Searches for supersymmetric particles in prompt decays with the ATLAS detector

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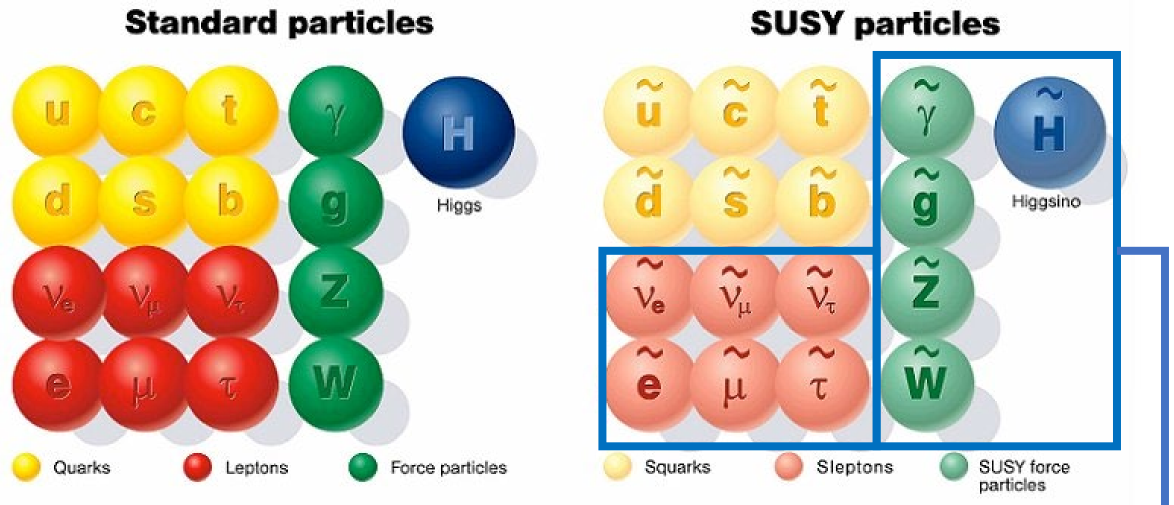
SUSY: a possible extension of SM

SUSY is a time-space symmetry linking a SM particle to a SUSY partner differing by 1/2 spin unit

Not an exact symmetry: mass of particles≠mass of sparticles. Loop corrections solve the quadratic divergence of Higgs boson mass

If R parity is conserved, SUSY Lightest SUSY particle (LSP) provides a natural Dark matter candidate

Roughly doubles the number of particles hence it has a complex phenomenology and large number of free parameters



Ingredients for today:
Electroweakinos: Partners of the Higgs and electro-weak bosons mix into chargino and neutralino mass states

Gluinos: strong partners of the gluons

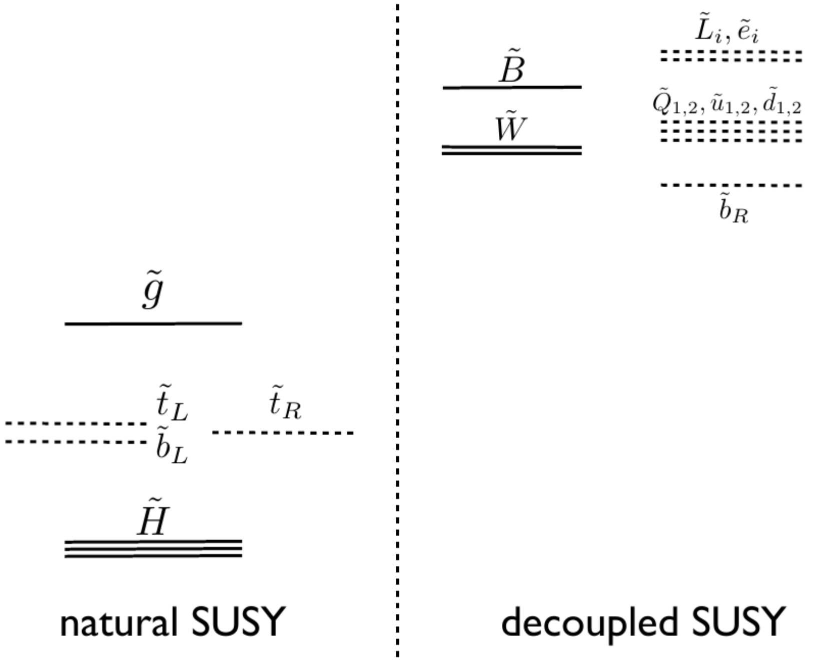
Sleptons: partners of leptons

SUSY searches motivation

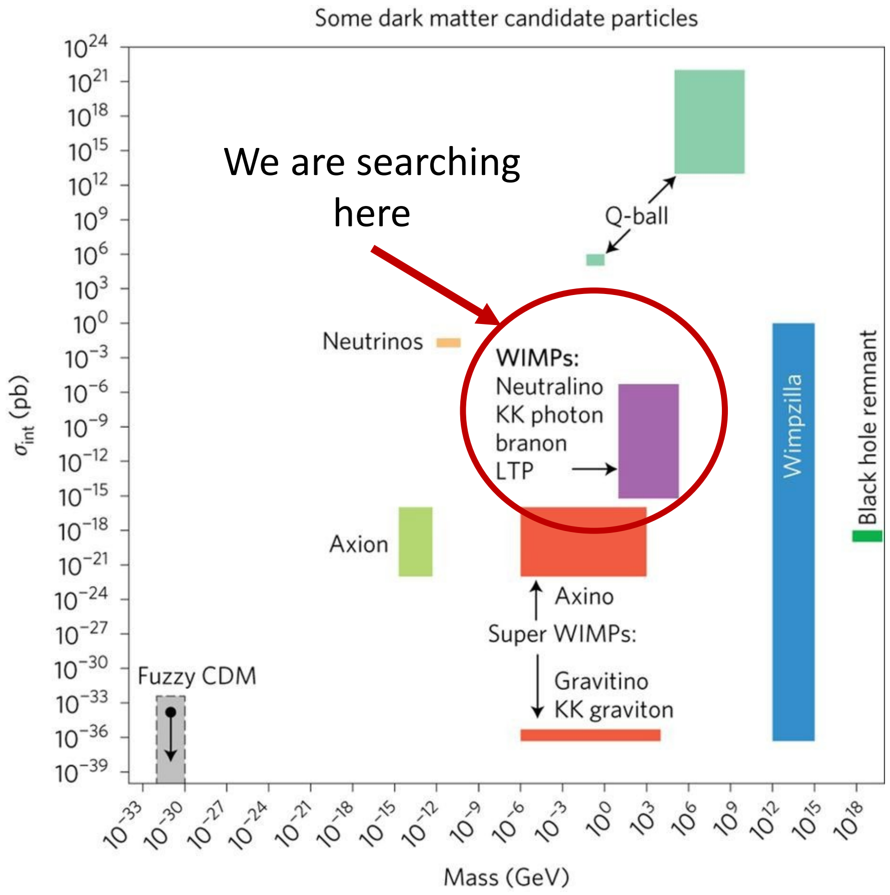
Searches for light charginos and neutralinos

Naturalness: implications from Particle physics measurements: Higgs mass at electroweak scale

[JHEP 1209 (2012) 035]

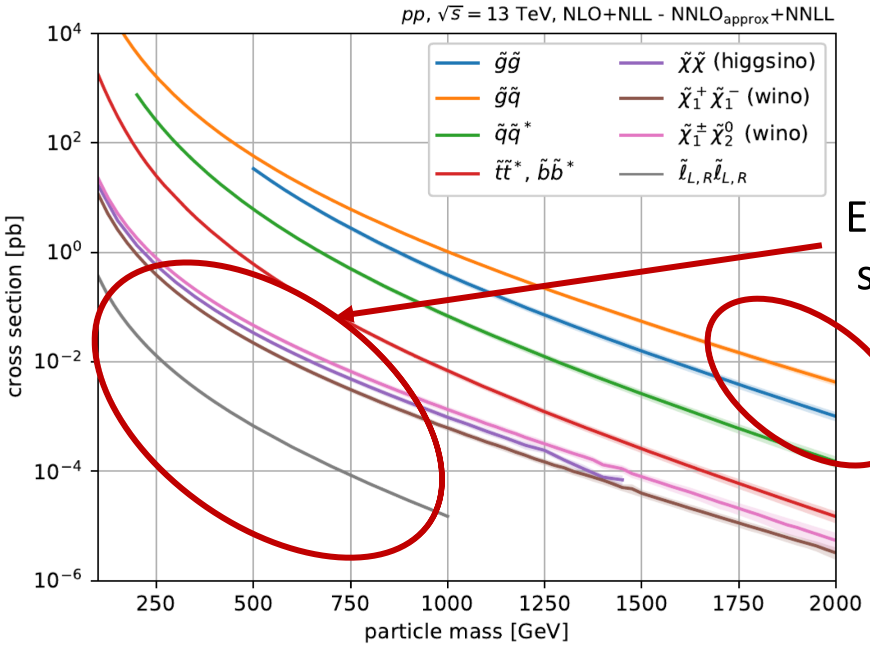


Dark Matter candidates



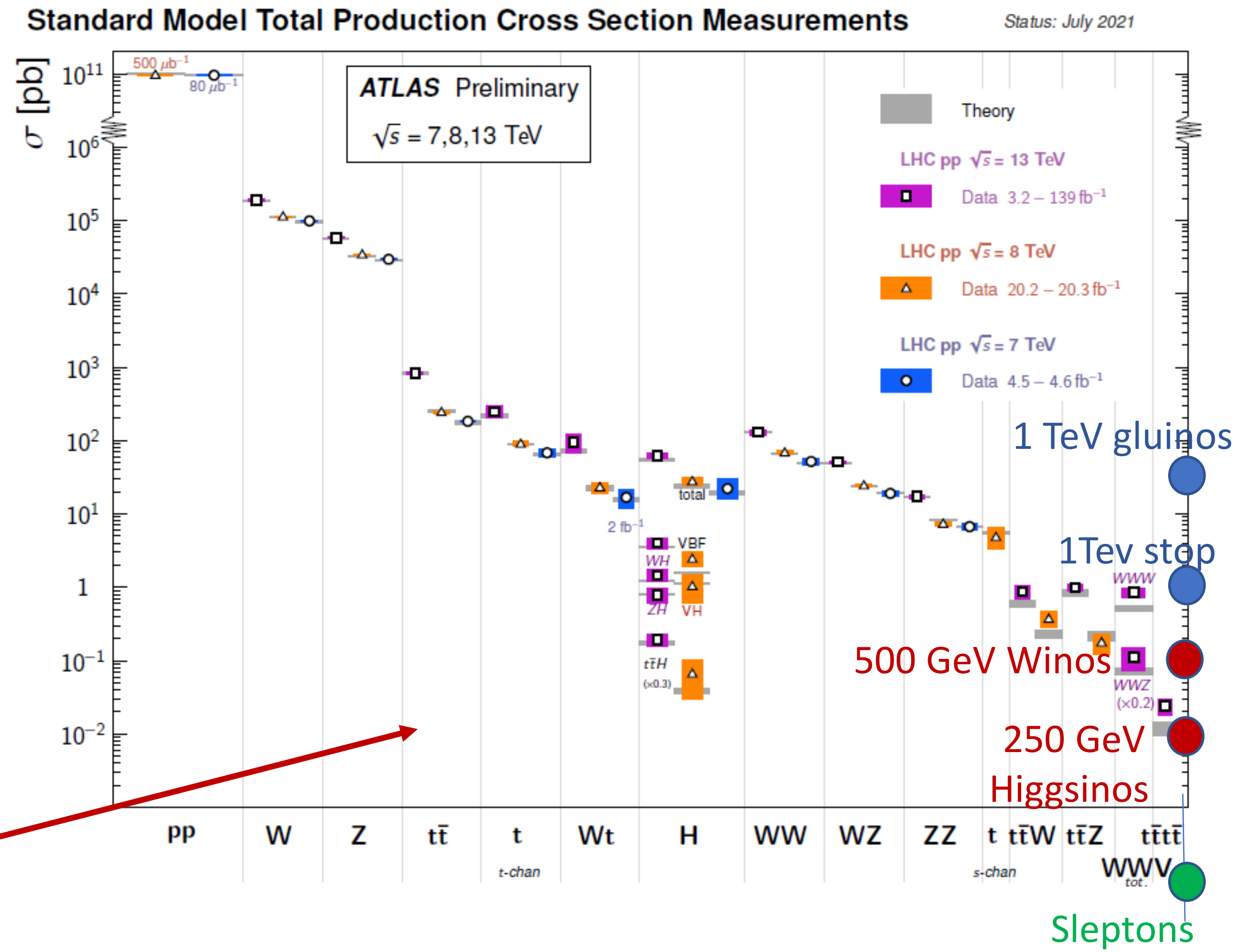
[Nature Physics volume 13, pages 224–231 (2017)]

SUSY in ATLAS run 2



EWKinos/sleptons sensitivity region

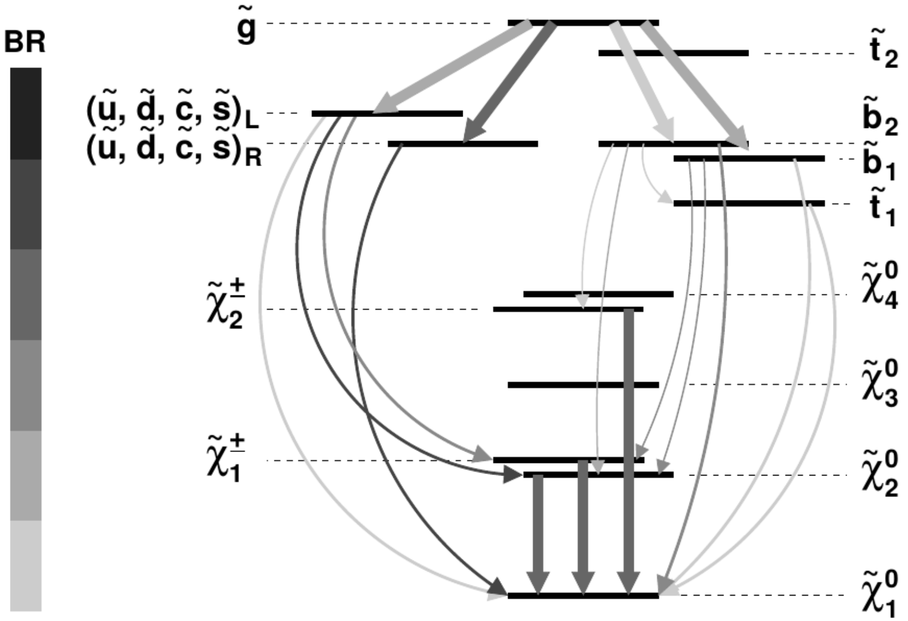
Gluinos reach



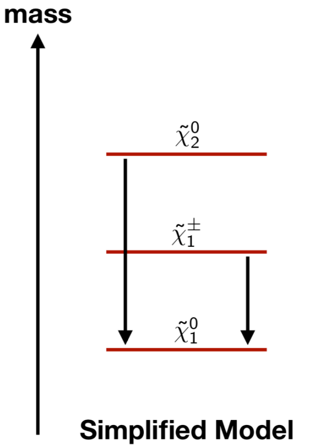
Very small cross sections for SUSY electroweak production
Compared to the most common background
Need High statistics and robust analysis methods

Simplified Models in SUSY

FULL MODEL



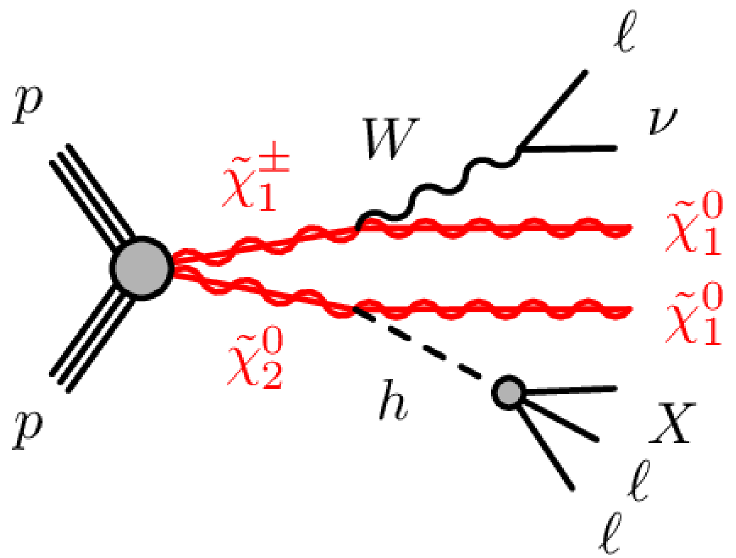
SIMPLIFIED



SUSY, even in its minimal implementations **has a large number of free parameters**

Complex phenomenology: need to reduce the parameter space in our searches

Solution: consider only few parameters and focus on a single decay chain



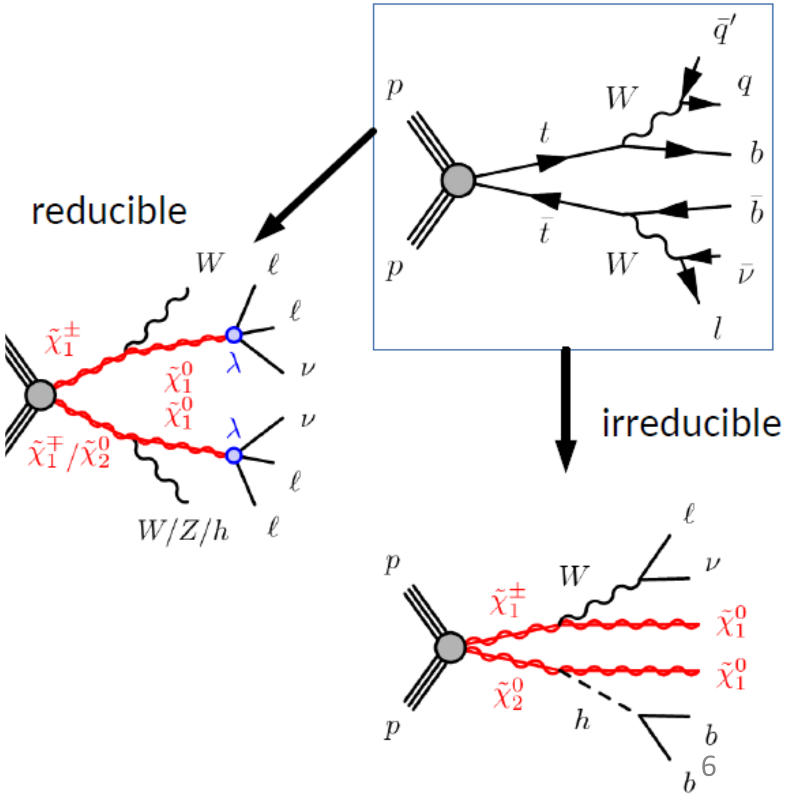
A SUSY analysis in a nutshell

Typical handles on new physics:
Object counting (number of leptons/jets etc), kinematic variables (p_t, $\not{E}_T, m_T$…) , composite objects (jet substructure, razor variables…)

Search optimization:
Discovery: Typically inclusive cut and count analysis in SR
Exclusion: more elaborate methods such as MVA, shape fits..

Reducible backgrounds: backgrounds with another final state similar to the signal

Irreducible backgrounds: backgrounds show the same final state as the signal



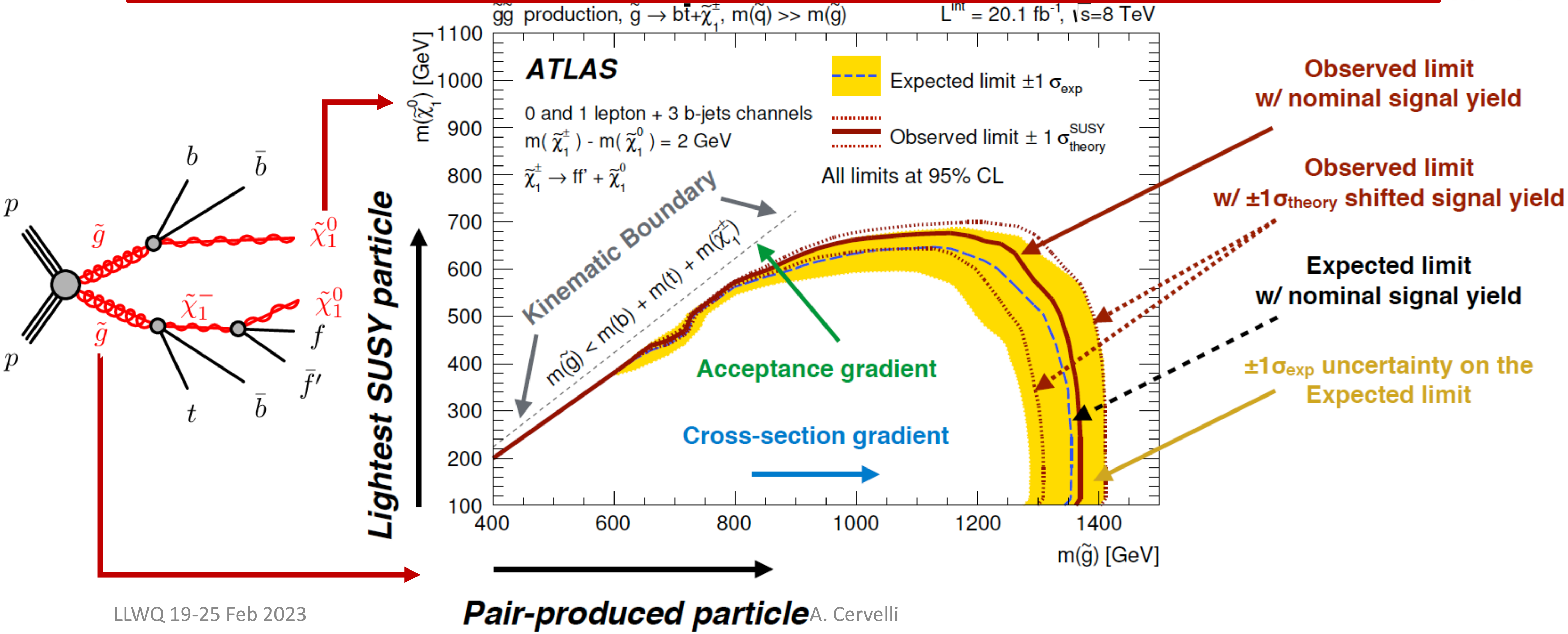
Irreducible Backgrounds
- Dominant processes:
  - MC normalised to data in process-enhanced control regions (CRs)
  - Extrapolation to validation regions (VRs) & SRs
- Subdominant processes: Pure MC predictions

Reducible Backgrounds
- Fake $E_{T,miss}$, fake leptons backgrounds: Pure data-driven estimates
- Validation in VRs

Combined Fit
- Simultaneous fit of all components in CRs (and SRs for exclusion)

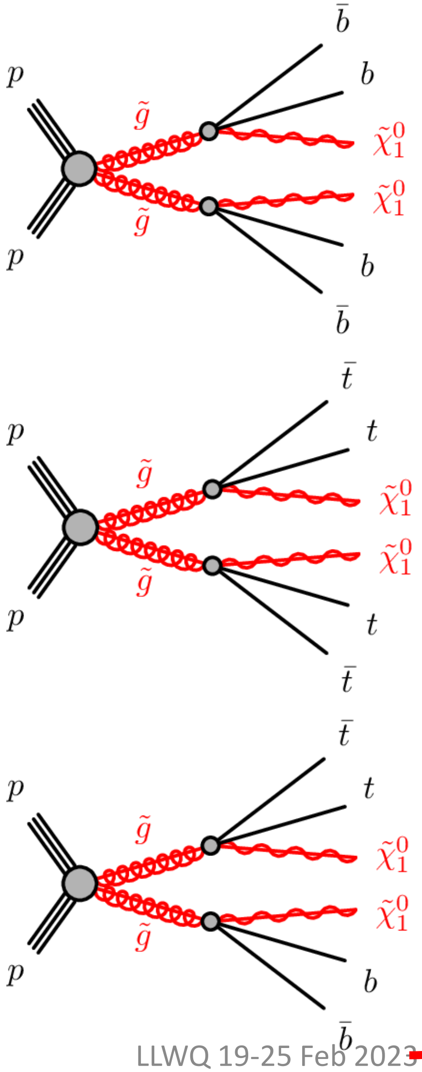
Interpretation of results

Results typically presented in 2D slices of SUSY particle masses
Consistency between signal and bkg is evaluated for each signal point in the plane as a p-value
Model dependent limits are set on production cross sections



arXiv:2211.08028

Strong Production: Multi-b



Prompt production of strong interacting particles (gluinos), decaying to the LSP directly or through charginos

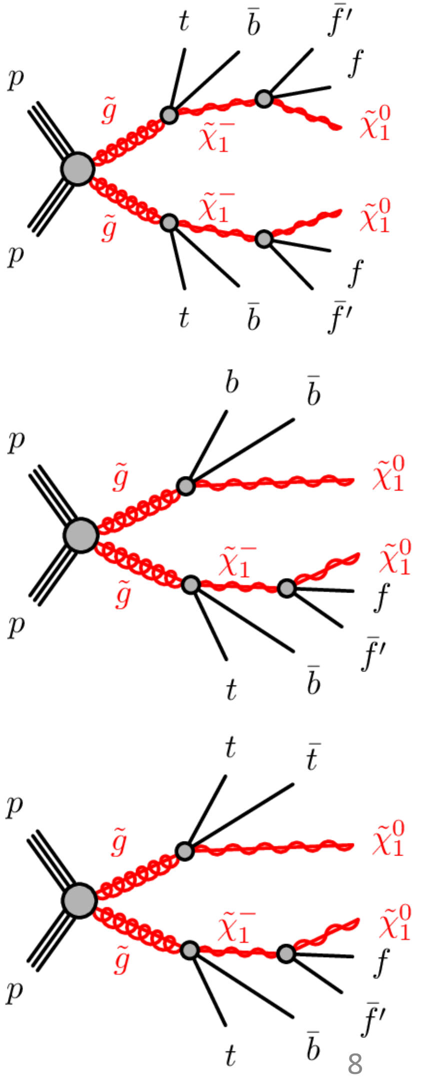
Final state: >3 b-tagged jets, 0 or 1 light lepton, large E_T^{miss}

Signal regions defined via cut-and-count and NN procedures: Inputs to the NN 4-vector of (b)-jets, lepton, and E_T^{miss}

3 decay modes interpretation: $\tilde{g} \rightarrow tt\chi_1^0, \tilde{g} \rightarrow bb\chi_1^0$, $\tilde{g}\tilde{g} \rightarrow ttbb\chi_1^0\chi_1^0$: model parameters $m(\tilde{g}), m(\chi_1^0)$

3 decay modes with 1 step decays: sensitive to $\tilde{g} \rightarrow b\bar{t}\,\chi_1^+$ and $\tilde{g} \rightarrow t\bar{b}\,\chi_1^-$ branching fractions

Main backgrounds: $\bar{t}t$, Z + jet production



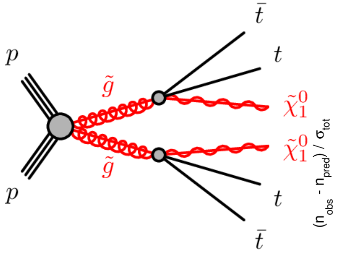
arXiv:2211.08028

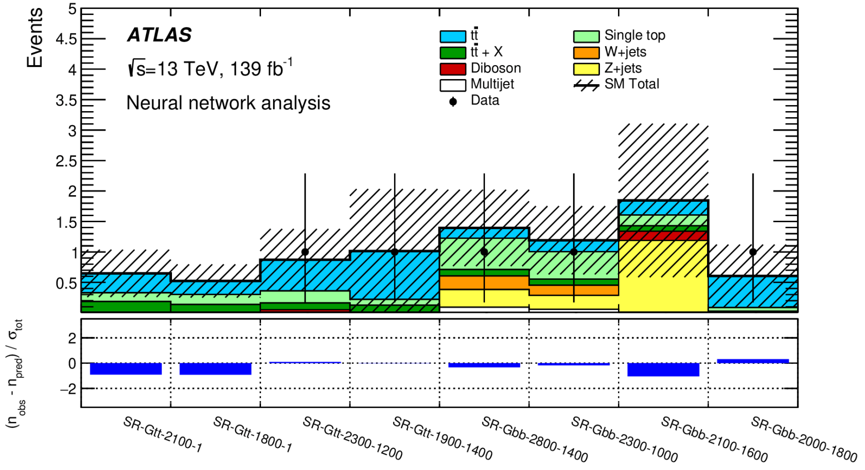
Strong Production: Multi-b

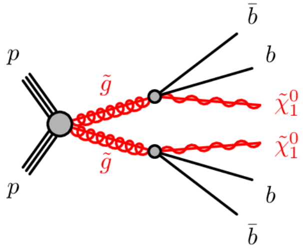
No excess found over SM expectation:

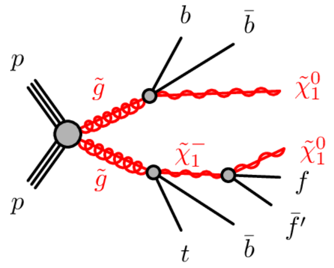
Limits set up to 2.4 TeV in gluino mass in direct decays

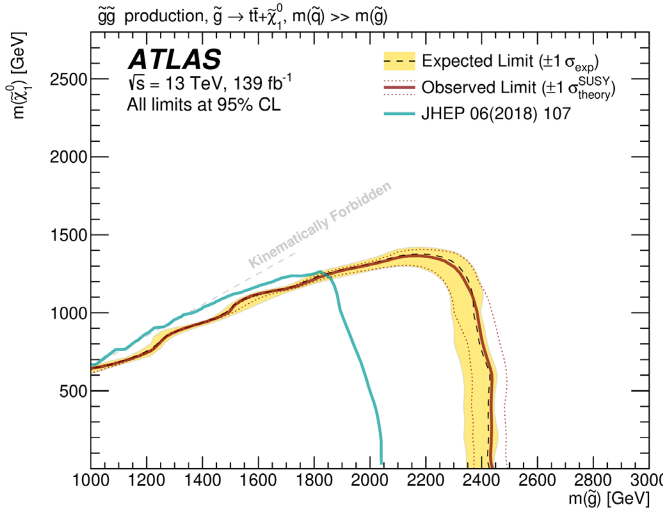
Large phase space restriction for decays via charginos

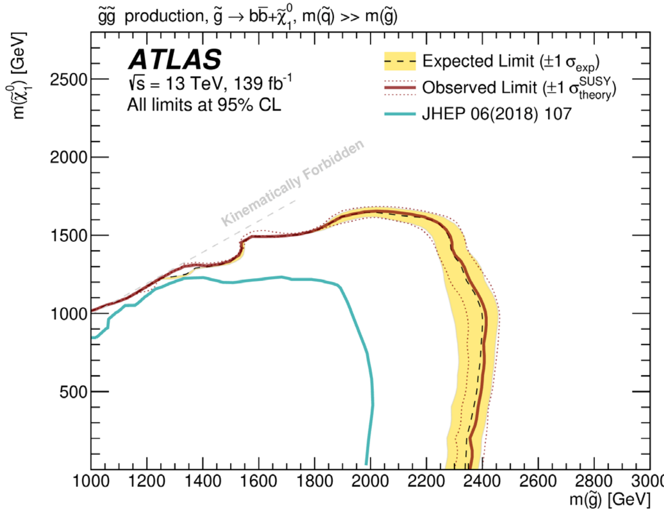


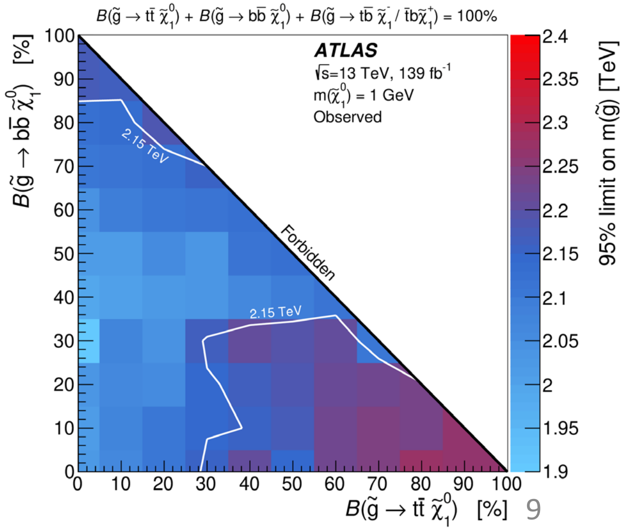












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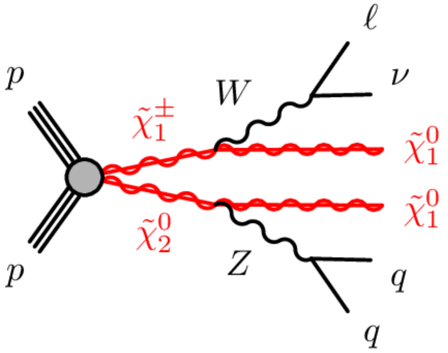
EWK production: 1L final state

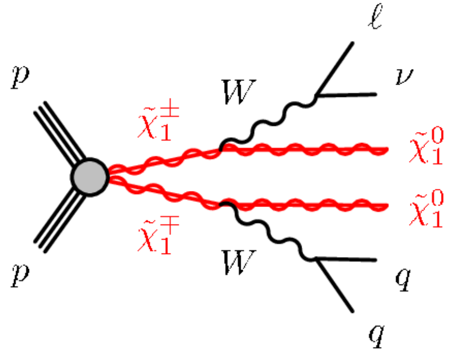


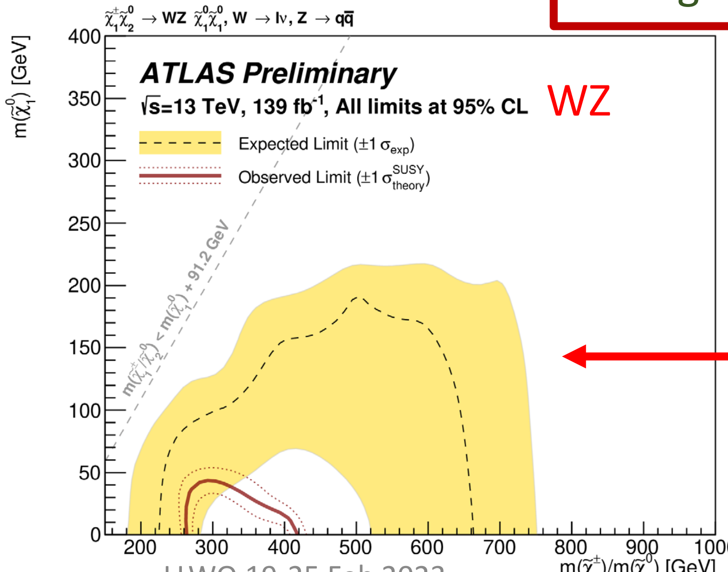
Chargino-Chargino or Chargino-Neutralino pair production

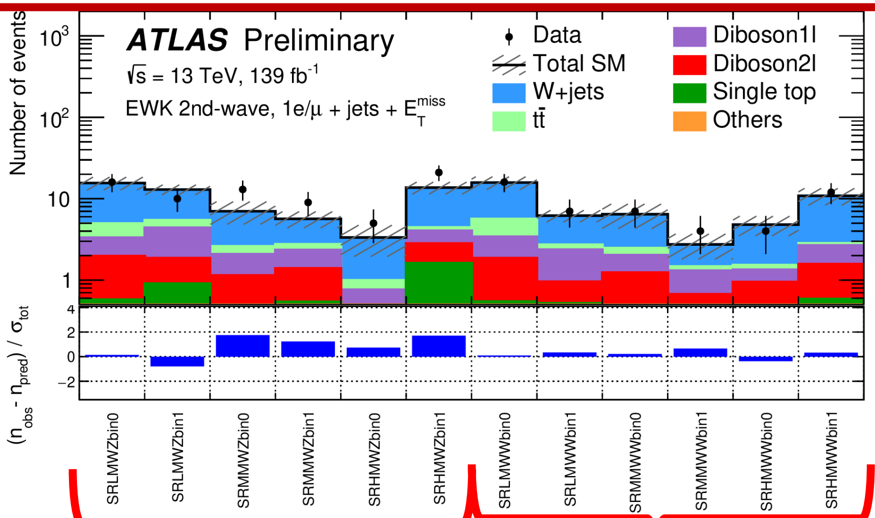
Final state: 1 Large-R jet, 1 light lepton, large $\not{E}_T$, b-jet veto
Count and count analyses, main discriminating variables:
$m_T, m_{eff}, \not{E}_T$

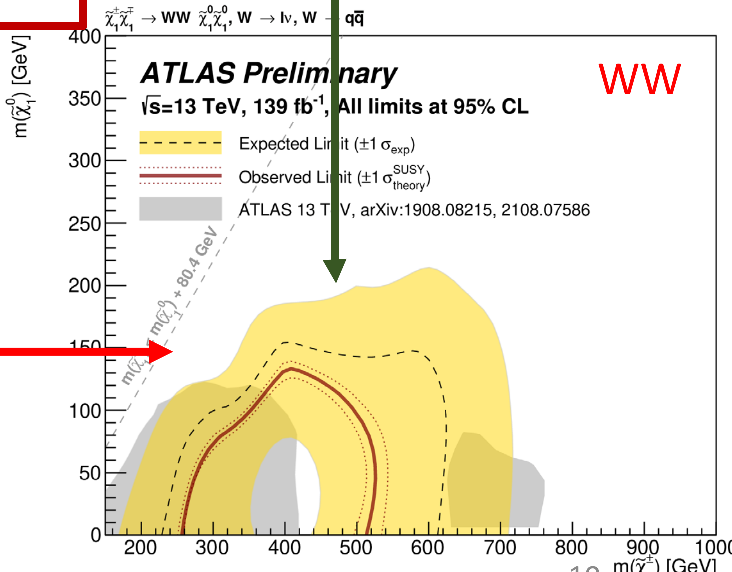
Main backgrounds: Diboson production, W+jets

Strong complementarity with 0L and 2L searches









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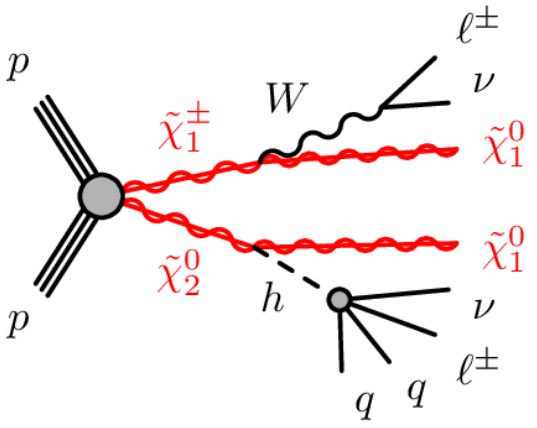
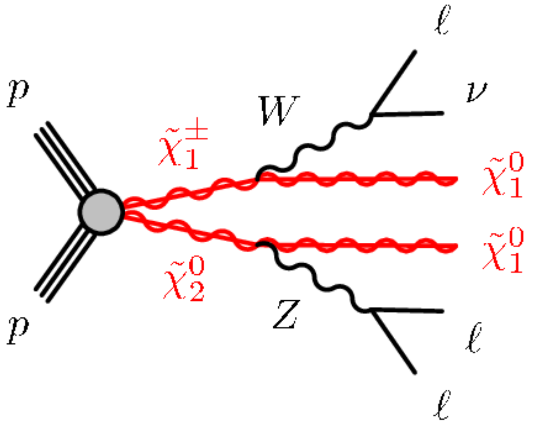
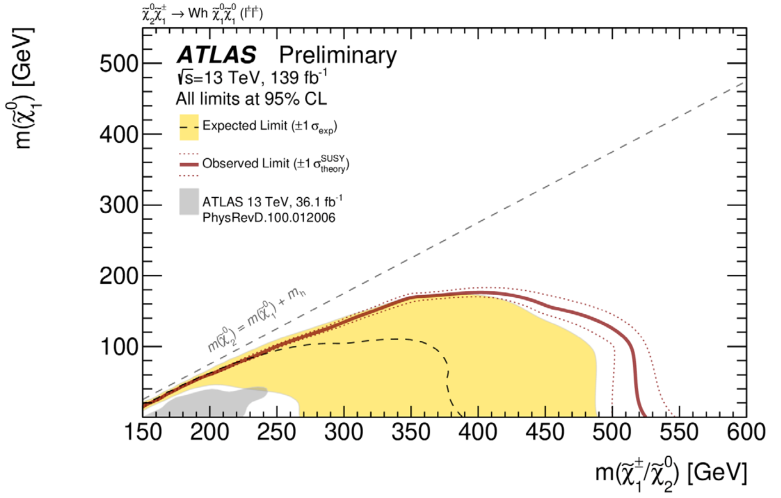
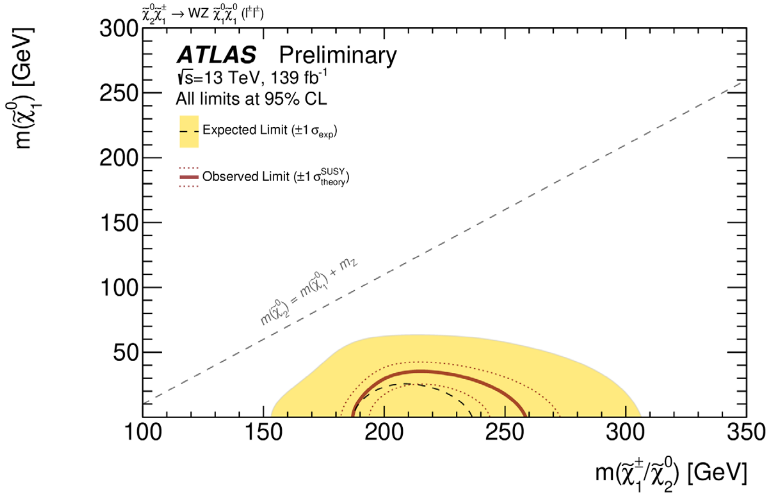
EWK Production: 2 Same Sign or 3 Leptons









Search for Electroweakly produced Chargino-Neutralino pairs

R-parity conserving decay of prompt particles in LSP and bosons

Final state: 2SS/3L + ≥ 0 jets + $E\!\!\!/_T$

Main backgrounds from irreducible fake-non prompt leptons

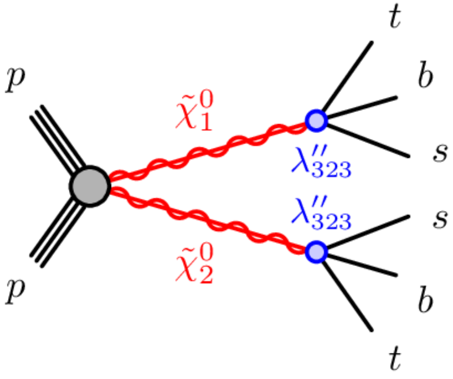
No signal excess found, observation consistent with SM expectations

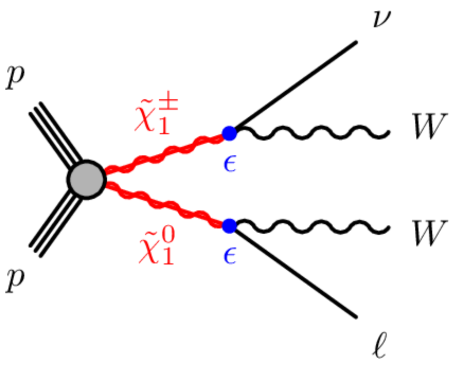
EWK Production: 2 Same Sign or 3 Leptons

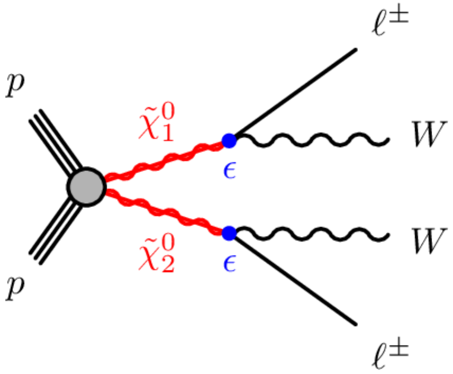
RPV decays of promptly produced Neutralino pairs, and chargino-neutralino pairs

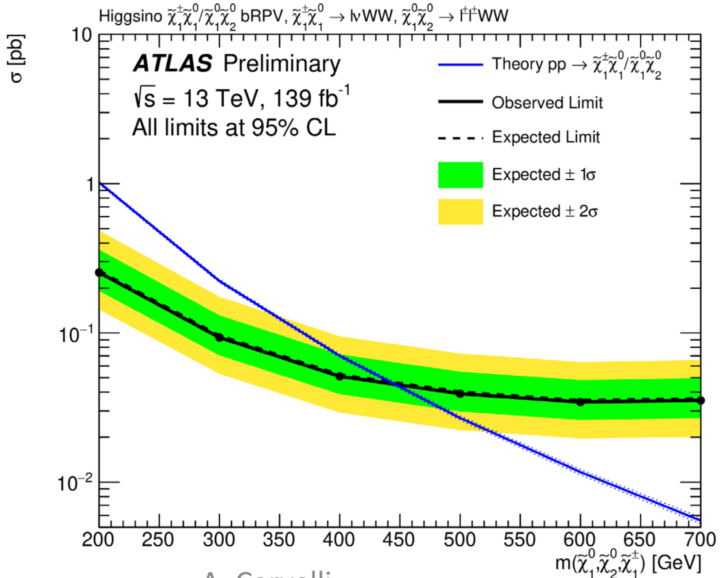
Interpretations:
- With bilinear lepton violating terms bRPV
→ neutrino physics interplay
- With Baryon number violating terms UDD
→ Baryogenesis

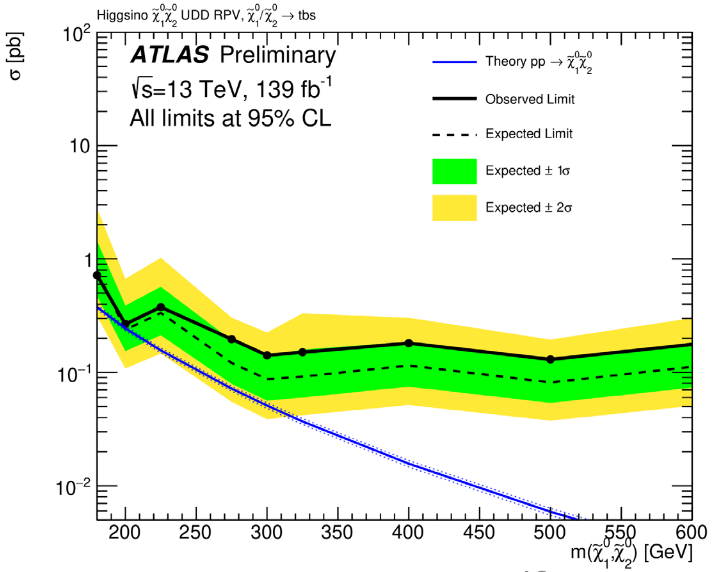
No signal excess found, observation consistent with SM expectations. Limits set on production-cross sections





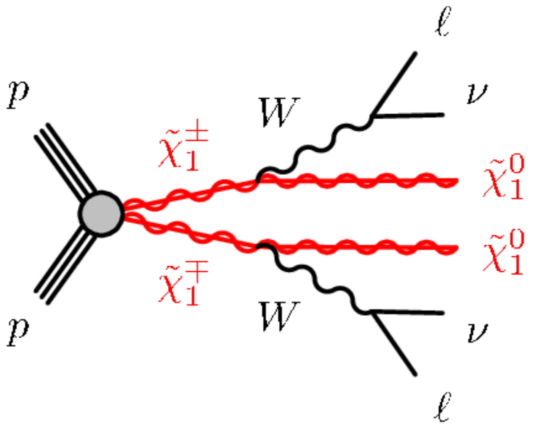






arXiv:2209.13935

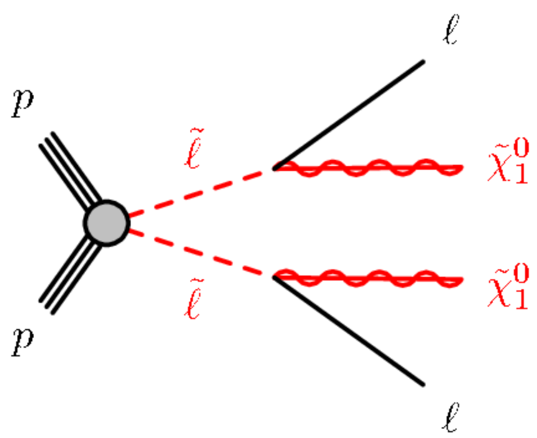
EWK Production: 2 Leptons

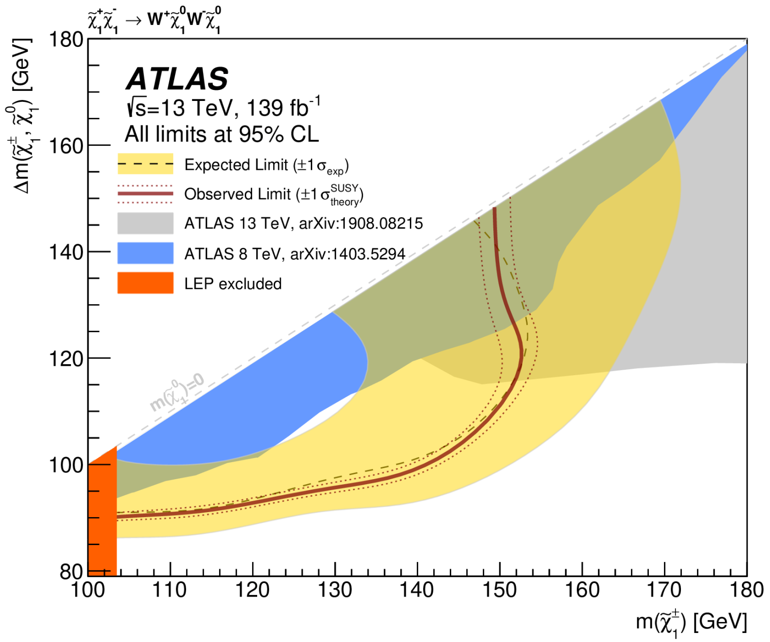


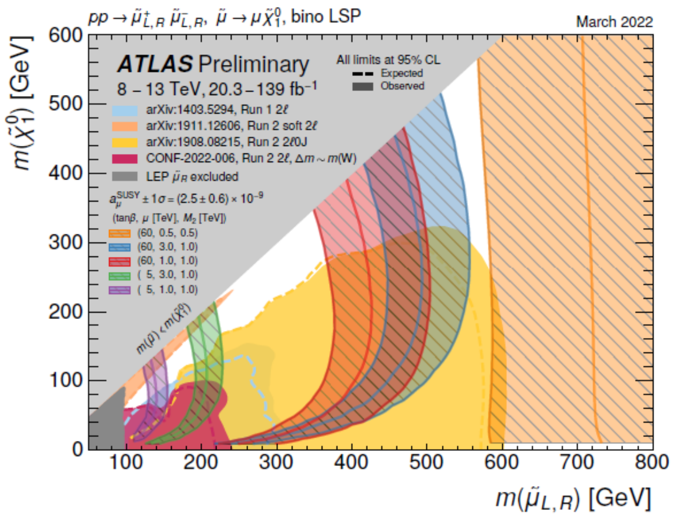
Prompt production of Chargino, or slepton pairs: sensitive to small $\Delta m(\chi_1^{\pm},\chi_1^0)$ and $\Delta m(\tilde{\ell},\chi_1^0)$

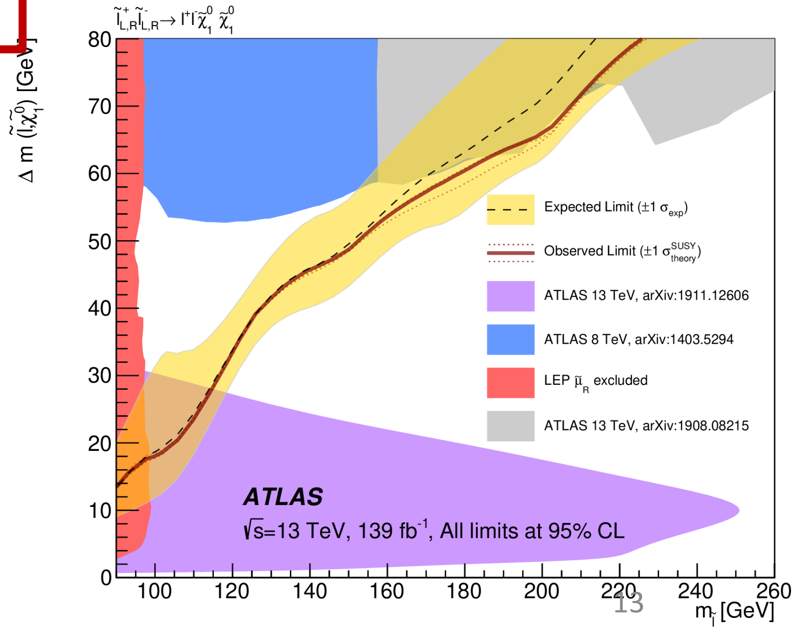
Strongly motivated by g-2 observations

Significant improvement in both scenarios in intermediate regions of chargino and slepton mass (100-150GeV)









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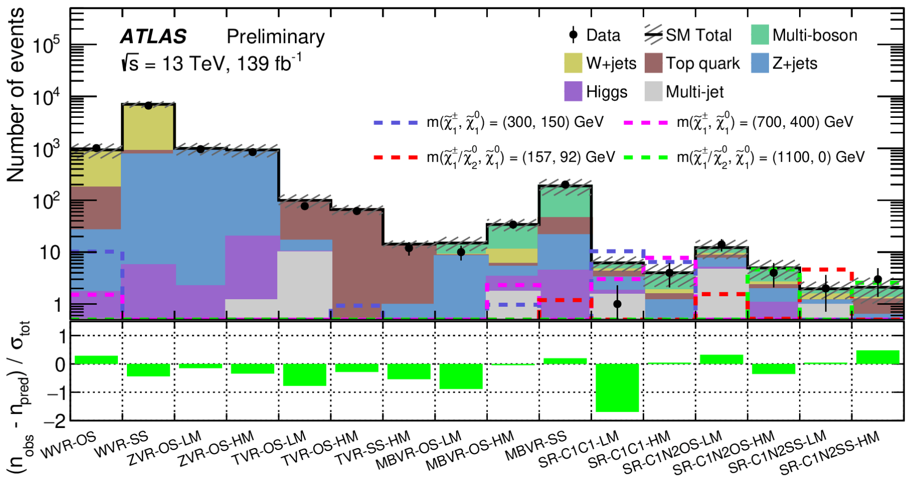
EWK Production: Final states with τ's

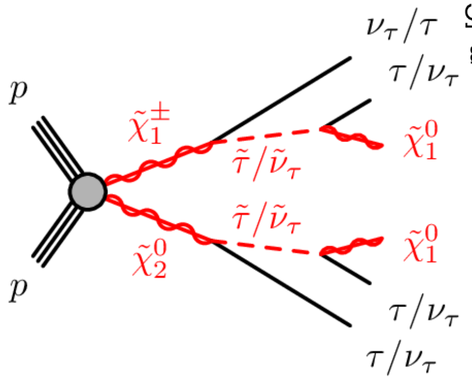
Searches targetting Chargino-Neutralino pair production mediated by staus or SM bosons

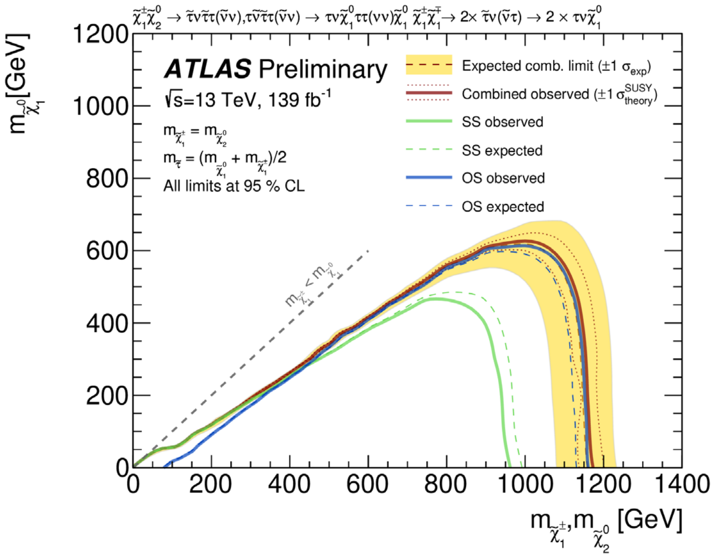
Signature: 2 hadronically decaying τ's, ≥ 0 light leptons, large E_T^{miss}

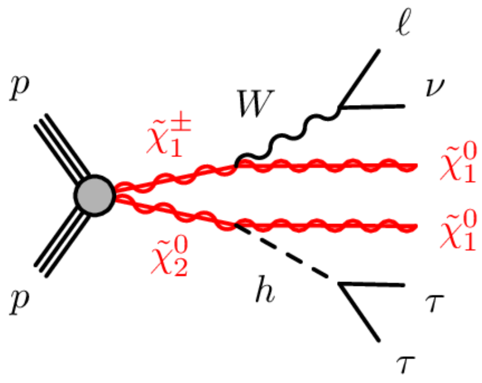
τ's identified with recurrent-NN

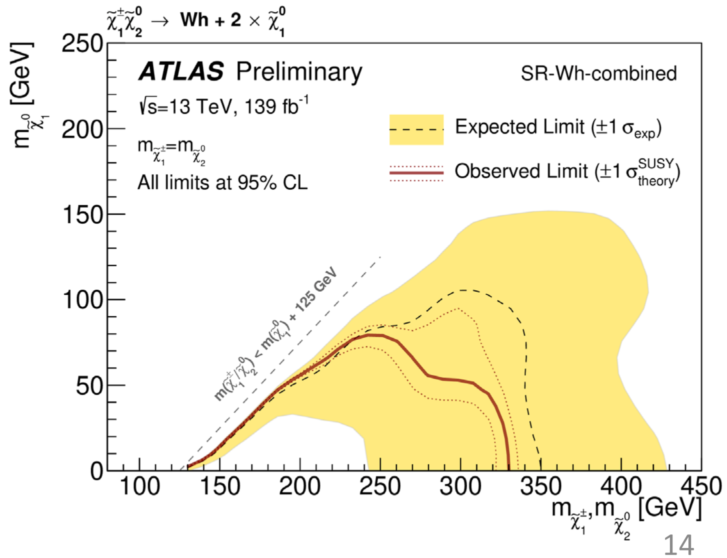
Main backgrounds diboson production and W+Jets











Conclusions

ATLAS Run2 integrated luminosity paired with more complex search techniques provided unprecedented sensitivity to SUSY process, however no evidence of BSM physics has been observed YET.

The present results show that ATLAS paved the road for new searches, and we expect in Run3 to increase the phase space of the SUSY parameters we are sensitive to, and to be able to look for more complex phenomenology

While waiting for new data, present results are being statistically combined….
Maybe SUSY is just hiding among our data… or maybe is barely out of our grasp today.