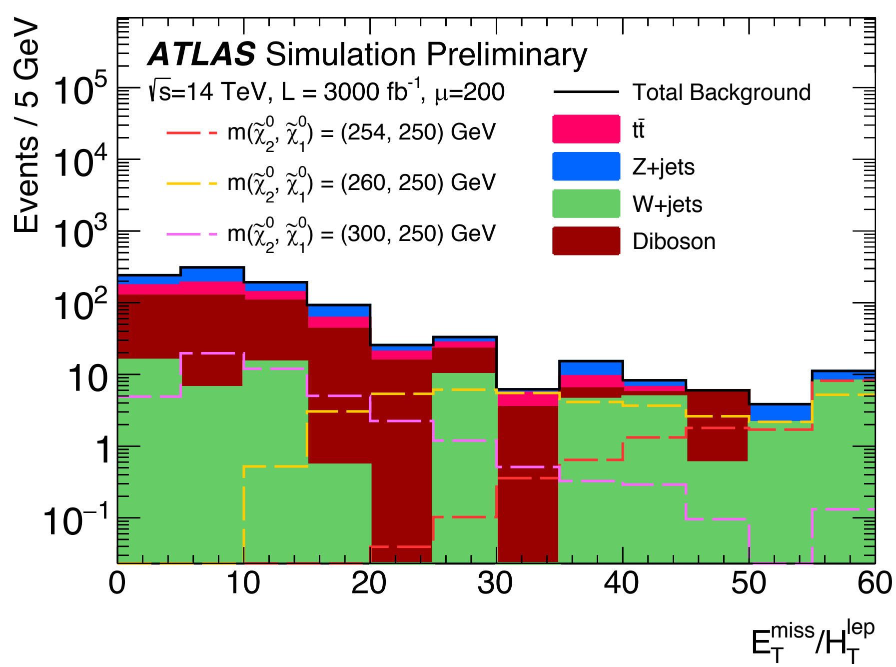
DONE at DESY!



Di-lepton final state

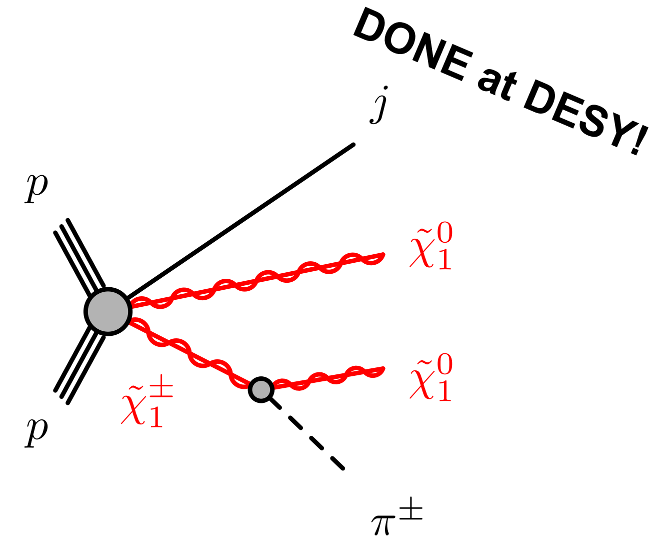
- ISR to boost C1N2-system
- Challenging lepton identification
- Multi-bin selection on dilepton invariant mass (m_{ll})





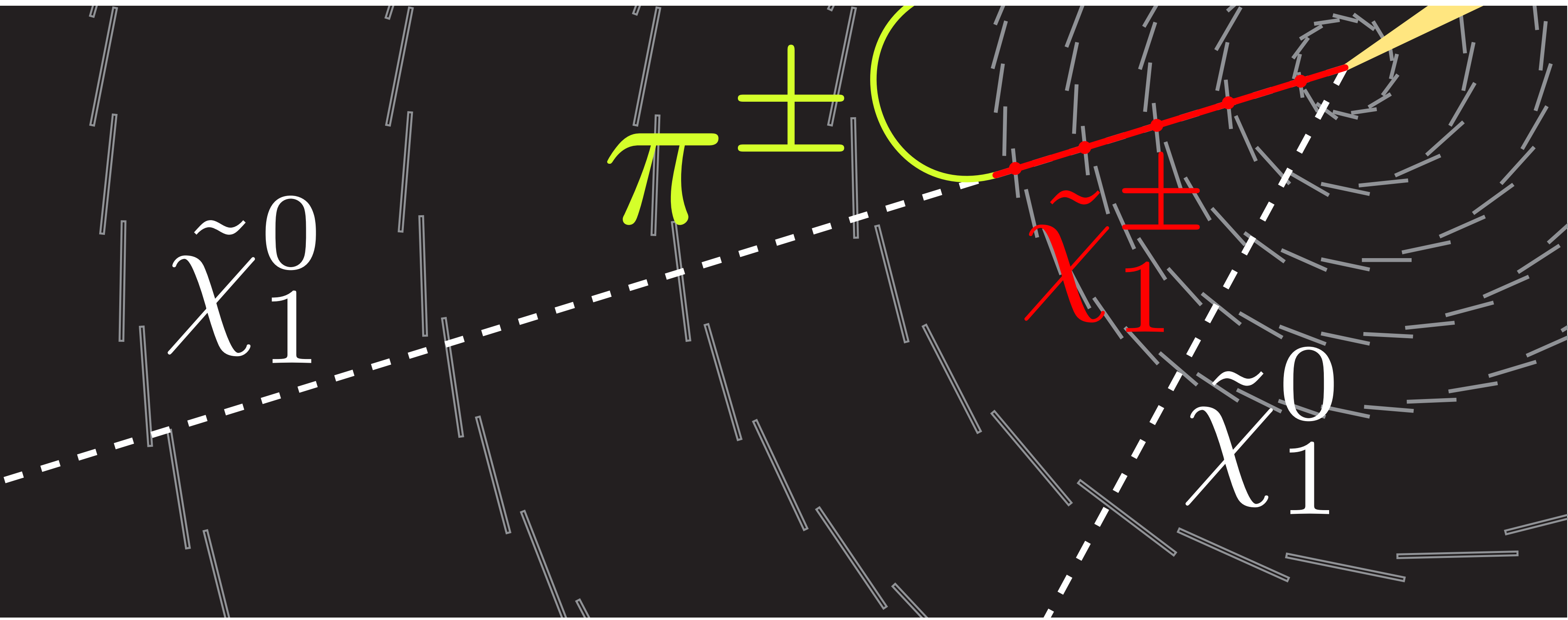
Search for Higgsinos

Ultra compressed electroweak-inos



In very compressed spectra, charginos can acquire sizeable lifetime

- Exploit the disappearing track signature
- Challenging tracking environment!



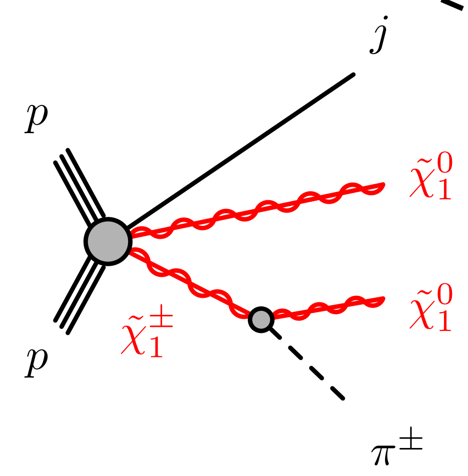
Search for Higgsinos

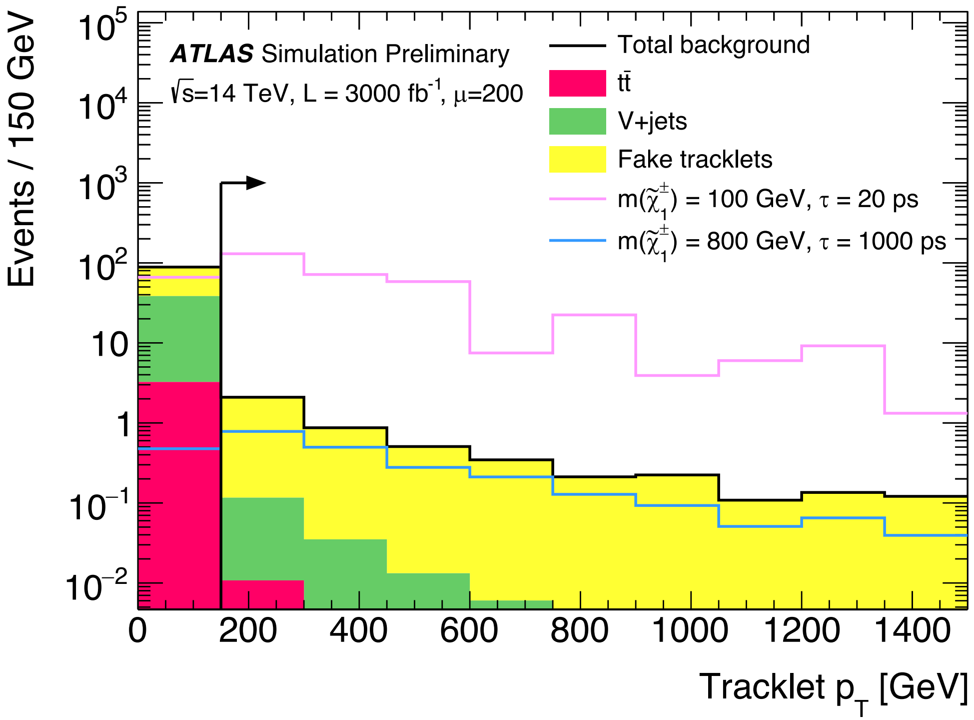
Tracklet requirements

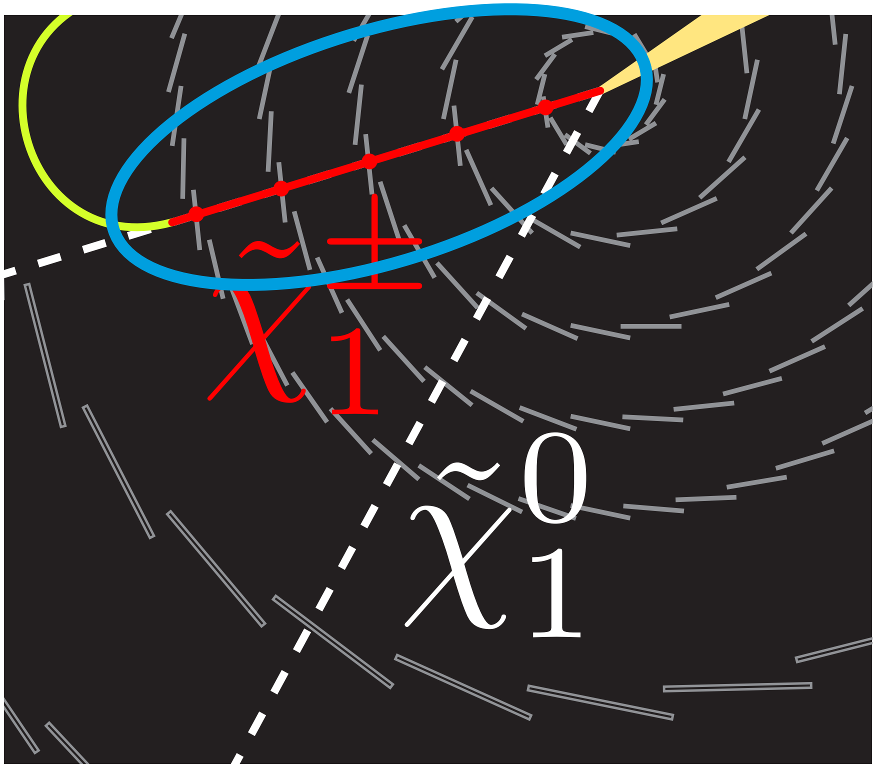
DONE at DESY!

Pixel detector-only tracklets reconstructed with 4-5 hits

- $p_T > 150$ GeV
- ISR jet $p_T > 300$ GeV



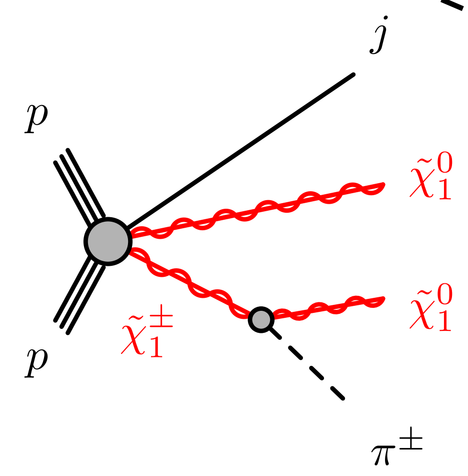




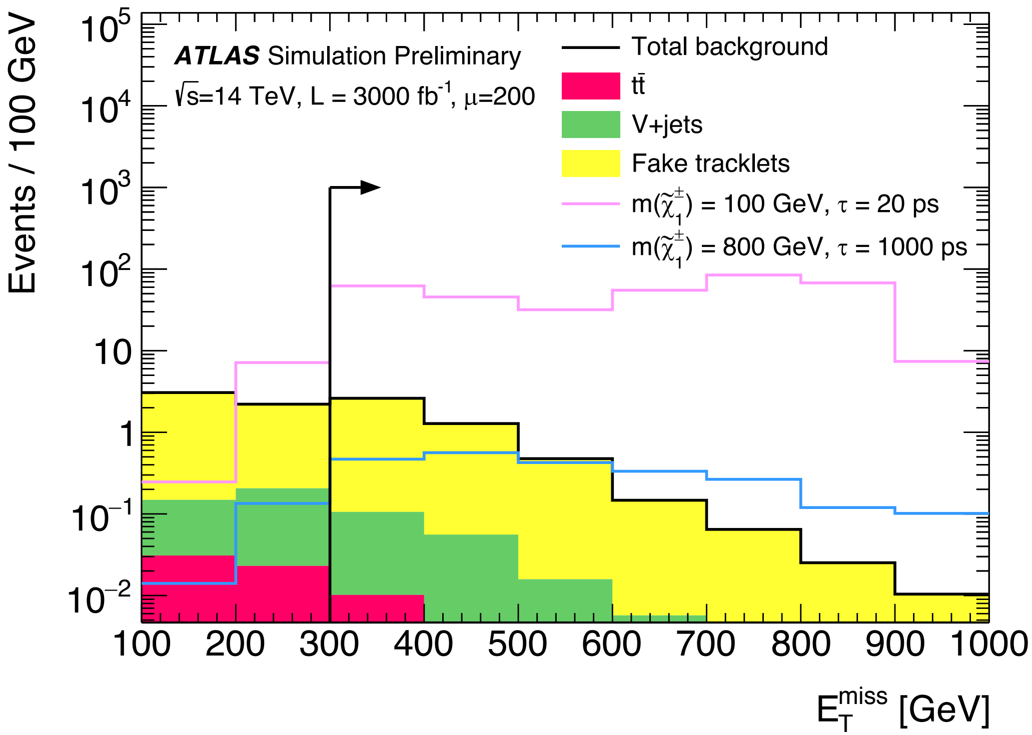
Search for Higgsinos

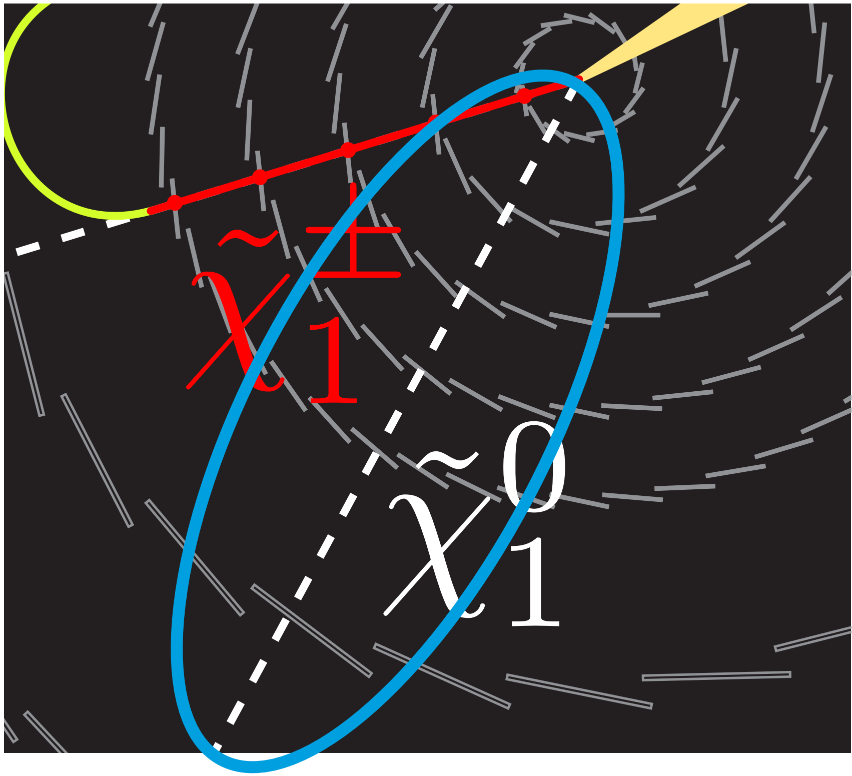
Disappearing tracks

DONE at DESY!



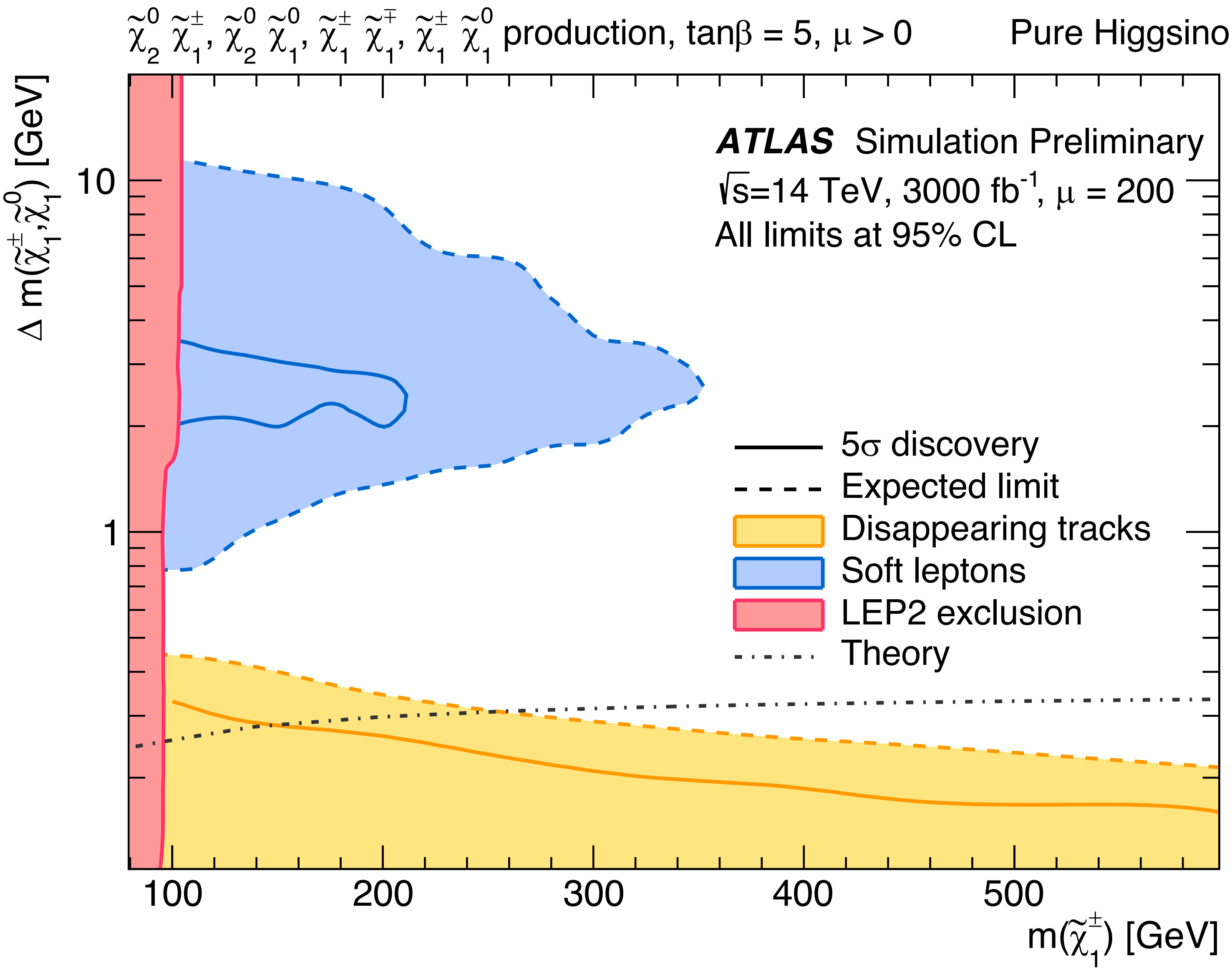
- $E_T^{miss} > 300$ GeV



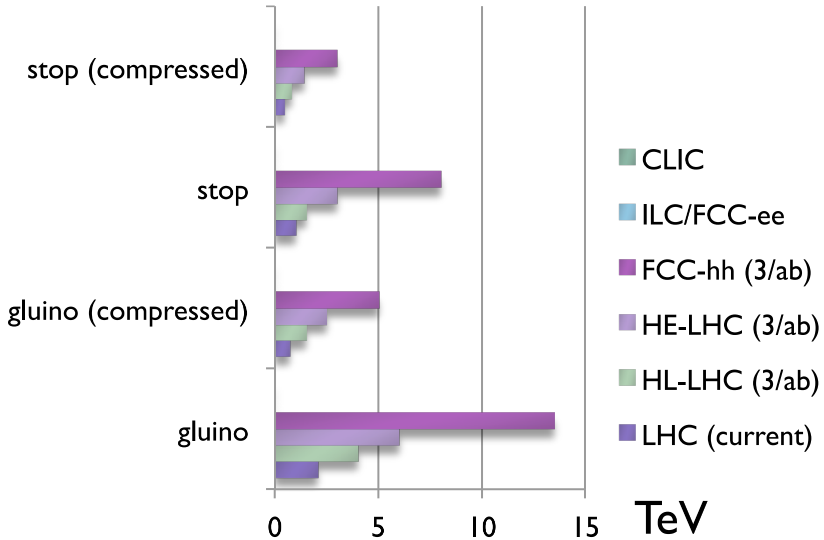


Higgsinos expected sensitivity

DONE at DESY!



The HL-LHC and beyond



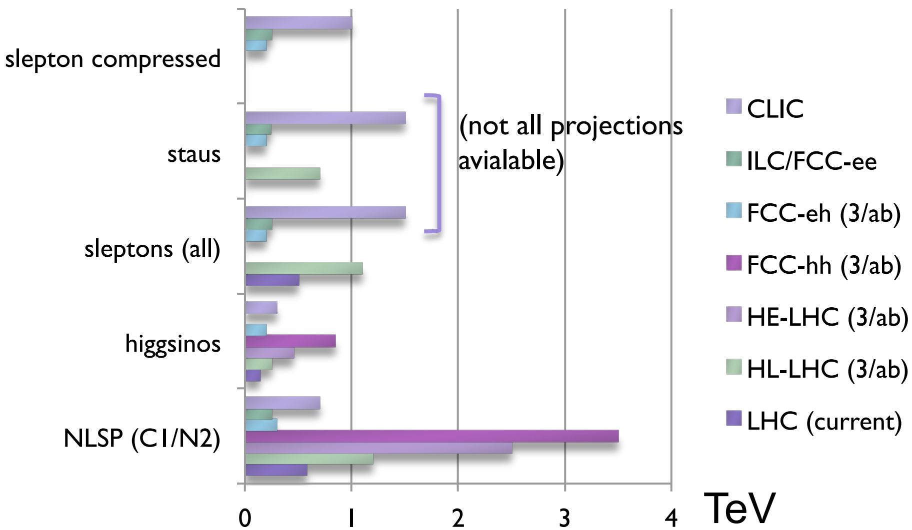


Image credit: M. D'Onofrio

Image credit: M. D'Onofrio

Summary

The reach of simplified natural SUSY searches at the HL-LHC has been explored.

- A comprehensive programme spanning from strong to electroweakly produced sparticles
- Worth to look into unconventional corners (e.g. long-lived SUSY)

Overall large effort to prepare updated prospects for the update of the European Strategy for Particle Physics.

- Many additional interesting prospects to be released in just a few days!

Stay tuned!

Thank you

Top squark SR definitions

High mass

Preselection	
$N_{\text{lep}} = 0$	
$N_{\text{jet}} \geq 4$	
$\Delta\phi\left(E_{\text{T}}^{\text{miss}}, \text{jet1}\right) > 0.4$, $\Delta\phi\left(E_{\text{T}}^{\text{miss}}, \text{jet2}\right) > 0.4$	
$N_{b-\text{jet}} \geq 1$	
$E_{\text{T}}^{\text{miss}} > 400$ GeV	
$p_{\text{T}}^{\text{jet1}} > 80$ GeV, $p_{\text{T}}^{\text{jet2}} > 80$ GeV	
$p_{\text{T}}^{\text{jet3}} > 40$ GeV, $p_{\text{T}}^{\text{jet4}} > 40$ GeV	
$m_1^{\text{anti-}k_t^{1.2}} > 120$ GeV	
$m_{\text{Tb}}^{\text{min}} > 250$ GeV	
$m_1^{\text{anti-}k_t^{0.8}} > 60$ GeV, $m_2^{\text{anti-}k_t^{0.8}} > 60$ GeV	
Signal region selection	
Number of b-tagged jets	Other selections
$N_{b-\text{jet}} = 1$	$m_2^{\text{anti-}k_t^{1.2}} \in [0, 60), [60, 120), [120, \infty)$ $E_{\text{T}}^{\text{miss}} \in [400, 600), [600, 900), [900, 1200), [1200, 1600), [1600, \infty)$
$N_{b-\text{jet}} > 1$	$m_2^{\text{anti-}k_t^{1.2}} \in [0, 60), [60, 120), [120, \infty)$ $E_{\text{T}}^{\text{miss}} \in [400, 600), [600, 900), [900, 1200), [1200, 1600), [1600, \infty)$ $m_{\text{T}}^{\chi^2} > 400$, $\Delta R_{bb} \geq 1$

Top squark SR definitions

Compressed

Preselection	
$N_{\text{lep}} = 0$	
$N_{\text{jet}} \geq 4$	
$\Delta\phi\left(E_{\text{T}}^{\text{miss}}, \text{jet1}\right) > 0.4$, $\Delta\phi\left(E_{\text{T}}^{\text{miss}}, \text{jet2}\right) > 0.4$	
$N_{b-\text{jet}} \geq 1$	
$E_{\text{T}}^{\text{miss}} > 400$ GeV	
$p_{\text{T}}^{\text{jet1}} > 80$ GeV, $p_{\text{T}}^{\text{jet2}} > 80$ GeV	
$p_{\text{T}}^{\text{jet3}} > 40$ GeV, $p_{\text{T}}^{\text{jet4}} > 40$ GeV	
$N_{b-\text{jet}}^{\text{S}} \geq 1$	
$N_{\text{jet}}^{\text{S}} \geq 5$	
$p_{\text{T},b}^{0,\text{S}} > 40$ GeV	
$m_{\text{S}} > 300$ GeV	
$\Delta\phi(\text{ISR}, \mathbf{p}_{\text{T}}^{\text{miss}}) > 3$	
$p_{\text{T}}^{\text{ISR}} > 400$ GeV	
$p_{\text{T}}^{4,\text{S}} > 50$ GeV	
Signal region selection	
R_{ISR} selection	$E_{\text{T}}^{\text{miss}}$ selection
$0.5 < R_{\text{ISR}} < 0.65$	$E_{\text{T}}^{\text{miss}} \in [500, 700), [700, 1000), [1000, 1400), [1400, \infty)$
$R_{\text{ISR}} > 0.65$	$E_{\text{T}}^{\text{miss}} \in [500, 700), [700, 1000), [1000, 1400), [1400, \infty)$

Search for Higgsinos

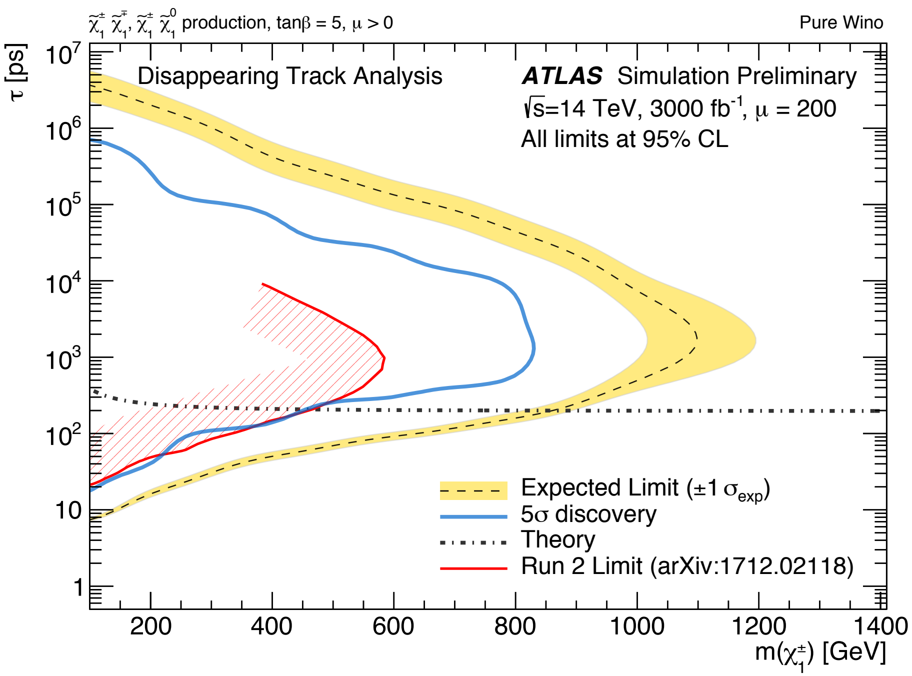
Soft leptons SR

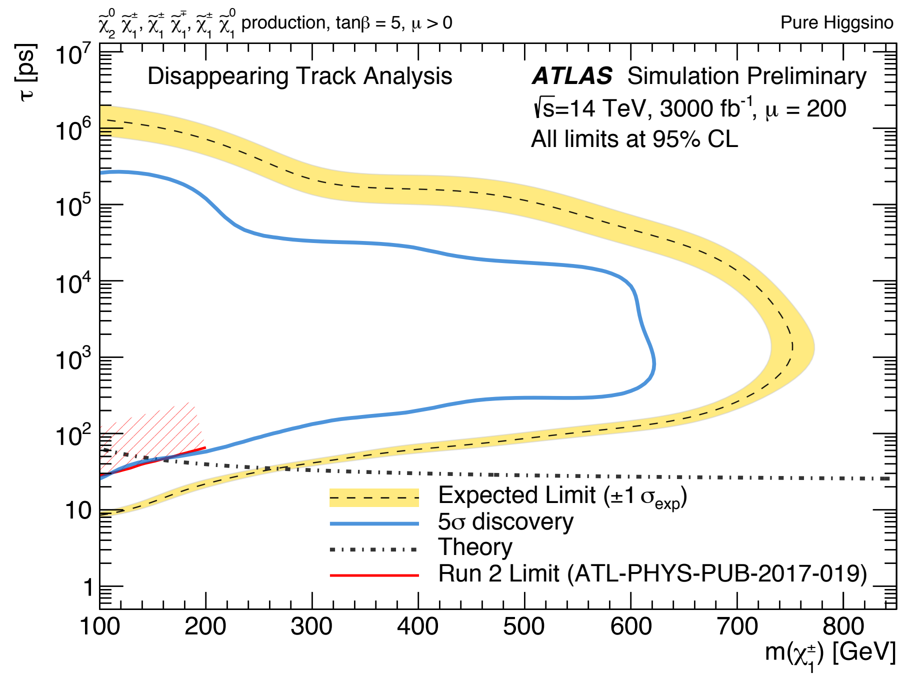
Variable	SR Selection ($m_{\ell\ell} < 20\,\text{GeV}$)	SR Selection ($m_{\ell\ell} > 20\,\text{GeV}$)
n_μ	$= 2$	$= 2$
$p_\text{T}(\mu_{1,2})$ [GeV]	> 3	> 8
n_jets	≥ 1	≥ 1
$n_\text{b-jets}$	$= 0$	$= 0$
E_T^miss [GeV]	> 500	> 500
$\Delta R(\ell, \ell)$	< 2	< 2
$m_{\ell\ell}$ [GeV]	$[1, 20]$ excluding $[3.0, 3.2]$	$[20, 50]$
$p_\text{T}(\text{jet}_1)$ [GeV]	> 100	> 100
$\Delta\phi(j_1, E_\text{T}^\text{miss})$	> 2	> 2
$\min(\Delta\phi(j, E_\text{T}^\text{miss}))$	> 0.4	> 0.4
$m_{\tau\tau}$ [GeV]	< 0 or > 160	< 0 or > 160
$E_\text{T}^\text{miss}/H_\text{T}^\text{lep}$	$> \max(5, 15 - 2m_{\ell\ell})$	$> \max(10, 15 - 2m_{\ell\ell})$

Search for Higgsinos

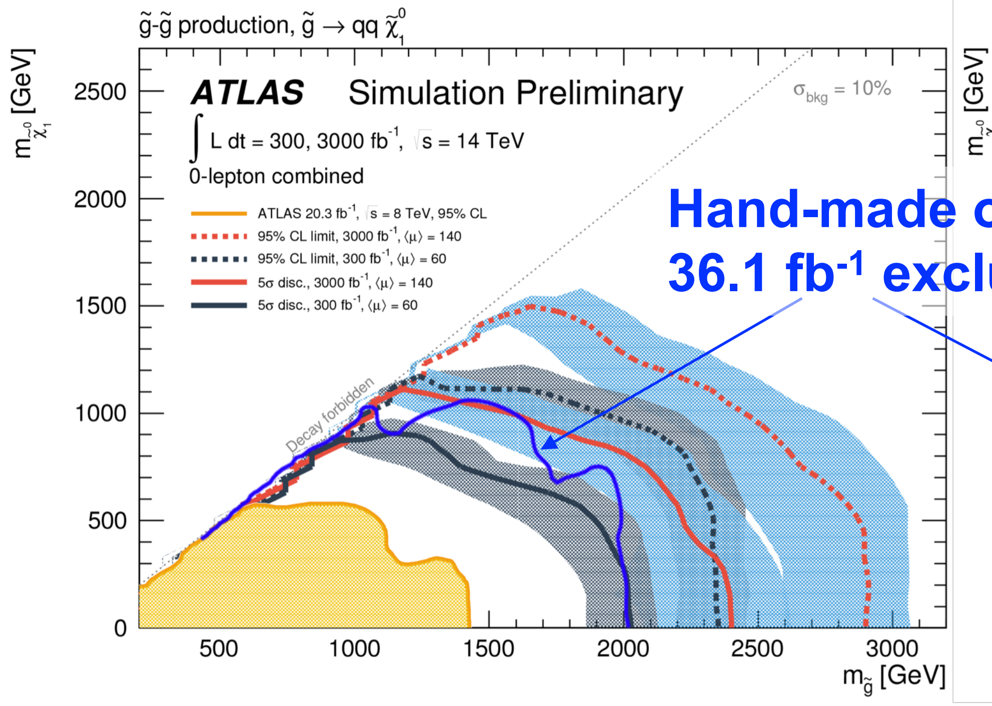
Disappearing tracks SR

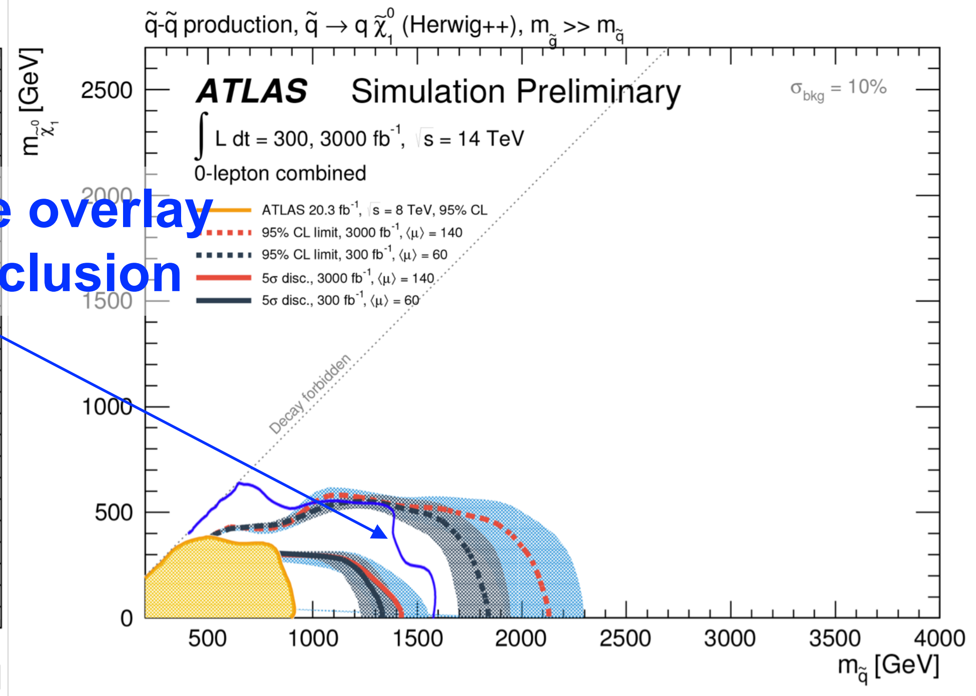
Variable	SR Selection
Lepton veto p_T [GeV]	>20
$\min\{\Delta\phi(\text{jet}_{1-4}, E_T^{\text{miss}})\}$	>1
E_T^{miss} [GeV]	>300
Leading jet p_T [GeV]	>300
Leading tracklet p_T [GeV]	>150
$\Delta\phi(E_T^{\text{miss}}, \text{trk})$	<0.5





Prompt squark and gluinos

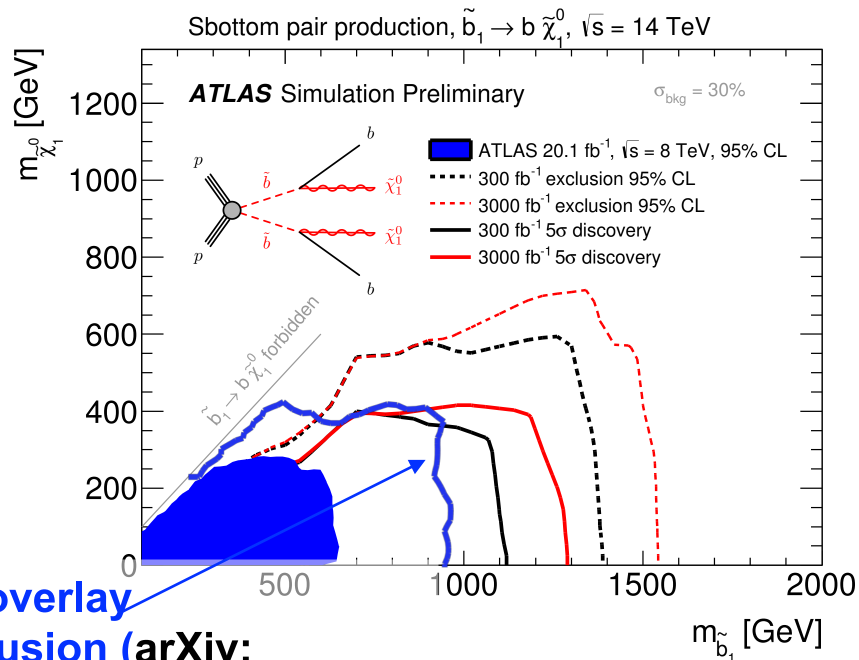




Hand-made overlay
36.1 fb^{-1} exclusion

ATL-PHYS-PUB-2014-010

Bottom squarks

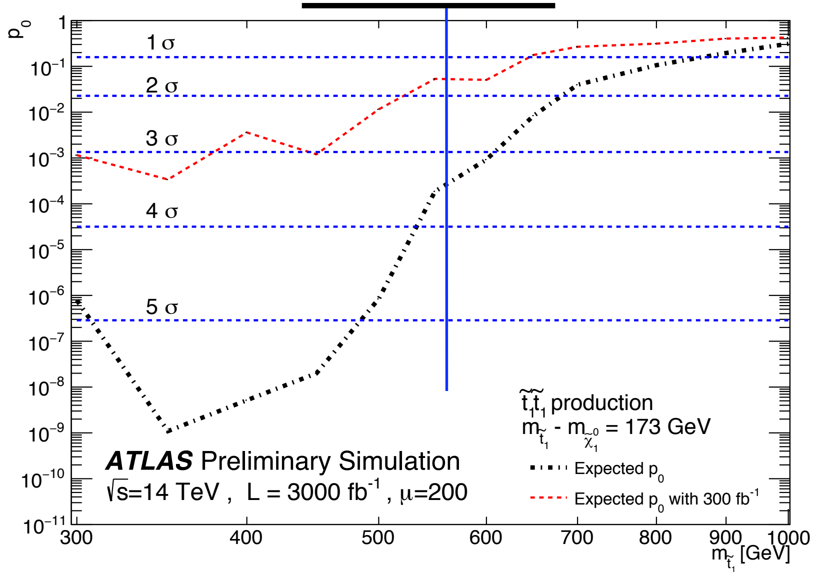


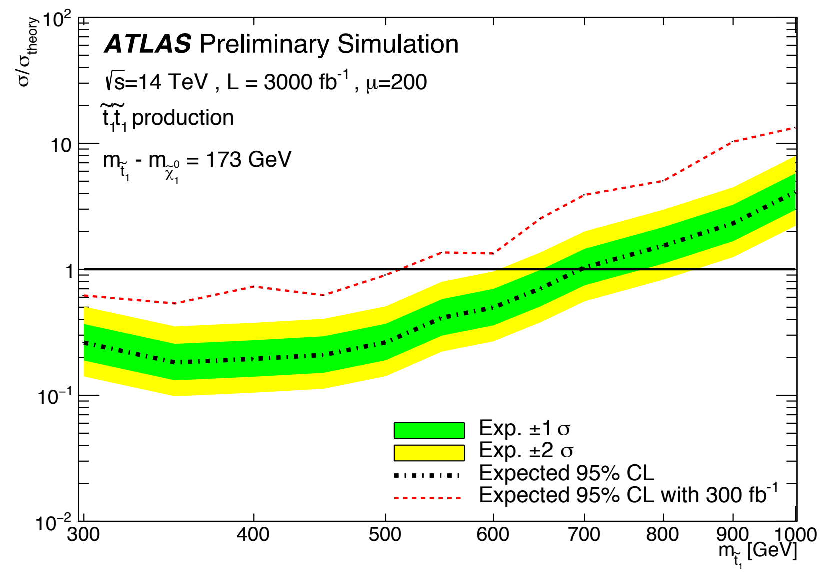
Hand-made overlay
36.1 fb^{-1} exclusion (arXiv: 1708.09266)

ATL-PHYS-PUB-2014-010

Compressed stops. (di-lepton)

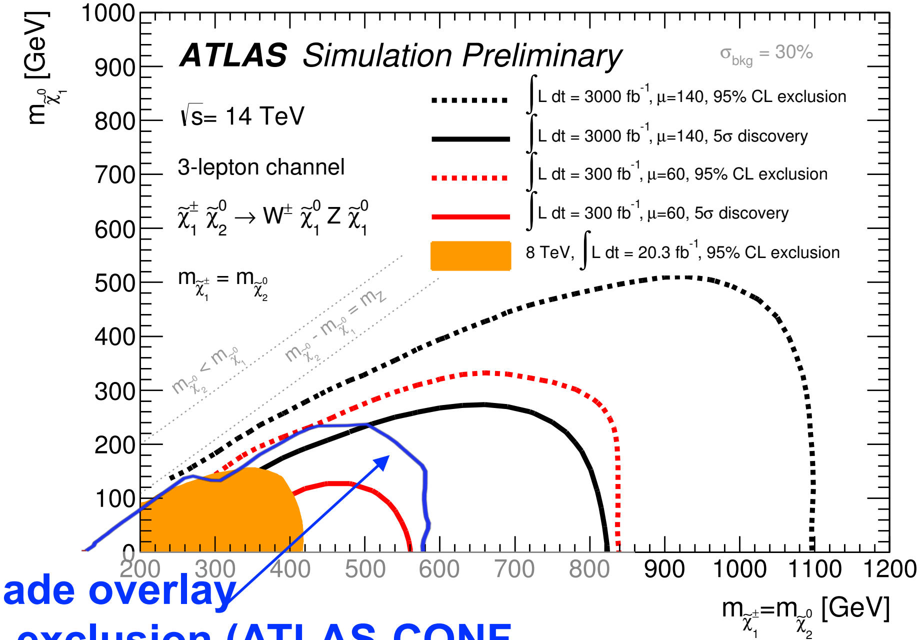
36.1 fb^{-1} exclusion
1709.04183





ATL-PHYS-PUB-2016-022

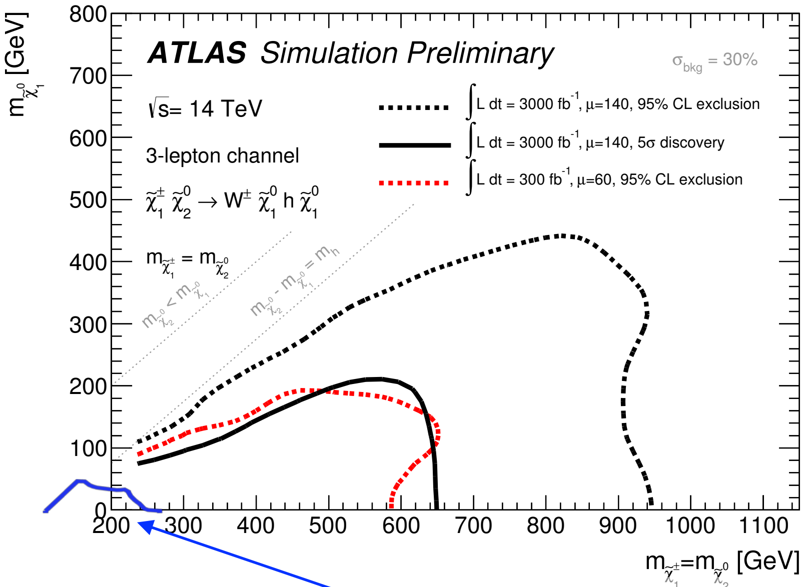
Electroweakinos (multi-leptons)

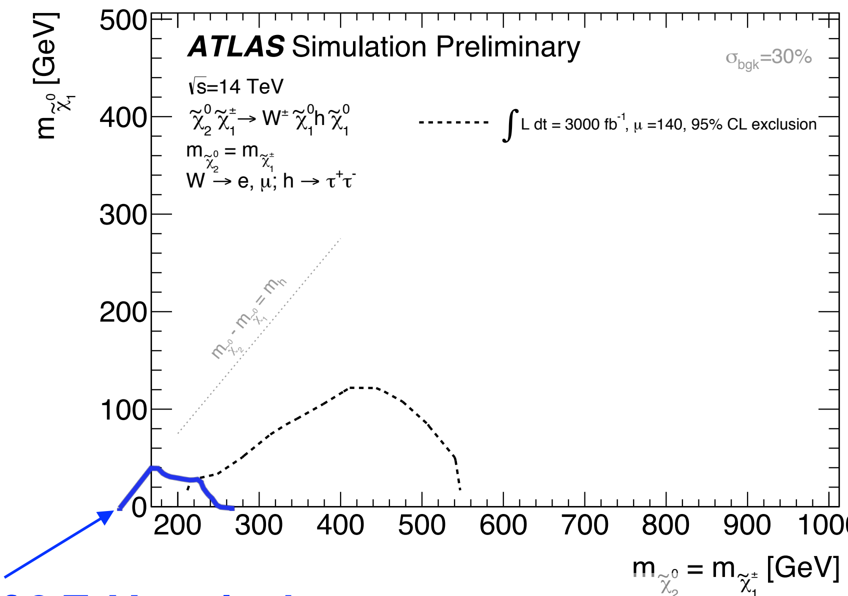


Hand-made overlay
36.1 fb^{-1} exclusion (ATLAS-CONF-2017-039)

ATL-PHYS-PUB-2014-010

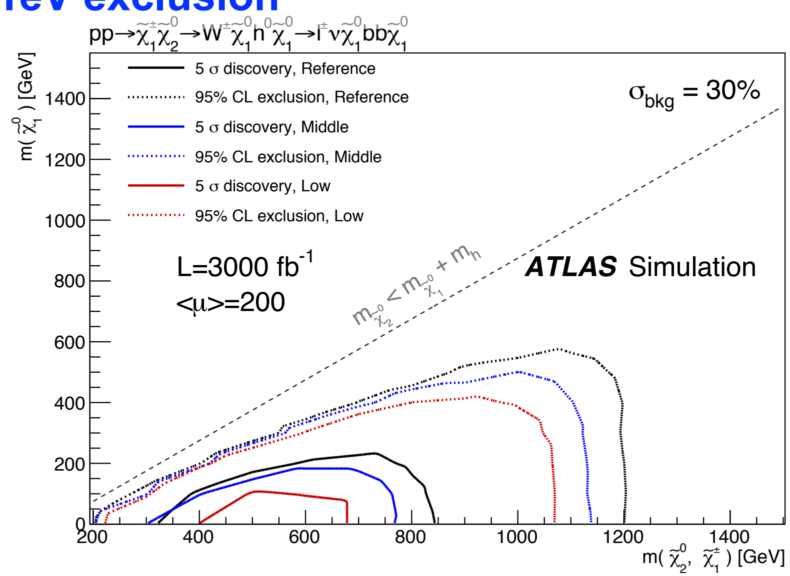
Electroweakinos (via Higgs)





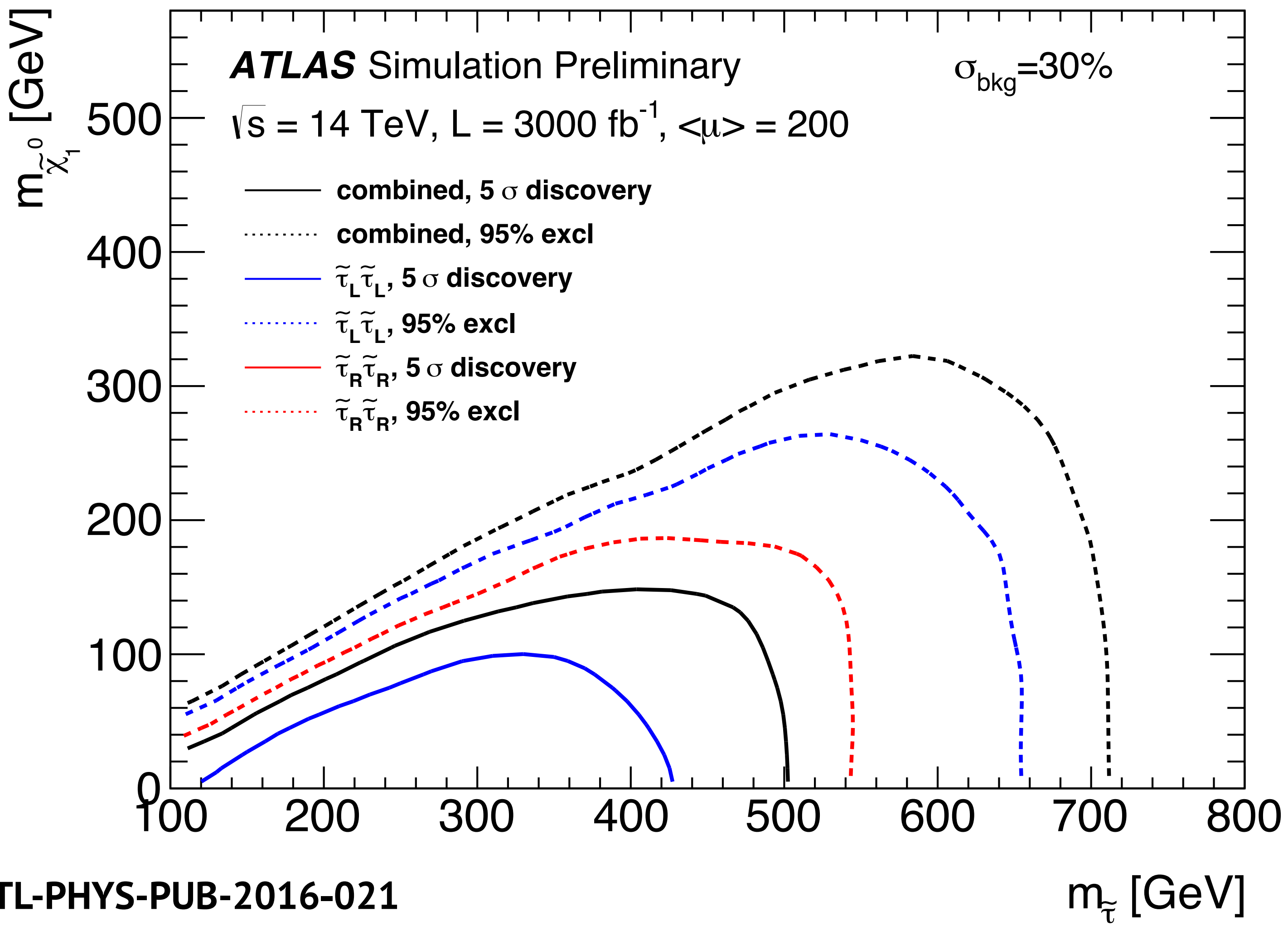
Hand-made overlay of 8 TeV exclusion (arXiv:1501.07110)

ATL-PHYS-PUB-2014-010



ATL-PHYS-PUB-2015-032
CERN-LHCC-2015-020

Stau pairs



ATL-PHYS-PUB-2016-021